Dataquest ALERT

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Graphics Giant S3 Retrenches for 1998

Graphics chip giant S3 Inc. has released its fourth quarter and year-end results in addition to disclosing a new intellectual property agreement with Cirrus Logic Inc., the former No. 1 graphics chip supplier. Year-end 1997 revenue totaled $436.4 million, falling only $3 million short of S3's record level from the previous year. Fourth quarter revenue reached $101.9 million, down 20 percent from the same quarter one year ago. Pretax charges turned the quarterly earnings into a net loss of $8.1 million. The pretax charges were largely the result of management's decision to pare the number of development projects and to refocus R&D resources on graphics products.

$40 Million Technology Deal with Cirrus

S3 announced a technology purchase and cross-licensing deal with Cirrus Logic that results in a $40 million payment to Cirrus. The payment covers 10 graphics technology patents and 25 patent applications. The cross-licensing element of this deal covers all other graphics patents held by both companies. S3's press release stated the agreement involves a perpetual license for graphics patents and additional licenses for nongraphics patents subject to certain time restrictions. The deal does require regulatory approval before becoming final.

Cuts Workforce by 100

S3 announced one week ago that the company would reduce its workforce by 15 percent, or about 100 positions. The reduction is necessary to rein in S3's expenses as the company faces declining market share in the volatile graphics chip market. This follows a recent management change in which Terry Holdt, former president and CEO of S3, returned to that leadership position.

The company's changes also include refocusing engineering resources. S3 plans to bring two new product families to market this year for deskbound graphics and subsequently introduce mobile variations of those deskbound products. Company management assures Dataquest that S3 will target "best-of-class" performance for its new graphics architectures. The goals are to return to a technology and product leadership position and subsequently regain the design-win momentum that S3 enjoyed two years ago—with sales volume, of course, to follow from that design activity.

Dataquest Perspective

Is this the beginning of the end for S3? The answer lies in S3's ability to bring compelling products to market this year. Without competitive benchmark performance, S3 will not secure the design-wins it needs to maintain its unit sales volume. Additionally, the sales volume will increasingly trend to the lower third of the graphics market where average selling prices (ASPs) and margins are less attractive.

The technology exchange with Cirrus Logic is a positive indicator for several reasons. First of all, it shows that S3's management is putting their money where their mouth is. Company management stated that S3 is paring back the number of R&D projects to focus on its core product line: graphics controllers. This deal shows that S3 is shoring up some weak areas in its graphics technology levee. Dataquest presumes that S3 gained rights to some 3-D technology that Cirrus developed but chose not to bring to market as a product. The broad cross-licensing eliminates the risk of graphics patent litigation between these two companies. Cirrus is an excellent choice for licensing because the company has a rich technology portfolio and is steering away from the traditional graphics market where S3 is focusing its own resources. In a manner of speaking, S3 is re-entering the fray with its own weapons and those of the former champion, Cirrus Logic.

What happens if S3 does succeed in delivering competitive products? S3 could continue to benefit from the demise of Cirrus Logic's graphics business and the fact that ATI will not sell chips to add-in board vendors other than its own board division. There is currently a shortage of good chips from established vendors, and most new vendors cannot grow fast enough to fill the vacuum. One new graphics chip vendor that could grow at a ferocious pace in 1999 is Intel. Other vendors face more internal challenges from such rapid growth than Intel faces. Intel will introduce the i740 this spring, and by the end of 1998 Intel will be established as a major vendor as a consequence of i740 sales and the company's acquisition of mobile graphics chip vendor Chips & Technologies Inc. This brings the discussion to the issue of how much performance is required of S3's new products. The blunt answer is simple: enough performance to beat the i740.

By Geoff Ballew

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Intel Gets a Green Light from the FTC (for Now)

Intel Corporation announced on January 13 that the Federal Trade Commission (FTC) decided not to block the company's tender offer for graphics chip vendor Chips & Technologies Inc. (C&T). The tender offer of $17.50 per share was due to expire on January 21 and had already been extended twice while waiting to see what action the FTC would take. The next day, Lockheed Martin Corporation announced that Intel purchased a 20 percent share of Real3D. Lockheed recently spun off Real3D as an independent company but kept majority ownership. The trio of companies--Intel, Real3D and C&T--jointly designed Intel's imminent graphics chip product, the Intel740 or i740.

Dataquest Perspective

Graphics chip vendors and their investors have been anxiously awaiting the FTC's decision. The potential impact of Intel's latest move into the graphics chip business is tremendous. Of course, Intel was moving into the graphics chip business with or without ownership of C&T, but the tacit approval from the FTC paves the road for Intel to play a greater role.

Last July when the tender offer was first announced, Dataquest published an alert examining Intel's motives and interests in purchasing C&T; it is appropriate to revisit the main ideas now. Intel already had a business relationship with C&T through work on the i740. Intel partnered with Real3D, and Real3D partnered with C&T for access to 2-D graphics and video display technology. Intel's purchase of C&T brings that element of the joint effort completely under Intel's control. Intel may have been interested in purchasing all of Real3D for the same reason. Dataquest believes that Lockheed was unwilling to part with all of Real3D, as evidenced by the company's retention of the remaining 80 percent interest in the spin-off.

Another benefit Intel gets from the purchase of C&T is immediate entry into the graphics chip business. C&T is the largest vendor of graphics chips for mobile PCs with a 36 percent share of the market, according to Dataquest's market statistics for the first half of 1997. Dataquest does not want to overemphasize this benefit because C&T's market share is declining, largely because of an aging product line. C&T has been slow to bring integrated frame buffers and 3-D graphics features to market and consequently has lost considerable market share to more nimble competitors.

The real jewels of the C&T purchase could be the engineering personnel and a portfolio of technologies for displaying graphics and video on liquid crystal displays (LCDs). As the number of companies designing graphics products has expanded over the past few years, experienced graphics engineers have been in short supply. In this case, Intel acquired a whole team of seasoned engineers in one fell swoop. Also, these engineers have expertise in designing controllers for LCDs, which adds new areas of expertise to Intel's graphics team as well as more bodies. Dataquest believes that mobile graphics controllers are more difficult to design because of issues related to LCDs. As desktop LCDs begin to replace bulky and heavy CRTs, that mobile graphics expertise could have substantial value for Intel.

The benefits of this deal for C&T are clear. The company was facing increasing competition and falling market share. Intel brings deep pockets, manufacturing expertise, and industry leadership to the table.

What does this mean for graphics chip competitors? It means the competitive landscape remains just that--competitive. Intel's market influence, dominance of the microprocessor and core logic chip markets, and control of million-unit design-wins for its own motherboard division create the potential of an ominous competitor. However, the scenario for competing graphics vendors is not quite so dark, as some would have us believe. The reasons are as follows:

- The market dynamics for graphics chips are different than core logic. The assumption that Intel will grow its graphics business like it has its core logic business is inappropriate. Core logic is more tightly coupled to the microprocessor, which is Intel's forte. Core logic is also made with trailing-edge process technology compared to MPUs and graphics products, which are made with leading-edge process technology. The final point here is one of competition. When Intel ventured into the core logic business, the PC industry was suffering from a lack of good core logic products. VLSI was the leader in core logic at the time, and that company's flagship product, the SuperCore 590, was buggy and slow. No one really stood in the way of Intel's success when it introduced a faster, more reliable chipset. The graphics market is different.

- Intel remains supply constrained on manufacturing capacity. This is a problem because of the similarities between graphics chips and microprocessors. Both products have millions of transistors and require leading-edge process technology to be manufactured competitively. A major difference is the average selling price. The average Intel microprocessor is 10 times more expensive than the average graphics chip. Intel does not want to lose microprocessor sales because too much capacity is being used for graphics products. MPUs are simply more profitable.

- The FTC is watching. The FTC's decision not to file a preliminary injunction does not preclude action to be taken at some future date. The recent work by the FTC provides a foundation for further examination, although the issue is moved to a back burner. At least it is on the stove, rather than in the cupboard. If Intel engages in anticompetitive behavior, the FTC will have a running start for further investigation.

Will Intel be competitive in the graphics business? Dataquest believes so. In fact, some of the recent changes in the graphics market help Intel as it ventures, again, into the graphics chip business. Competition is steep in the graphics chip business today, but there is a shortage of great products from large, established vendors. The largest graphics chip vendors are S3, ATI Technologies, Trident Microsystems, Matrox, and Cirrus Logic. Among these vendors, there is a shortage of great chips. S3 has the broadest product line of all of these companies but is not competitive at the higher end of 3-D acceleration. ATI has a competitive 3-D chip, the RAGE PRO, but will not sell any chips to add-in board vendors because of the company's own board-level products. Trident is in the same boat as S3—a broad product line but not competitive on the 3-D side of the business. Matrox produces great 2-D and video products but has not targeted consumer or gaming 3-D effectively with its own chip designs. Matrox sells a board-level 3-D product, called m3D, that uses NEC's PowerVR PCX2 chip. Last is Cirrus Logic, whose graphics strength has severely declined over the past two years. In fact, Cirrus Logic's decline and S3's lack of a more competitive 3-D product have left a vacuum. ATI won a flurry of motherboard design-wins with its RAGE PRO because it was the only mainstream graphics chip to support 2X AGP last year. There is now a shortage of parts from established vendors to service motherboard designs and $200 street price add-in cards. Intel has the opportunity to move from "graphics start-up" to graphics heavyweight much more quickly than other new graphics vendors because of its resources and role in the industry. There are great products from other new graphics vendors; those companies just do not have the resources that Intel has.

Why is Intel getting into the graphics business? Graphics is becoming a more critical aspect of PC performance, and Intel wants to have a hand in it. Intel needs the PC platform and its applications to continue evolving to maintain PC market (and MPU market) growth. Pixel rendering functions are not well served by general-purpose MPUs, so Intel wants to be a graphics vendor. Becoming a major graphics vendor benefits Intel because it will serve many purposes. The company will have a more direct and influential role in the development of graphics feature and performance trends. Intel's involvement also serves as a veiled threat to current graphics vendors that they had better continue innovating and driving performance as fast as they can. (Dataquest believes it is a human tendency to run faster if a grizzly bear is chasing you.) With an internal graphics development effort, Intel will also have direct experience with trade-offs between MPU and graphics accelerators. In short, graphics is too important for Intel not to get involved. Dataquest believes the most beneficial level of involvement for Intel and the graphics industry overall is as a major vendor but not as a market behemoth.

The bottom line here is that Intel's investments in the graphics market are moving forward with the goal to be a major vendor. Would Intel gain much from becoming the largest graphics chip vendor? Dataquest believes the result would be a combination of lower margins for Intel and increasing heat from the FTC. However, Dataquest also believes that Intel will become a major graphics chip supplier, breaking into the top five list of vendors by the end of 1998.
By Geoff Ballew

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It's Not Just Intel Inside Compaq's New Presarios

On January 6, Compaq Computer Corporation revamped its desktop lineup, adding several new models based on microprocessors from Advanced Micro Devices Inc. The new Presario 2240 incorporates a 200-MHz AMD-K6, 32MB of synchronous DRAM memory, the usual hard, floppy and CD-ROM drives, and carries an aggressively low price of $799. Upscale buyers can opt for the Presario 4500 series, which includes a 233-MHz K6, 32MB or 48MB of synchronous DRAM, the usual disks, and an Iomega Zip drive, all for prices that range from $1,099 to $1,299.

Intel retains the high-end of Compaq's line. The Presario 4600 series includes Pentium II processors running at 266 MHz and 300 MHz, 48MB to 64MB of synchronous DRAM, a DVD-ROM drive, and AGP graphics. Even these expensive systems are relatively affordable at $1,799 to $1,999. Compaq also has added a new notebook model, the Presario 1220, priced at $1,999, with a 200-MHz Media GX processor from Cyrix Corporation, 32MB of synchronous DRAM, a 20X CD-ROM, and a 2.1GB hard drive.

This announcement contains great news for PC buyers and good news for AMD. It may even prove beneficial to Intel, which nonetheless will probably feel stung by Compaq's moves. Two years ago, users paid over $700 for 32MB of DRAM--without any computer attached. One year ago, users paid over $500 for a 200 MHz MMX-enhanced processor, also without a computer. Now, for $800, they can get the CPU, the memory, and all the other fixings needed for a satisfying computing experience. (OK, they need a monitor, which never gets included in these price comparisons, but wait until next year.) Buyers of high-end systems also get a deal. One year ago, a 300-MHz Pentium II processor sold for $1,981, *sans* system. Now, for the same price, users get the whole box, too.

For AMD, Compaq's endorsement signals that the K6 is ready for prime time. Compaq does its homework and carefully scrutinizes a supplier's ability to deliver products that meet its quality standards and volume requirements. Ever since AMD encountered yield problems on its K6 production line last fall, that company's ability to deliver in volume has been in some doubt. Regardless of the yield situation, AMD faced a formidable problem in finding buyers for the 15 million processors it hopes to produce in 1998. With its decision to build the K6 into all its low-priced, high-volume desktop products, Compaq indicates its belief that AMD's yield problems are now a matter of history, and expresses its confidence that value-oriented consumers will continue to select Compaq systems, regardless of the brand of microprocessor inside.

Dataquest suspects that Intel, given its reputation as an aggressive competitor, took little joy in Compaq's moves. Nevertheless, this situation is not all bad news for Intel. Intel's success rests on selling high volumes of processors at incredibly high average selling prices (ASPs), compared to other semiconductor vendors or even other microprocessor vendors. Dataquest estimates that the MPUs that go into $800 systems cannot sell for more than $100, and probably sell for slightly less than that amount. The sale of too many processors at such low prices can seriously drag down ASPs, with serious side effects to the company's business model. Processors targeted at server applications, priced at $2,000, can offset only so much of this low-price pressure. Intel already participates in this sub-$1,000 segment, as illustrated by Hewlett-Packard Company's announcement of an $800 Pavilion PC with specifications remarkably similar to those of the new low-end Presario. As long as Intel remains constrained by its manufacturing capacity, which has historically been the case, despite years of massive capital spending, it makes sense for the company to slough off the lowest-price business and concentrate on the areas with the greatest revenue potential.

Dataquest suggests one other way Intel can find solace in these recent developments. The company should distribute copies of the Compaq press release to all members of the Federal Trade Commission, the European Trade Commission, and all the other governmental agencies that have recently suggested that Intel wields monopoly power in the personal computer market. Compaq's move demonstrates that the market remains open to competitors with credible products.

By Nathan Brookwood

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The Second Celeron Will Add to Intel's Pile of Cash

Today Intel Corporation introduced the new version of its Celeron processor, based on a design known internally as "Mendocino." Unlike the original Celeron, this one packs a real performance punch and dramatically strengthens Intel's product offering at the low end. Its arrival marks the end of the vacation from low-end competition that Advanced Micro Devices Inc. and Cyrix Corporation enjoyed this year. As summer gives way to fall, the air temperature may cool, but the competitive scene will warm up considerably.

The new Celerons run at speeds of 300 and 333 MHz, and cost $149 and $192 respectively. Their performance matches almost exactly that of the 300- and 333-MHz Pentium II processors priced at $209 and $316. Why would anyone want to spend the extra $124 for the Pentium II? Maybe for the cute hologram Intel uses on the Pentium II line, but omits (for reasons of cost) on the Celeron.

Some might worry that these new processors will cannibalize Pentium II sales. Intel will try to avoid this problem by increasing the Pentium II's performance. The company took a step in this direction when it added a 450-MHz Pentium II to the 350- and 400-MHz versions already on the market. The more expensive products have a clock-rate advantage over the more affordable Celerons, and they also incorporate a 100-MHz memory bus that improves performance over Celeron's 66 MHz memory system.

Last spring, Intel hastily brought the original Celeron to market in response to the increasing clamor for low-priced systems. To shorten its time to market, Intel merely deleted the two 256KB SRAMs that make up the Pentium II's cache memory subsystem. These parts contribute about $10 to the cost, but add 20 percent to the performance of the processor subsystem, and this omission led to rather unimpressive benchmark scores for the initial Celeron systems. (Caches provide a small block of high-speed memory to make it possible for a CPU that gobbles data at the rate of 32 bits every 3 nanoseconds to work with a memory system that needs 50 nanoseconds to deliver these 32 bits. Even "10-nanosecond PC100" synchronous DRAMs require 40 nanoseconds to extract the first bits of data the processor needs from their 64 million bits of storage. To understand how caches work their magic, Dataquest recommends *The Cache Memory Book* [Academic Press, 1997] by Jim Handy, Dataquest's resident memory analyst.)

The new Celerons incorporate 128KB of on-chip cache in lieu of the 512KB of off-chip cache used in the Pentium II. Unlike the Pentium II's cache, which runs at only half the speed of the CPU, Celeron's on-chip cache runs at the same speed as the processor (i.e., 300 or 333 MHz).

The faster speed just about offsets the loss in efficiency due to the new Celerons' smaller size, resulting in the same level of delivered performance as the Pentium II. (In caches, both size *and* speed matter.)

But nothing of value is free. At 153 square millimeters, the new Celeron chip is 17 percent larger than the die in the original cacheless Celeron, which measured 130.9 square millimeters. This makes it a little bigger than the original Pentium with MMX technology that debuted early in 1997. Fortunately, the accelerated rate at which Intel now plans to move to 0.18-micron technology for its higher-end processors will free up the capacity needed to support volume manufacturing of this larger die. Dataquest expects that Intel will waste little time in moving the market from the old to the new Celeron, but even so, the move won't come quickly enough for us.

The new Celeron must overcome the checkered reputation its progenitor amassed with regard to performance. Many brand managers argue that it is difficult if not impossible to remake the image of a product that has gotten off to a wobbly start in the market. They recommend that the brand be scrapped and a new one created. Intel has successfully resisted such advice in the past. Few today remember the chants of "Intel Inside, Don't Divide" that brought as much pain to Intel in December 1994 as a blue dress has brought to the U.S. White House in August 1998. Dataquest expects that Intel will once again defy the experts and stubbornly persist until it makes the Celeron brand a success. Regardless of its name, the new version delivers screaming performance at a very attractive price.

Largely to support the infrastructure of system vendors and motherboard builders, the new Celeron comes packaged on a small printed circuit board that plugs into the same physical connector ("Slot 1") used for Pentium II systems. Intel started packaging processors in cartridges in order to accommodate the separate cache chips needed by the Pentium II. Because the Celeron omits these external chips, the Slot 1 arrangement adds cost, but not value. Dataquest would not be surprised if Intel were to eliminate the slot arrangement and revert back to the socket-type connectors it used with the 486 and Pentium designs. Of course, it might take a few months for the motherboard suppliers to revise their designs to incorporate a socket instead of a slot, so socketed Celerons are unlikely to appear before next year.

The new Celeron allows Intel to restore the smooth flow of its pricing strategy, described last year in the Dataquest Perspective "A Ride Down Intel's Pricing Escalator" (PSAM-EU-DP-9722, October 31, 1997). In the Pentium's heyday, Intel offered a range of processors that differed only in clock rate (i.e., performance) and price. As faster chips came along at the high end, last year's $600 166-MHz chip became this year's entry-level $100 offering. When Intel abandoned the Pentium II's cache to drive the 266-MHz Pentium II into the $100 slot, the chip became a marginal value at best. Mendocino gives Intel the ability to reduce the cost of these products without destroying their value. So, do not despair if you really need but cannot afford all the performance of the $669 450-MHz Pentium II Intel announced today. Just wait a year or so, and you will be able to get the Celeron version (with on-chip cache, but no hologram) for roughly $100.

By Nathan Brookwood

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To One Gigahertz and Beyond

This week, two suppliers started to talk about microprocessors capable of running at speeds of 1 gigahertz (GHz), equivalent to 1,000 megahertz (MHz), or 1 billion computing cycles per second. On Monday, Digital Equipment Corporation unveiled its Alpha 21264 technology road map, which calls for a 1-GHz version, based on 0.18-micron CMOS technology, to be delivered sometime in the year 2000. (This announcement assumes the world can survive the year 2000 problem and will not collapse as the clock strikes 12 on December 31, 1999).

At midweek, IBM announced that it had successfully demonstrated an "experimental CMOS processor" that runs at speeds up to 1,100 MHz. Both announcements come hard on the heels of Intel's recently unveiled 333-MHz Pentium II processor, a device that runs only one-third as fast as these two speed demons. Buyers who just spent $2,500 to $3,000 on the latest 333-MHz systems may ask themselves if these announcements from Digital and IBM will hasten the demise of Intel's fastest-ever chip. Dataquest prepared this note to help readers understand this week's announcements and how they relate to products like the Pentium II that sit already on dealers' shelves.

Just as *Toy Story*'s Buzz Lightyear zoomed off "to infinity and beyond," these announcements lay the groundwork for microprocessors that run at 1 GHz and beyond. The technical hurdles designers must overcome to make any microprocessor operate at these extraordinary speeds are not inconsequential. One GHz operation implies a processor cycle time of 1 nanosecond (1ns, or one one-billionth of a second). Even traveling at the speed of light, electrical signals can progress less than 10 inches in such a brief interval. It is a real challenge to make such signals move through a succession of semiconductor circuits and do useful work before the clock strikes 1ns. At these speeds, even small on-chip wires turn into antennas, and the signals they radiate interfere with the other circuits on the chip. This complicates the design as well as the manufacturing processes for these new devices.

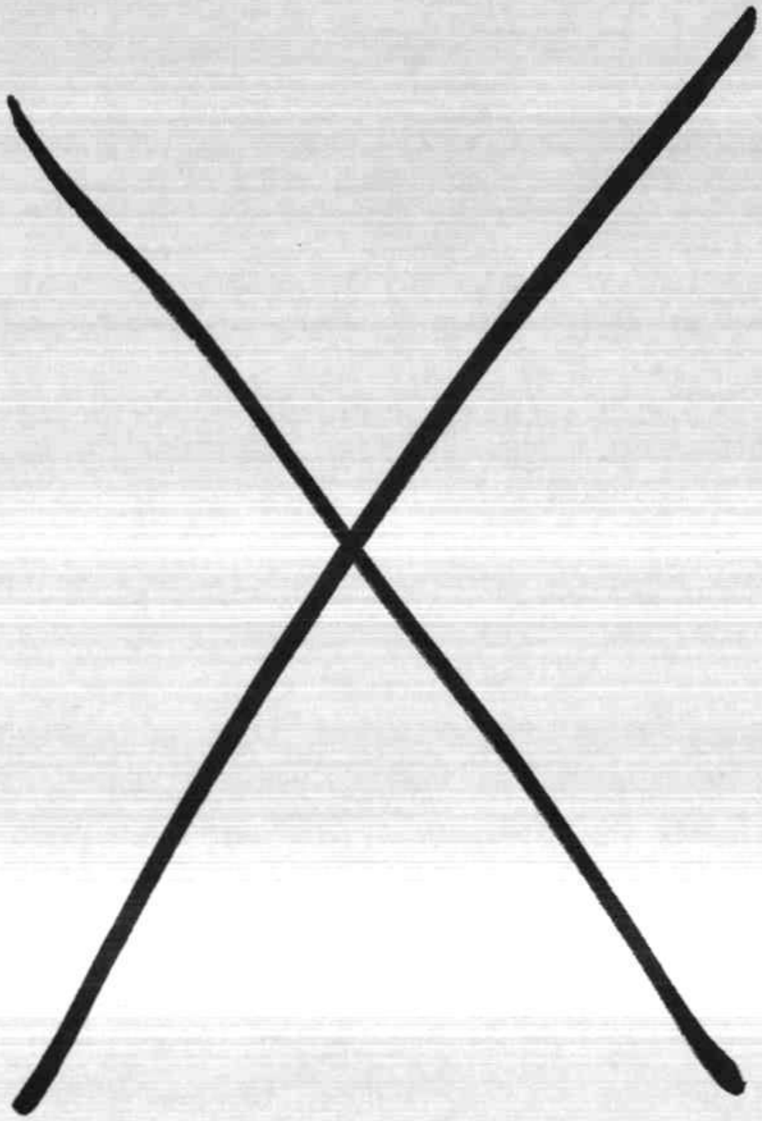
Digital announced its Alpha 21264 *technology* this week, but did not announce a *product* per se. It plans to ship a 600-MHz version of this new processor in the second quarter and will manufacture this chip using the same 0.35-micron CMOS process it uses today to build the 600-MHz 21164 processor. Although both old and new chips operate at the same clock frequency, the more sophisticated internal architecture of the 21264, coupled with the greatly increased capacity of its external buses, will allow it to deliver twice the computational performance of its predecessor. Next year, when Digital gains access to a 0.25-micron manufacturing technology, a modified 21264 should run at speeds beyond 750 MHz. In two years, a further shrink to 0.18-micron technology should push the 21264 beyond the magic 1-GHz benchmark.

IBM made its 1-GHz announcement at a technically focused conference on integrated circuit design. Its engineers implemented a working subset of a PowerPC microprocessor using conventional 0.25-micron manufacturing technology. (Dataquest believes the phrase "conventional 0.25-micron manufacturing technology" comes close to being an oxymoron.) The subset of PowerPC architecture IBM included contains most of the standard integer functions but omits the more complex floating-point operations. The chip also lacks an interface to main memory and can execute only programs that fit entirely within its 4KB caches—it runs these small programs extremely quickly. It now remains for IBM to transfer to its product development groups the design techniques it invented to build this prototype in its research labs. When IBM combines these features with its previously announced copper metallization capabilities and moves everything to 0.18-micron technology, the resulting products should be faster than fast.

What do these announcements portend regarding the longevity of Intel's brand new 333-MHz Pentium II? Intel's chip differs from the ones described in these announcements in that users can call up their favorite PC vendor and get a 333-MHz Pentium II system delivered today. They will have to wait a few years (and probably pay a little more) for systems containing 1-GHz Alphas. It will take at least that long for the technology IBM displayed at this week's conference to find its way into the marketplace. Intel increased the frequency of its fastest processors by 50 percent, from 200 MHz to 300 MHz, in 1997. It plans to add another 50 percent and move to 450 MHz this year. Two more years of similar improvements will push Intel into the gigahertz club as well. Those who buy today's 333-MHz systems and are committed to remain on the cutting edge of performance should be prepared to buy new systems (or at least new CPUs) on a quarterly basis for the next two years.

Does anyone really need the level of computational performance these forthcoming systems will deliver? Dataquest recalls that when Intel introduced its astonishingly fast 25-MHz 386 microprocessor in April 1988, most observers saw little use for that much computational performance on the desktop, although it was generally agreed that it would make a dynamite server. Shifting paradigms and graphical user interfaces managed to absorb that level of performance and left users hungry for more. For the past year or two, hardware suppliers have clearly outpaced the software industry's ability to build more ambitious applications that consume the available computing cycles. From a historic perspective, the software suppliers have always managed to catch up. Although the timing of this cycle remains somewhat clouded at this point, Dataquest doesn't see why the cycle wouldn't repeat itself.

By Nathan Brookwood



Perspective

Personal Computer Semiconductors and Applications Worldwide

Product Analysis

AMD's K7 Shows Promise

Abstract: *At the 1998 Microprocessor Forum, Advanced Micro Devices Inc. disclosed its next-generation K7 architecture. Its relatively small (163mm²) die size and first half 1999 availability bode well for AMD in 1999. In Dataquest's opinion, the architecture is a half-step ahead of Intel's current P6 offerings and, if AMD can deliver the clock speeds, should compete successfully with Intel's forthcoming Katmai processors on a clock-for-clock basis. In this Perspective, we examine the highlights of the K7 and examine AMD's future in the PC market.*
By Martin Reynolds

Recommendations for System Manufacturers

Although Advanced Micro Devices Inc. presents a higher risk to system manufacturers than Intel, there are clear cost/performance advantages to AMD's current K6 products in the lower end of the market. The road map that AMD presents looks good, therefore, we make the following recommendations to system manufacturers:

- Continue to deploy K6 systems.
- Evaluate the K7 for desktop and server applications.
- Examine the Alpha platform, if practical, alongside K7.

Continue to Deploy K6 Systems

AMD and the K6 have earned their place in the consumer market. K6-based machines from Compaq, Hewlett-Packard, and IBM dominate some retail channels in the sub-$1,000 space. Although, perhaps marred by a somewhat short supply of the higher-frequency devices, AMD's K6 has come through for its customers and users in the second half of 1998. Originally, Dataquest was concerned about AMD's prospects as Intel's Slot 1 permeated the market, but AMD has shown that its partners and customers can support the Socket 7

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infrastructure without Intel's participation. The Sharptooth product, with its integrated L2 cache, will enable AMD to track Intel to 500 MHz and beyond. This performance should allow AMD to hold onto its current market segment.

Evaluate the K7 for Desktop and Server Applications

K7 is a different opportunity. Its sophisticated architecture should meet or beat Katmai on a clock-for-clock basis, and its monstrous 1.6-GB/sec bus bandwidth is well ahead of Intel's offerings until at least the year 2000. If AMD delivers K7 in the first half of 1999 at clock speeds in excess of 500 MHz, the company has a good chance of going toe-to-toe with Intel's premier desktop and server offerings. Not that one should underestimate Intel. The company is potentially capable of delivering 500 MHz as an entry-level processor in 1999, if necessary to maintain its longstanding lead over AMD's product line.

Therefore, Dataquest recommends that manufacturers continuously evaluate K7 platforms as parts become available, preparing to put them into production should the market opportunity arise. This advice applies to desktop systems and low-end server applications, where K7's high-speed bus could enable new levels of uniprocessor performance at competitive prices.

Examine the Alpha Platform, If Practical, Alongside K7

The K7 will drive the Alpha EV6 infrastructure to volumes orders of magnitude above Alpha's best. As the Alpha is, in theory, pin-compatible with the K7, Dataquest expects to see low-cost Alpha designs appearing. However, it is incumbent on the chipset designers and BIOS developers to make sure that platforms also support Alpha parts. If the Alpha versions of K7 platforms are practical products, they will find favor in performance-driven segments for both server and workstation designs. Also, the popularity of alternative operating systems such as Linux is growing, and low-cost, high-performance devices could create a small but lucrative market opportunity.

AMD's (Slow) Renaissance

At the Microprocessor Forum in 1996, AMD disclosed its K6 architecture. Dataquest analyzed the die photo and came to the conclusion that, despite a large cache and sophisticated design, the K6 had a relatively small die size capable of being manufactured in high volume.

Based on this analysis, Dataquest was optimistic about AMD's prospects for 1998 and estimated that the company could ship almost 20 million units from its manufacturing lines in 1998. Unfortunately, manufacturing problems crippled production of the K6 until mid-1998, leaving AMD with a worthwhile but unexciting profit in the third quarter of 1998. The good news is that a 3.8 million-unit quarter indicates that AMD now has its lines running at a decent yield. At the same time, Intel has advanced its clock speeds beyond general expectations, rendering the K6 a low-end solution. The good news is that the K6 has been completely accepted by the major consumer PC manufacturers as the premier processor for low-cost conventional PCs; the position has been bolstered by acceptance of AMD's 3DNow! architecture, and the forthcoming Sharptooth processor. This acceptance has enabled AMD to maintain and enhance the Socket 7 infrastructure and secure a position for the K6-2 processor well into 1999.

The K7

The K7 has a few surprises for us. First is the die size. Again AMD has delivered an aggressive part with 22 million transistors in 184 square millimeters of silicon area. This density comes in part from a six-layer metal process with local interconnect and the use of C4 packaging with its improved power and ground distribution. Second is the availability. AMD has silicon now and expects to ship products in the first half of 1999 with clock speeds in excess of 500 MHz. According to AMD, the device uses only 6.1 million transistors in the caches, excluding the branch history table, return address stack, L1 tags, L2 tags, parity, or modified exclusive shared invalid (MESI) bits. This count leaves well in excess of 10 million transistors in the core, dwarfing other x86 processors.

In terms of manufacturing capacity, Dataquest hesitates to pin a number on AMD's K7 process. However, it is built in a variant of AMD's now-successful 0.25-micron process and should not be yield-limited. The die size is a trifle large, but AMD should be able to manufacture up to 10 million of these devices a year. Its 1999 volume, however, is heavily dependent on ramp start, ramp rate, and demand for the Sharptooth processor.

The K7 Architecture

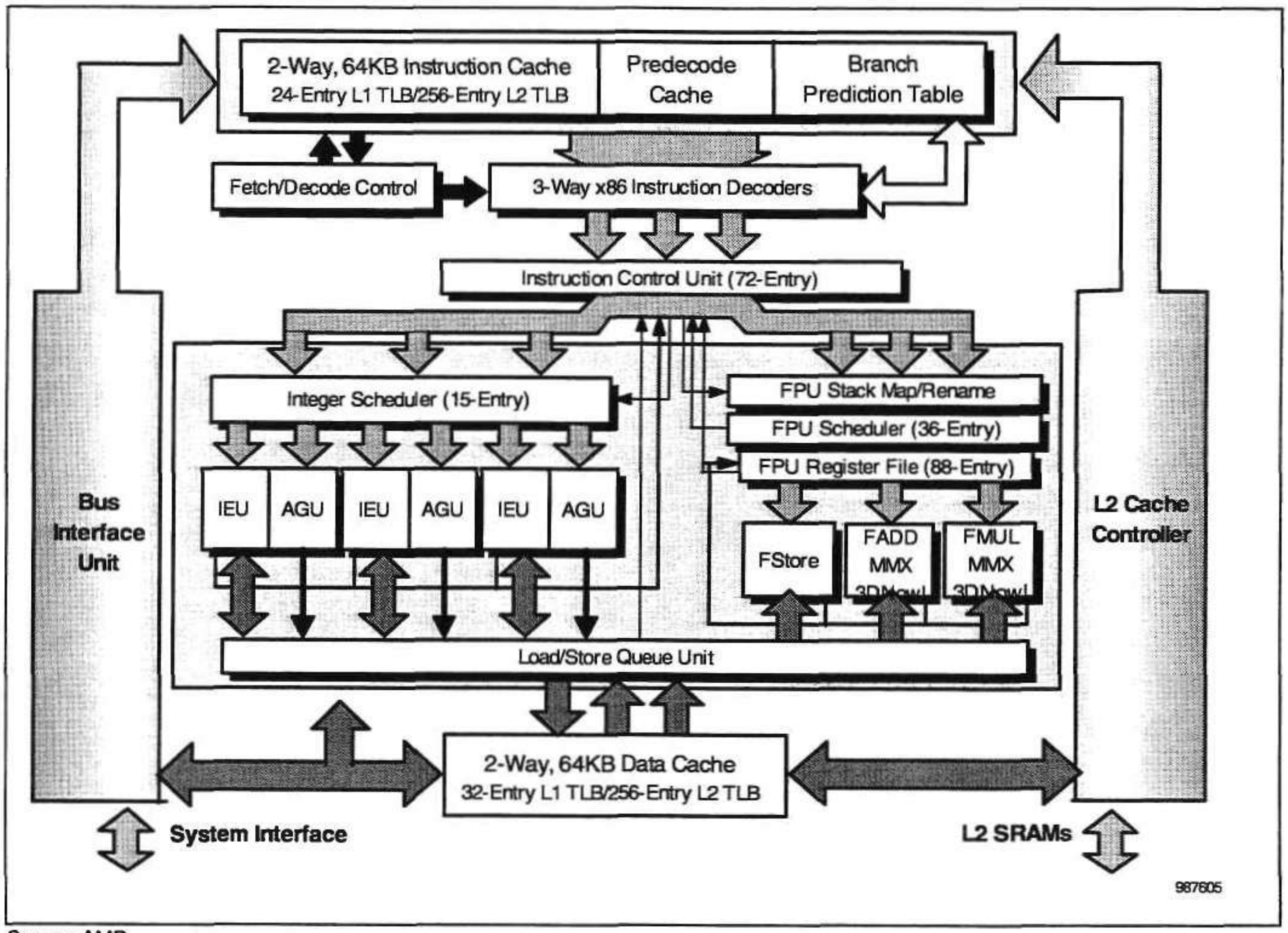
The core itself is a new decoupled, translating architecture following the P6, K5, and K6 designs. However, it is radically different from AMD's K5 and K6 designs in many key areas.

Pipeline

The K7 integer pipeline is 10 stages long, echoing Intel's move to a double-digit pipeline for the P6 architecture. A long pipeline allows the processor to be broken up into physically smaller functional units, resulting in shorter electrical connections and lower signal loading. Therefore, timing becomes much less of a challenge and AMD will be able to aggressively scale the K7's clock speed as its processes advance. This approach also makes copper technology more a luxury than a necessity. When AMD gets copper, clock speeds will increase, but copper will not be needed to remain competitive.

Figure 1 shows an overview of the K7's architecture. The design is unusual in that it is a hybrid of decoupling techniques. The execution-unit reservation stations of a Tomasulo-type design are in evidence, but it also has a large reservation station. The design is, therefore, effectively double decoupled.

Figure 1
AMD's K7



Source: AMD

Instruction Decomposition

The x86 instructions are translated to MacroOps, so named because each can accommodate up to two operations. The MacroOps map closely to the x86 instruction set, with many x86 instructions yielding just one MacroOp. The really complex instructions are caught by a ROM-based vector decoder, which issues three MacroOps at a time to the Instruction Control Unit (ICU). The MacroOps are stored in a 72-entry buffer in the ICU, from which they are dispatched to one of three integer units or a sophisticated floating-point unit. The MacroOps resemble two RISC-type instructions paired together—one arithmetic instruction and one load/store instruction—blurring further the distinctions between RISC and CISC.

Integer Units

The processor has three identical integer units, each with a five-entry instruction queue. Each integer unit incorporates an arithmatic logic unit (ALU) paired with an address generation unit (AGU). One MacroOp can contain both an addressing and an arithmetic subinstruction, so one instruction can keep the whole pipeline occupied. One could argue that separate AGUs and smaller instruction widths would have saved some transistors, but this approach makes it far easier to keep track of what happens to the x86 instruction stream. Furthermore, the transistor budget is becoming less and less of an issue.

In many cases, the K7 can complete three simple ALU instructions per clock. Multiply instructions, however, can return a double-width result and as such consume two of the integer pipelines to complete their function.

The Floating-Point Unit

AMD has a beefy floating-point unit (FPU) in the K7, addressing a historically weak point for AMD and the x86 architecture. It also incorporates a dual MMX unit and support for AMD's successful 3DNow! architecture. In the execution units, the first order of business is that of unraveling the x86 FPU stack architecture, a legacy from the 1970s and a tough architecture from which to gain maximum performance. AMD achieves this objective through a renaming architecture, along with a substantial 88-entry register file. The FPU has three pipeline units, a storage element, and two arithmetic elements. The arithmetic elements are both capable of working in x87 floating-point, MMX, or 3DNow! instruction spaces, although only one of the two units can perform multiply operations. The FPU has a 36-entry scheduler, which should allow it to deliver healthy floating-point performance in all three of its supported environments.

Load/Store and the Result Bus

The K7 brings a result bus through the heart of the processor. Every execution unit presents its result onto this bus at completion, and the result bus is available to all relevant inputs. This technique, although generating a large amount of interconnect, allows the K7 to pass data between execution units without losing clock cycles to run the information in and out of memory. Again, this is an example of the benefits of a 10 million-transistor core!

The system interface includes a healthy complement of buffers designed to manage cache misses. There are two instruction cache miss address buffers, eight data cache miss address buffers, four write address buffers, and eight victim address buffers. The interface can handle one load and one store per cycle. Each transaction can be two 32-bit words or one 64-bit word, the latter being used to speed throughput of 3DNow! data. This extensive layering, coupled with a 44-entry load/store queue, allows the K7 to keep its core running at maximum possible speeds.

On-Chip Caches

The K7 incorporates a total of 128KB of cache, comprised of separate two-way set associative 64KB instruction and data caches. Although smaller than Katmai's expected 256KB of cache, this is sufficient to keep K7 well fed at 500 MHz and beyond. The caches account for an estimated 10 million transistors, leaving about 12 million transistors for the K7's core.

As with the K6, the K7 incorporates a profligate branch prediction table with 2,048 entries. The K7 also has two-level translation look-aside buffers (TLBs), with 24 entries in level one and 256 entries in level two in the instruction TLBs and 32 entries in level one and 256 entries in level two in the data TLBs.

The System Bus

In many ways, the Alpha EV6 bus is the most interesting part of this architecture. In the AMD implementation, it uses both edges of a 100-MHz clock for an effective 200-MHz transfer rate. With an 8-byte data path, the bus can transfer up to 1.6 GB/sec. At 400 MHz, 3.2 GB/sec becomes possible—well ahead of Intel's Foster part. The bus is a point-to-point design, supporting only one processor and one interface. This is not a problem for mainstream desktop systems, and AMD will be able to leverage Alpha's multiprocessing infrastructure for servers.

To achieve these speeds, the bus uses clock-forwarding. In this technique, the bus clock is transmitted alongside the data—much like the Rambus memory interface—and allows the receivers to synchronize with the incoming data. The design problem moves from one of minimizing delays to one of controlling relative skew, a far easier challenge to meet at these high speeds.

The EV6 bus is intended for multiprocessor designs, and includes two distinct address paths. One path provides address request information to transactions, and the other provides snoop information back to the processor. Its signaling protocols are restricted to the three buses, keeping the pin count low (fewer than 150 pins) and providing a simple platform for scalable multiprocessing.

The Package

The K7 uses similar packaging to Intel's Pentium II. The connector and module are identical in size to the Intel product, allowing the K7 to use mounting components, heat sinks, fans, and chassis designed for the Pentium II. The pinout, however, is totally different and requires a different chipset. The module also allows AMD to break free of the cache challenges of a single-chip package. K7 can support up to 8MB of in-module cache, presumably running at up to full clock speed—if AMD can find the necessary fast-cache RAMS.

Alpha, K7, and Compaq

The K7 has a unique opportunity in the server field. Compaq's ongoing endorsement of its Alpha architecture ensures that there will be some advanced server devices with multiple EV6 slots in the market. These devices could just as easily accept K7 processors, giving the K7 a shot at the highest end of the PC server market. To capitalize on this opportunity, AMD will have to deliver robust multiprocessing in the K7. Historically, this has been a major challenge for Intel. The products have either not worked or have yielded only small increments in performance. If K7 can crack this barrier, deliver a 200-MHz (400-MHz transfer rate using both edges of the clock) 3.2-GB/sec front-side bus, incorporate an 8MB cache, and scale its frequency up to 1 GHz, it will undoubtedly become a fixture in Compaq's high-end server line. These challenges are significant, but AMD could realize a huge reward for success. On the plus side, the entire system architecture below the level of the processor is a known quantity.

Sharptooth

Sharptooth is an evolution of the K6-2 core, bringing 256KB of L2 cache on-board and converting the still-supported external cache to L3. This integration will allow AMD to push the K6 core clock speed upward, relatively unbounded by bus constrictions, to speeds in excess of 500 MHz. Dataquest believes that AMD will be able to maintain its hold in the consumer market through the end of 1999 with this part, as long as the company executes on its manufacturing strategy. At this stage, the company has won the confidence of its customers both at the OEM level and the user level. However, a slip will be catastrophic for AMD as Intel's Celeron lineup is a very fine alternative.

Perspective

Personal Computer Semiconductors and Applications Worldwide

Market Analysis

The Calculus of the 1998 Core Logic Market: Differentiation and Integration Drive Market Growth

Abstract: *Vendors shipped 14 percent more PC core logic units in 1997, but price erosion resulted in a 4 percent decline in revenue. Over the next five years, Dataquest forecasts that average selling prices will rise as vendors integrate system functions such as graphics and audio into core logic products.*

By Nathan Brookwood

What Does Core Logic Do?

Core logic is like underwear. It gets little respect. Few want to talk about it, but everyone needs it—just try to build a modern computer without it, and see how far you get. Core logic provides the glue that links a computer's microprocessor to the rest of the system. Over the past decade, designers have used increasing transistor density to integrate more diverse capabilities into the chipsets they create. Today's core logic chipsets incorporate functions that once occupied large areas of motherboard real estate. More often than not, decreases in board space lead to decreases in bill-of-materials cost and increases in performance and function.

As shown in Figure 1, contemporary PC core logic products usually are delivered in a two-chip set that Dataquest counts as a single core logic unit. One of these chips—the "north bridge"—typically mates with the microprocessor and its memory system, including any cache subsystems external to the processor itself. The other chip in the set—the "south bridge"—controls the various system buses that tie peripherals to the system. These include the traditional Industry Standard Architecture (ISA) bus; the

Dataquest

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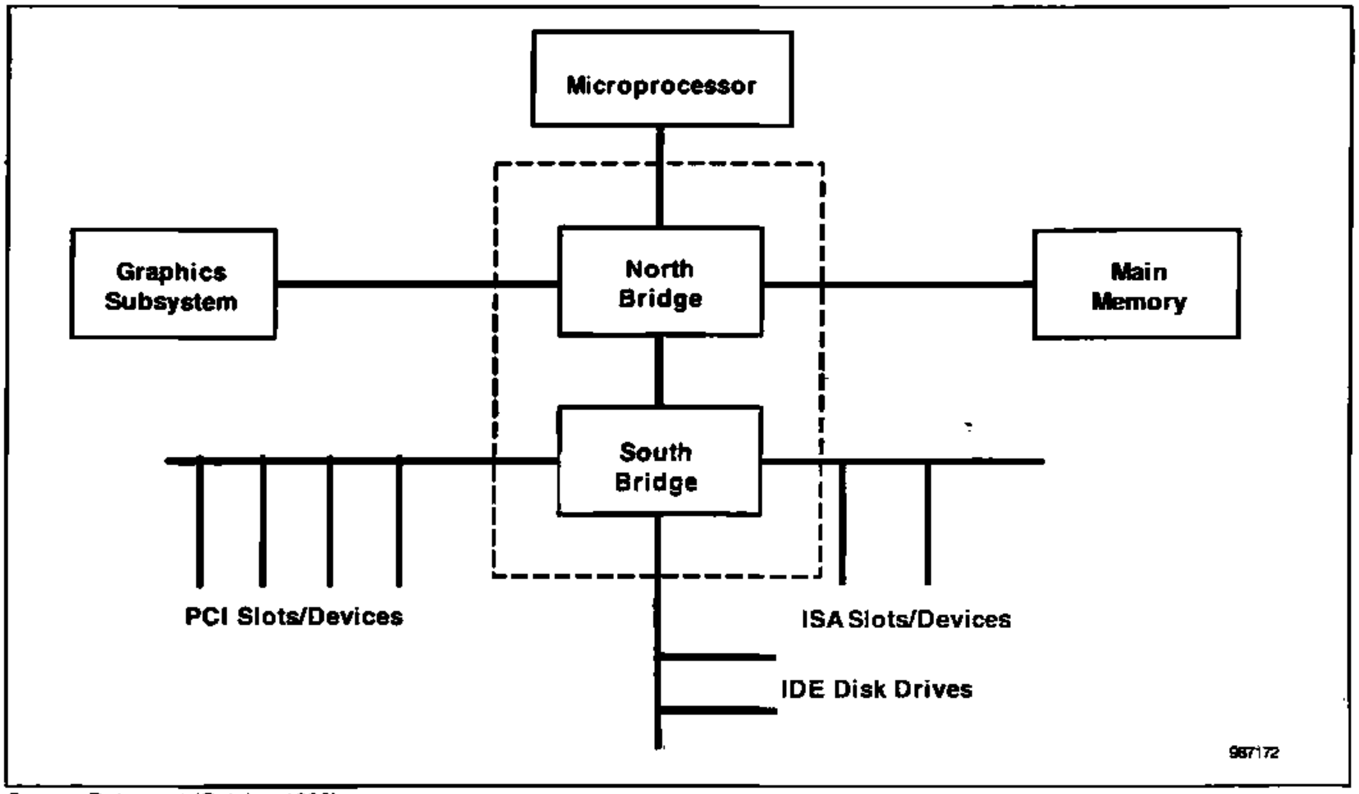
IDE bus that controls hard disks and CD-ROM drives; the newer Peripheral Component Interconnect (PCI) bus; and the newer-still Universal Serial Bus (USB) that can connect keyboards, mice, printers, modems, scanners, and other (relatively) low-speed devices.

Figure 1
Block Diagram for the Core Logic in a Contemporary PC



Source: Dataquest (October 1998)

Increasing semiconductor device density provides many alternatives for the integration of core logic functions. Eventually, it will become possible to incorporate the processor core, the north and south bridges, and the graphics subsystem onto one piece of silicon. Such a chip would interface directly with the main memory subsystem and input/output (I/O) devices and could be used as the basis for a low-cost system with moderate performance. In the near term, such an approach is not likely to be employed in high-performing systems because developers have been unable to line up the product development and technology cycles for processors, graphics, memory, and I/O architectures. Consequently, designers merge various combinations of these elements, depending on the components available to them and the product features they intended to optimize. Dataquest anticipates that designers will continue to take varied approaches to this design problem during the forecast period, 1998 to 2002.

Review of the 1997 x86 Core Logic Market

After several years of rapid gains in market share, Intel's portion of the PC core logic market finally stabilized in 1997, with Intel having 70 percent of the chipset revenue and 59 percent of unit shipments. Of the dozen vendors that serviced this market as recently as 1994, only a handful still remained at the end of 1997. Three of the remaining contenders, VIA Technologies, Silicon Integrated Systems, and Acer Laboratories, traded positions but together consolidated their positions, increasing overall market share from 17 percent of revenue in 1996 to 24 percent in 1997 and going from 25 percent of unit shipments in 1996 to 34 percent in 1997.

The Pentium-style bus continued to dominate desktop PC system shipments in 1997, with over 60 million units using this design. Pentium, Pentium with MMX, AMD-K5 and AMD-K6, and Cyrix/IBM 6x86MX processors all used this bus design. These systems are typically labeled "socket 7" designs, although some mobile versions lack the specific socket from which they draw their name. Over 9 million systems utilized the newer P6 bus that Intel devised for its Pentium Pro and Pentium II lines. (The Celeron and Xeon processors that Intel introduced early in 1998 also use this bus arrangement.) In 1997, Intel was the only vendor to ship core logic that worked with the P6 designs.

In 1997, core logic evolved to support three new key features. Support for synchronous DRAM (SDRAM) memory and for the accelerated graphics port (AGP) graphics primarily affected system performance. Support for the USB peripheral interface appeared in both the socket 7 and P6 bus products but proved largely irrelevant in 1997. Few USB peripherals emerged that could take advantage of this new feature. Dataquest anticipates that the growing installed base of systems with USB capability will eventually make the market for USB peripherals an attractive one, but this certainly was not the case in 1997. AGP features first appeared in Intel's 440 LX chipset designed for Pentium II systems. At the time of the 440 LX introduction, Intel argued that socket 7 designs could not meet AGP's memory bandwidth requirements, and thus, the company chose not to add this feature to its Pentium chipset, the 430 TX. Later in 1997, VIA Technologies introduced its Apollo VP3 socket 7 design with AGP support and proved that the Pentium bus could support this feature after all. By early 1998, Silicon Integrated Systems and Acer Laboratories also delivered socket 7/AGP solutions, thus proving the versatility of the Pentium bus that first hit the market in 1993.

Pricing remained extremely competitive in 1997. Intel continued to drive its own core logic prices lower, hoping that lower component prices would translate into lower system prices, which in turn would drive increased unit shipments of high-margin microprocessors. This approach, which Intel has employed for several years, helped drive industry unit growth to 14 percent from 1996 to 1997, although industry core logic revenue actually shrank a bit during the same time period. Intel's competitors offered their own products at a substantial discount to Intel's prices but remained in the game.

Dataquest traditionally has segmented the core logic market into "desktop" and "mobile" categories. This year, we have identified a new category of use—embedded products—where cost constraints and product life cycles differ substantially from those of desktop and mobile uses. Consequently, we have reported 1997 consumption along these lines when our data permitted us to do so.

Tables 1 and 2 rank core logic vendors by revenue and unit shipments, respectively, for aggregate sales into the desktop, mobile, and embedded markets. Tables 3, 4, and 5 report each vendor's sales in terms of revenue, unit shipments, and average selling prices, respectively, in each segment. Prices reflect the factory prices paid to component suppliers.

Table 1
Ranking of PC Core Logic Chipset Vendors by Revenue, 1996 to 1997 (Millions of Dollars)

1997 Rank	1996 Rank	Vendor	1996 Revenue ($M)	1997 Revenue ($M)	1996 Market Share (%)	1997 Market Share (%)	1996 to 1997 Growth (%)
1	1	Intel	1,056	1,032	69	70	-2
2	6	VIA Technologies	64	152	4	10	138
3	4	Acer Laboratories	78	109	5	7	40
4	2	Silicon Integrated Systems	129	103	8	7	-21
5	3	OPTi	84	51	5	3	-39
6	9	ITE	-	19	0	1	-
7	10	Cyrix Media GX	-	13	0	1	-
8	7	National Semiconductor	39	9	3	1	-77
9	5	United Microelectronics	67	-	4	0	-100
10	8	Cirrus Logic	28	-	2	0	-100
		Total	**1,546**	**1,488**	**100**	**100**	**-4**

Source: Dataquest (October 1998)

Table 2
Ranking of PC Core Logic Chipset Vendors by Shipments, 1996 to 1997 (Thousands of Units)

1997 Rank	1996 Rank	Vendor	1996 Unit Shipments (K)	1997 Unit Shipments (K)	1996 Market Share (%)	1997 Market Share (%)	1996 to 1997 Growth (%)
1	1	Intel	41,088	48,552	56	59	18
2	6	VIA Technologies	3,976	12,597	5	15	217
3	2	Silicon Integrated Systems	8,443	8,466	12	10	0
4	4	Acer Laboratories	5,600	7,670	8	9	37
5	5	OPTi	4,167	2,275	6	3	-45
6	9	Cyrix Media GX	-	1,300	0	2	-
7	10	ITE	-	1,250	0	2	-
8	7	National Semiconductor	1,925	380	3	0	-80
9	3	United Microelectronics	5,720	-	8	0	-100
10	8	Cirrus Logic	1,375	-	2	0	-100
		Total	**72,294**	**82,490**	**100**	**100**	**14**

Source: Dataquest (October 1998)

Table 3
PC Core Logic Chipset Vendors' Revenue by Category, 1996 to 1997 (Millions of Dollars)

Vendor	1996 Desktop Revenue	1997 Desktop Revenue	1996 Mobile Revenue	1997 Mobile Revenue	1996 "Others" Revenue	1997 "Others" Revenue	1996 Total Revenue	1997 Total Revenue
Acer Laboratories	71	92	7	8	-	9	78	109
Cirrus Logic	-	-	28	-	-	-	28	-
Cyrix Media GX	-	13	-	-	-	-	-	13
Intel	885	680	50	163	122	189	1,057	1,032
ITE	-	8	-	11	-	-	-	19
National Semiconductor	-	-	39	9	-	-	39	9
OPTi	34	7	50	44	-	-	84	51
Silicon Integrated Systems	124	89	5	5	-	9	129	103
United Microelectronics	48	-	19	-	-	-	67	-
VIA Technologies	59	134	5	-	-	18	64	152
Total	**1,220**	**1,023**	**204**	**240**	**122**	**225**	**1,546**	**1,488**

Source: Dataquest (October 1998)

Table 4
PC Core Logic Chipset Vendors' Shipments by Category, 1996 to 1997 (Thousands of Units)

Vendor	1996 Desktop Unit Shipments	1997 Desktop Unit Shipments	1996 Mobile Unit Shipments	1997 Mobile Unit Shipments	1996 "Others" Unit Shipments	1997 "Others" Unit Shipments	1996 Total Unit Shipments	1997 Total Unit Shipments
Acer Laboratories	5,100	6,710	500	460	-	500	5,600	7,670
Cirrus Logic	-	-	1,375	-	-	-	1,375	-
Cyrix Media GX	-	1,300	-	-	-	-	-	1,300
Intel	36,917	38,278	1,786	6,496	2,385	3,778	41,088	48,552
ITE	-	700	-	550	-	-	-	1,250
National Semiconductor	-	-	1,925	380	-	-	1,925	380
OPTi	1,976	567	2,191	1,708	-	-	4,167	2,275
Silicon Integrated Systems	8,118	7,666	325	300	-	500	8,443	8,466
United Microelectronics	4,830	-	890	-	-	-	5,720	-
VIA Technologies	3,726	11,597	250	-	-	1,000	3,976	12,597
Total	**60,667**	**66,818**	**9,242**	9,894	**2,385**	5,778	**72,294**	82,490

Source: Dataquest (October 1998)

Table 5
PC Core Logic Chipset Vendors' Average Selling Prices by Category, 1996 to 1997 (Dollars)

Vendor	1996 Desktop	1997 Desktop	1996 Mobile	1997 Mobile	1996 "Others"	1997 "Others"	1996 Total	1997 Total
Acer Laboratories	13.86	13.70	14.80	17.83	-	18.00	13.95	14.22
Cirrus Logic	-	-	20.36	-	-	-	20.36	-
Cyrix Media GX	-	10.00	-	-	-	-	-	10.00
Intel	23.96	17.76	28.00	25.10	51.11	49.94	25.71	21.25
ITE	-	10.71	-	20.00	-	-	-	14.80
National Semiconductor	-	-	20.39	-	-	-	20.39	24.00
OPTi	17.00	12.35	23.00	25.76	-	-	20.16	22.42
Silicon Integrated Systems	15.30	11.60	15.69	15.67	-	18.00	15.31	12.12
United Microelectronics	9.94	-	21.35	-	-	-	11.71	-
VIA Technologies	15.83	11.55	20.00	-	-	18.00	16.10	12.07
All Vendors	**20.11**	**15.30**	**22.09**	**24.26**	**51.11**	**38.88**	**21.39**	**18.03**

Source: Dataquest (October 1998)

Forecast for x86 Core Logic Markets, 1998 to 2002

Dataquest's forecast for the core logic market reflects the increasingly wide range of markets into which x86-based systems are, or will be, sold in the future. In days past, vendors could focus on the "desktop" or "mobile" markets—a distinction that has become blurred as the requirements for these two segments begin to overlap. However, now, vendors must address low-end PC markets, where cost matters most of all, along with high-end markets, where flexibility and performance are used to differentiate products. They may also choose to address workstation markets, where limited multiprocessing capabilities and high-speed I/O make a difference. Server markets demand data integrity and system scalability features, for which desktop and mobile users have no use and will not pay.

To gauge the size of each market, Dataquest turns to the system-level forecasts prepared by our Personal Computer program, Advanced Desktops and Workstations program, and our Client/Server Hardware program. These forecasts allow us to determine the overall size of the market for x86 core logic and the split between the various MPUs (and thus the bus structures) for these devices. Not all of this demand is reflected in merchant market sales of core logic chipsets, because some system vendors choose, at least for some products, to develop system core logic internally and to utilize the features they incorporate in their proprietary designs to gain some system marketing advantage. Table 6 shows the split between the chipsets sold on the merchant market and those sourced internally by system vendors. The latter occur primarily in workstation and server environments where off-the-shelf solutions do not yet adequately address the complete range of market requirements.

Table 6
Forecast of Merchant and Proprietary x86 Core Logic Chipset Unit Shipments (Thousands of Units)

	1997	1998	1999	2000	2001	2002
Merchant Chipsets	82,490	102,595	122,370	145,249	170,548	205,708
Proprietary Chipsets	14,360	13,990	13,597	12,630	12,837	13,130
Total	**96,850**	**116,585**	**135,966**	**157,879**	**183,385**	**218,839**
Percentage of Chipsets That Are Proprietary	15	12	10	8	7	6

Source: Dataquest (October 1998)

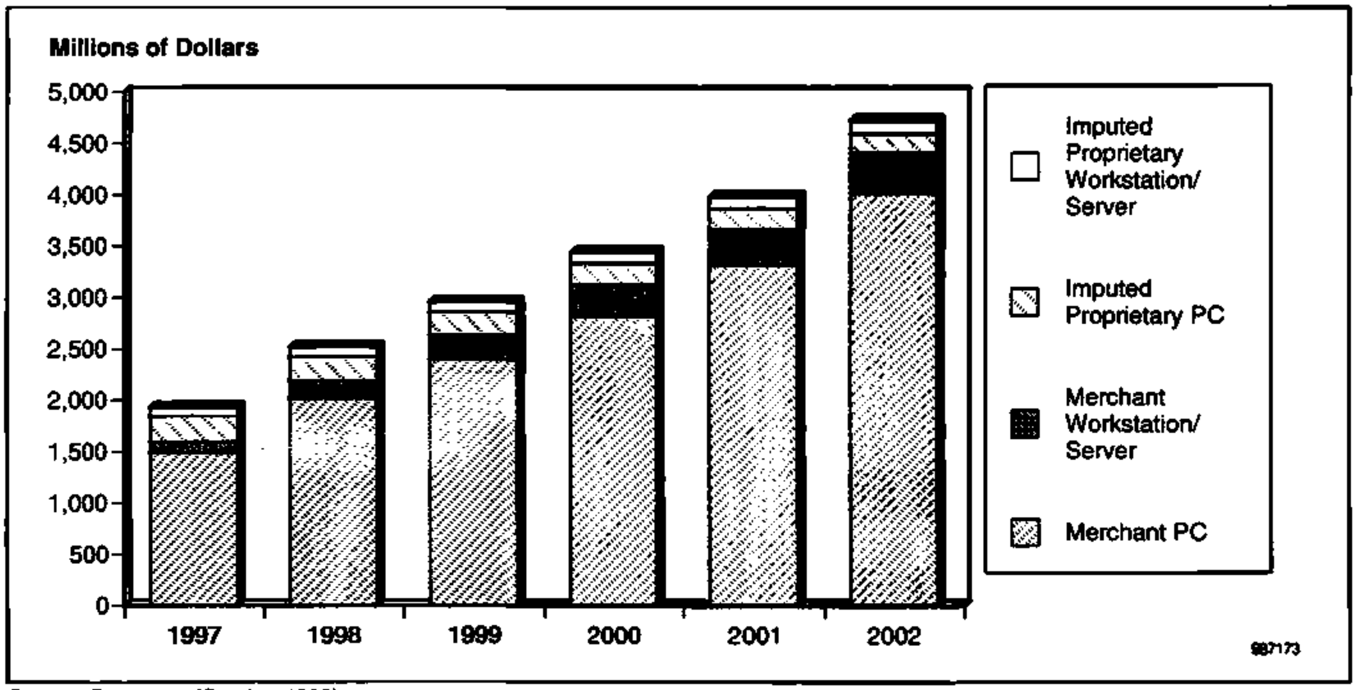
Table 7 and Figure 2 contain Dataquest's estimate of the revenue that will result from these sales. This table accounts for the revenue that will remain captive within system vendor organizations and will not result in merchant market chipset sales.

Table 7
Forecast of Revenue from Sales of x86 Core Logic Chipsets (Millions of Dollars)

	1997	1998	1999	2000	2001	2002
Merchant PC	1,487	2,019	2,398	2,825	3,323	4,022
Merchant Workstation/Server	113	174	240	305	347	390
Imputed Proprietary PC	247	234	223	212	201	191
Imputed Proprietary Workstation/Server	82	93	94	99	112	126

Source: Dataquest (October 1998)

Figure 2
Forecast of Merchant and Imputed x86-Based PC, Workstation, and Server Core Logic Chipset Revenue (Millions of Dollars)



Source: Dataquest (October 1998)

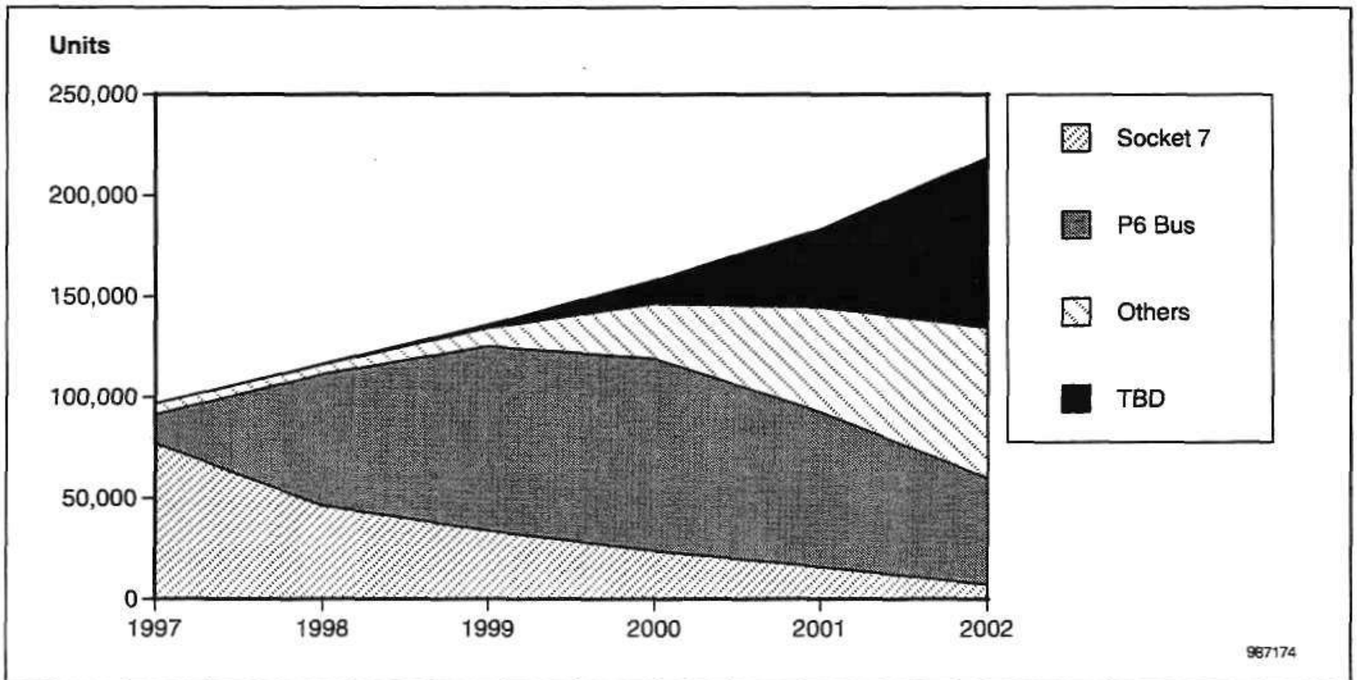
Table 8 and Figure 3 divide chipset solutions (merchant and proprietary, PC, workstation, and server) by processor and bus type. The "others" category includes devices such as the Cyrix Media GX and the AMD-K7, while "TBD" includes forthcoming Intel processors such as Merced and Willamette, for which the bus structures have not yet been disclosed.

Table 8
Forecast of Core Logic Chipset Shipments by System Bus (Thousands of Units)

	1997	1998	1999	2000	2001	2002
Socket 7	77,136	46,254	33,862	23,807	15,996	7,157
P6 Bus	14,386	65,199	91,523	95,301	76,678	52,844
Others	5,328	4,742	9,028	27,143	51,807	74,453
TBD	-	390	1,554	11,628	38,904	84,386
Total	**96,850**	**116,585**	**135,966**	**157,879**	**183,385**	**218,839**

TBD = To be determined
Source: Dataquest (October 1998)

Figure 3
Forecast of Core Logic Chipset Shipments by System Bus (Thousands of Units)



TBD = To be determined
Source: Dataquest (October 1998)

Tables 9, 10, and 11 display Dataquest's forecasts for core logic shipments into desktop, mobile, and embedded markets, respectively, broken down by microprocessor bus type. The Pentium-style socket 7 approach will continue in all three markets, although its relevance will fade faster in the desktop market and will linger longer in the relatively slow-moving embedded market. (Vendors that service the embedded market should be prepared for very long product cycles; some of their customers may only now be ready to move from a Z80-based solution to something a bit faster, such as a 486.)

Table 9
Forecast of Core Logic Chipset Shipments for the Desktop PC Market (Thousands of Units)

	1997	1998	1999	2000	2001	2002
Desktop 7	60,307	33,835	24,623	17,055	11,287	4,964
Desktop P6	9,250	50,279	69,805	68,086	46,892	26,589
Other Desktop	3,357	1,229	3,373	19,874	43,936	62,222
Desktop TBD	-	137	843	8,518	29,291	62,222

TBD = To be determined
Source: Dataquest (October 1998)

Table 10
Forecast of Core Logic Chipset Shipments for the Mobile PC Market (Thousands of Units)

	1997	1998	1999	2000	2001	2002
Mobile 7	12,388	7,418	4,801	2,664	1,753	789
Mobile P6	2,500	11,059	15,943	20,186	20,114	15,680
Other Mobile	132	1,229	2,813	3,785	4,642	7,840
Mobile TBD	-	-	-	1,262	6,189	15,680

TBD = To be determined
Source: Dataquest (October 1998)

Table 11
Forecast of Core Logic Chipset Shipments for the Embedded x86 Market (Thousands of Units)

	1997	1998	1999	2000	2001	2002
Embedded 7	4,441	5,001	4,439	4,087	2,957	1,404
Embedded P6	63	154	888	2,044	4,731	5,616
Other Embedded	1,840	2,285	2,841	2,861	2,484	3,510
Embedded TBD	-	254	710	1,226	1,656	3,510

TBD = To be determined
Source: Dataquest (October 1998)

Tables 12 and 13 offer Dataquest's estimates for core logic consumption in the workstation and server markets, respectively. These markets have already abandoned the socket 7 interface and will utilize a combination of Pentium II and Pentium II Xeon processors over the next few years. Eventually, Intel's Willamette and Merced products will begin to affect these markets—and only these markets during the forecast period—resulting in some shift to the "TBD" category. Dataquest has not made any effort to forecast any penetration of these markets by Advanced Micro Devices' K7 processor, which will use core logic compatible with the Digital/Compaq Alpha 21264 bus. AMD has suggested that it will try to position some versions of its K7 in these markets, but Dataquest will await more details before attempting to incorporate these chips into this portion of the forecast.

Table 12
Forecast of Core Logic Chipset Shipments for the x86 Workstation Market (Thousands of Units)

	1997	1998	1999	2000	2001	2002
Workstation 7	-	-	-	-	-	-
Workstation P6	397	964	1,673	1,842	1,662	1,651
Other Workstation	-	-	-	230	277	330
Workstation TBD	-	-	-	230	831	1,320

TBD = To be determined
Source: Dataquest (October 1998)

Table 13
Forecast of Core Logic Chipset Shipments for the x86 Server Market (Thousands of Units)

	1997	1998	1999	2000	2001	2002
Server 7	-	-	-	-	-	-
Server P6	2,175	2,743	3,214	3,144	3,280	3,308
Other Server	-	-	-	393	469	551
Server TBD	-	-	-	393	937	1,654

TBD = To be determined
Source: Dataquest (October 1998)

Key Trends in the Core Logic Market

The features, performance, and cost that core logic vendors offer can differentiate their products. The following discussion provides a quick overview of the issues in each of these areas.

Features

System Bus Speed (66/100/133 MHz)

The system bus (sometimes referred to as the "front-side bus") links the microprocessor to the system memory and I/O devices. Today's processors operate at very high speeds (typically 200 MHz to 400 MHz), but the external devices attached to the processors run much more slowly. Many applications spend more time waiting for data to move from system memory or disk to the processor core than they do processing the data. Consequently, anything the system designer can do to speed memory access or I/O helps overall performance. Today's fast processors find the 66-MHz memory systems of yesterday's systems to be a serious limitation, and thus, 100-MHz memory systems have appeared. 133-MHz memory systems will arrive soon. To take advantage of faster memories, systems need faster pathways—hence, the focus on faster system buses. Intel has concentrated its development resources on 100-MHz buses for its P6 line, while the other socket 7 logic providers have added this capability to the traditional Pentium-style bus.

Cache Memory Support

Cache memory provides a high-speed buffer that feeds the processor's insatiable appetite for instructions and data. (At 333 MHz, a Pentium II processor wants to absorb three 32-bit instructions every 3ns, but the main memory takes at least 50ns to deliver 64 bits of data.) Intel's Pentium II design solves this problem by packaging the cache memory inside the processor cartridge, where the core logic never sees it. However, the older socket 7 design put the cache memory on the motherboard, where the core logic had to supervise the movement of data among the main memory, the cache, and the processor. The manner in which the core logic structured the cache memory had a profound effect on system performance and expandability. This will continue to be an issue in socket 7 designs; it also affects the design of multiprocessor server systems.

Main Memory Support (EDO/SDRAM/Rambus)

Faster processors want bigger and faster main memories, which in turn require different control logic. The core logic vendor must work hand in hand with the DRAM vendor to ensure that systems and memory components appear in the market in a synchronized manner. Memory vendors that cannot convince logic vendors to support their exotic new technologies, such as double data rate (DDR) SDRAM or burst extended data out (BEDO), are not likely to succeed in the market. The support Rambus has garnered for its unique design provides a high competitive barrier against competing designs in the near future.

AGP

AGP features first appeared in Intel's 440 LX chipset designed for Pentium II systems. At the time of the 440 LX introduction, Intel argued that socket 7 designs would not be able to satisfy AGP's memory bandwidth requirements, and thus, the company chose not to add this feature to its 430 TX Pentium chipset. Later in 1997, VIA Technologies introduced its Apollo VP3 socket 7 design with AGP support and proved that the Pentium bus could support this feature after all. By early 1998, Silicon Integrated Systems and Acer Laboratories also delivered socket 7/AGP solutions, thus proving the versatility of the Pentium bus that first hit the market in 1993.

USB/IEEE 1394

Support for the USB peripheral interface appeared in both the socket 7 and P6 bus products but proved largely irrelevant in 1997. Dataquest estimates that the installed base of USB-capable host computers totaled 58 million units at the end of 1997. Few USB peripherals emerged that could take advantage of this new feature, and fewer than 0.5 million of these devices were sold that year. This situation seems to be changing now that Windows 98 has hit store shelves and offers more complete support for USB devices. The situation regarding IEEE 1394, sometimes known as Firewire, lags behind that of USB by at least two years. There are few systems in the market now that include host support for this bus, and few are expected to appear in the next 12 months. Eventually, IEEE 1394 holds great promise for easier and less expensive connections for high-bandwidth devices such as disks and video accessories, but the timing looks increasingly lethargic at this point in late 1998.

Super I/O

Super I/O devices encompass support for the traditional (legacy) I/O devices found on almost every PC, including parallel and serial ports, keyboards, mice, and floppy drive interfaces. Some vendors have attempted to integrate most of these features into the basic core logic, but no vendor has completely eliminated the need for these chips.

Ultra DMA

Disk drive vendors have continued to emphasize storage capacity in their offerings, and increasing capacity has heightened the need for faster transfer rates. The current state of the (inexpensive) art includes Ultra DMA operation at speeds of up to 33 MB/second for data transfers between a buffer in the drive's integrated controller and the system's main memory.

Differentiation/Segmentation

Core logic vendors have opportunities to differentiate their product offerings by the type of processors they can support or the cost/performance trade-offs they make in their designs.

P5/P6 Bus

Since it introduced the P6 bus with its initial Pentium Pro products in 1995, Intel has been the only vendor to ship significant volumes of core logic for that bus. Other vendors continued to focus their efforts on the Pentium bus that Intel largely abandoned (at least with regard to new designs) by the end of 1997. These vendors stayed away from the P6 market because of its small size and also because of the patent portfolio that Intel had amassed to protect the intellectual property in its newer bus architecture. This situation appears ready to change in the second half of 1998. Other vendors have formulated a variety of approaches to sidestep Intel's patent issues, and the market for P6 solutions now has achieved mainstream status. Silicon Integrated Systems, VIA Technologies, and Acer Laboratories all have announced Pentium II designs, and shipments have begun.

Intel/Non-Intel MPU

Over the past two years, Intel placed the focus of its development efforts on P6 core logic, an area that Intel's competitors mostly avoided. Because the other suppliers of x86 —AMD, Cyrix/National, and, to a lesser extent, Centaur/IDT—needed core logic support that included USB, PC 100 memory, and AGP, a natural alliance evolved between those competing with Intel in the processor arena and those competing with Intel in core logic.

Basic/Performance/Workstation/Server

The enormous size of the current computer hardware industry allows many opportunities for niche vendors to focus their efforts. Although the traditional desktop and mobile core logic markets have melted together, new opportunities allow vendors to focus on low-cost PC systems, high-performance PCs, workstations, or servers. Intel has fielded entries in each of these segments, and Dataquest anticipates that Intel will continue to offer updated products in each segment.

Integration

The integration of additional system functions into core logic can play a key role in reducing bill-of-materials cost, a key issue at the low end of the market. Core logic vendors have no additional room to lower system costs only by reducing the price of their logic chips; these prices have already been reduced as far as they can go. Additional cost savings will come from eliminating other system components: graphics, audio, and super I/O, in particular. This was the approach Cyrix used to reduce system costs with its proprietary MediaGX and GXM products in 1997 and 1998. Dataquest expects other vendors to follow suit this year. Silicon Integrated Systems has already announced versions of its socket 7 and P6 bus core logic chips that include its own proprietary 3-D graphics engine. Intel is expected to have a similar low-end offering in its line early in 1999.

Perspective

Personal Computer Semiconductors and Applications Worldwide

Market Analysis

A Slice-in-Time Look at MB/PC

Abstract: *This Perspective examines the memory configurations of today's desktop PCs. It also presents estimates for megabytes per PC (MB/PC) by PC price band, as well as an overall MB/PC average.*

By George Iwanyc and James Seay

How Much Memory? ... Depends on Your Perspective

An important element of DRAM demand-side models is the megabytes per PC (MB/PC) estimate. As important as this estimate is, there is no universally accepted answer to this question. If one asks 10 different DRAM manufacturers for an opinion on MB/PC, they are likely to give 10 different answers. Today, most estimates from DRAM companies for the average number of megabytes of DRAM installed at the factory for desktop PCs ranges from the mid-40s to the high 50s. Dataquest believes two factors, regional differences and served customer base, explain the majority of the variation in these estimates. DRAM companies are likely to base their own estimates primarily on internally available sales statistics and to a lesser extent on externally available sources. This is a perfectly sound method as there is no question about the validity of internally available sales data, but the limited view of the market is sure to introduce some inaccuracy.

To clarify the issue, Dataquest has done an analysis of PC memory configurations. The results of this analysis confirmed that estimates in the range just mentioned are defensible. The analysis also provided insight into what drives low and high estimates.

Dataquest

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Methodology

During a week in August, Dataquest downloaded from various Web sites pricing and configuration data for 240 desktop/deskside PCs representing 12 different manufacturers. The configuration data collected included memory type, standard memory size, maximum memory size, number of memory slots, video memory size, and microprocessor type.

Dataquest implemented a simple model to determine an overall factory-installed MB/PC estimate. The key elements of the model include a PC unit forecast by price band, an average MB/PC by price band calculated with the collected data, and an adjustment factor to account for the difference between indirect and direct PC distribution.

The following PC price bands were used in this analysis:

- $1,000 and below
- $1,001 to $1,500
- $1,501 to $2,000
- $2,001 to $2,500
- $2,501 to $3,000
- Over $3,000

To determine the weighted average MB/PC estimate presented in Table 1, the PC unit forecast by price band was multiplied by the corresponding average MB/PC estimate to determine the total megabytes consumed by desktop PCs. The total was then divided by the total number of PCs to determine the overall average. The PC forecast by price band was published by Dataquest in the Focus Report titled *The Sub-$1,000 PC Opportunity*, dated January 26, 1998.

To determine the "best estimate" weighted average MB/PC presented later, the same process was implemented with the following exceptions: The PC unit forecast was multiplied by the corresponding average MB/PC estimate for indirect (such as Compaq, IBM, and HP) and direct (such as Dell and Gateway) PC distribution channels to determine the total possible megabytes consumed by the respective distribution methods. The totals were then analyzed using a ratio of 75 percent indirect distribution to 25 percent direct distribution to determine the overall MB/PC estimate. The 75 to 25 ratio is an approximation based on information provided by Dataquest's Distribution Channels Worldwide program.

The following assumptions were made for this analysis:

- For indirect PC manufacturers, the standard memory configuration is equivalent to factory-installed memory.
- For direct, build-to-order (BTO) PC manufacturers, the default setting on the manufacturer's Web page is equivalent to factory-installed memory.

- Factory-installed DRAM includes DRAM used for both main memory and video memory.
- The standard configuration for a particular PC model is the same throughout the world.

Limitations of This Approach

The sample suffers from weaknesses including, but not limited to, the following:

- U.S.-based manufacturers dominate the sample.
- White-box PC manufacturers were not accounted for in the sample.
- All PCs within a given price band are weighted the same.
- Splitting factory-installed from add-on upgrade memory for BTO PC manufacturers is a confused objective.

Even with the noted limitations Dataquest believes that the derived MB/PC number has merit. For example, a heavy weight for U.S.-based manufacturers is reasonable given that U.S.-based PC manufacturers have a dominant share of the worldwide PC market. The 12 manufacturers included in the sample account for more than 50 percent of worldwide PC unit shipments.

Adding complexity to the model—for example, by weighting each PC from a particular vendor by that vendor's market share—was considered as a way of improving the simple model used. Ultimately, it was decided that added complexity would not improve the final result given the uncertainty already associated with the data.

MB/PC Analysis Results

Table 1 presents the collected configuration data split by PC price band and an overall average MB/PC weighted by PC volume for each price band.

Table 1
Average MB/PC by PC Price Band

PC Price Band	Average Main Memory Size	Average Video Memory Size	Total
$1,000 and Below	30.77	2.19	32.96
$1,001-$1,500	38.28	3.13	41.41
$1,501-$2,000	62.81	4.62	67.43
$2,001-$2,500	85.33	5.60	90.93
$2,501-$3,000	72.00	7.00	79.00
Over $3,000	140.00	16.00	156.00
Weighted Average MB/PC	56.14	4.34	60.48

Source: Dataquest (September 1998)

As expected, the average MB/PC number increases in association with increases in PC price. An anomaly in the MB/PC progression occurs at the $2,501 to $3,000 price band. This anomaly does not represent an exception to the rule of higher price equating to more memory, but could be due to the smaller size of the sample for the $2,501 to $3,000 price band (30 systems for $2,001 to $2,500 versus eight systems for $2,501 to $3,000). It appears that between these two price bands, memory configuration is not key to PC product differentiation and that given a larger sample, the anomaly present in the table would probably disappear. A workaround for this problem is presented later.

Table 2 presents the sample by main memory size, and Table 3 presents the sample by main memory type.

Table 2
Sample Split by Memory Size (Number of PCs)

PC Price Band	16MB	32MB	48MB	64MB	96MB	128MB	256MB
$1,000 and Below	5	18	3	0	0	0	0
$1,001-$1,500	1	62	2	13	1	0	0
$1,501-$2,000	0	27	0	39	6	9	0
$2,001-$2,500	0	3	0	15	1	11	0
$2,501-$3,000	0	0	0	7	0	1	0
Over $3,000	0	0	0	3	0	10	3
Total	6	110	5	77	8	31	3

Source: Dataquest (September 1998)

Table 3
Sample Split by Memory Type (Number of PCs)

PC Price Band	EDO	SDRAM	SDRAM-100	Total
$1,000 and Below	2	24	0	26
$1,001-$1,500	3	76	0	79
$1,501-$2,000	0	39	42	81
$2,001-$2,500	0	4	26	30
$2,501-$3,000	0	3	5	8
Over $3,000	0	3	13	16
Total	5	149	86	240

Source: Dataquest (September 1998)

Tables 2 and 3 give a good snapshot of PC memory configurations. The $1,001 to $1,500 price band represents the PC market sweet spot and the best indicator of the most common PC configuration. Today's memory sweet spot is 32MB of 66-MHz SDRAM, with 64MB on the horizon. A look at the $1,500 to $2,000 price band is a good indicator of where the bulk of the market will be shortly. This indicator shows that 64MB of PC100 SDRAM is one or two PC price reductions away from being the sweet-spot solution.

Another way to judge the market for PC100 SDRAM is to split the data by microprocessor type. Table 4 presents the average MB/PC by the two dominant PC100 microprocessors, the PII350 and PII400, and other processors. As the PII350 and PII400 processors come down in price, PC100 SDRAM-configured machines will become the standard.

Table 4
Average MB/PC by Microprocessor

Processor	Average Main Memory Size (MB/PC)	Average Video Memory Size (MB/PC)	Total (MB/PC)
PII350 and PII400	84.57	6.71	91.28
Other Processors	44.16	3.60	47.76

Source: Dataquest (September 1998)

Table 5 presents the collected configuration data split by PC price band and PC distribution channel. As in Table 1, the respective overall average MB/PC estimates are weighted by PC volume for each price band.

Table 5
Average MB/PC by Distribution Channel

PC Price Band	Number of PCs	Average Main Memory Size	Average Video Memory Size	Total
Direct Distribution Channel				
$1,000 and Below	24	30.67	2.21	32.88
$1,001-$1,500	67	36.06	2.79	38.85
$1,501-$2,000	49	48.33	3.63	51.96
$2,001-$2,500	19	64.00	4.84	68.84
$2,501-$3,000	7	64.00	6.86	70.86
Over $3,000	12	133.33	12.67	146.00
Weighted Average MB/PC	178	46.88	3.69	50.57
Indirect Distribution Channel				
$1,000 and Below	2	32.00	2.00	34.00
$1,001-$1,500	12	50.67	5.00	55.67
$1,501-$2,000	32	85.00	6.13	91.13
$2,001-$2,500	11	122.18	6.91	129.09
$2,501-$3,000	1	128.00	8.00	136.00
Over $3,000	4	160.00	26.00	186.00
Weighted Average MB/PC	62	76.51	6.01	82.52

Source: Dataquest (September 1998)

Table 5 shows that a substantial configuration difference by PC channel exists. Simply put, direct PC manufacturers sell PCs with more memory. Intuitively, this fact makes sense. A standard configuration should offer the best configuration measured on a performance versus cost tradeoff. Indirect PC manufacturers, which sell PCs through various distribution channels, have to decide for their buyers what this configuration is and are likely to choose conservative memory selections.

Direct manufacturers, which sell directly to end users, implement BTO assembly models that allow buyers to customize, within reason, their memory configuration. Therefore, a direct manufacturer can select an aggressive standard MB/PC configuration and, if need be, let the consumer decide to take down the memory size. An argument can be made that this flexibility may mean that the average direct MB/PC estimate, as calculated here, overstates the actual result. A countering argument is that the indirect MB/PC estimate represents a minimum acceptable configuration and that the flexibility of the BTO model allows direct manufacturers immediately to reap the rewards of memory upgrade business. Essentially, the difference between indirect and direct manufacturers gives insight into memory upgrade trends.

Table 6 presents the "best estimate" average MB/PC ratio based on the simple model explained in the methodology section. Tables 1 and 5 show the same trends, except that in Table 6 the anomaly between the price points is eliminated and the overall average MB/PC number is lower because the influence of the direct channel is limited. This average amounts to 58.56 MB/PC. An estimate of 58.56 MB/PC is too high for an overall average for the third quarter of 1998. It does, however, represent a reasonable estimate for the fourth quarter.

Table 6
Best Estimate Average MB/PC by PC Price Bands (75 percent Indirect, 25 percent Direct)

PC Price Band	Average Main Memory Size (MB/PC)	Average Video Memory Size (MB/PC)	Total (MB/PC)
$1,000 and Below	31.00	2.16	33.16
$1,001-$1,500	39.71	3.34	43.05
$1,501-$2,000	57.49	4.26	61.75
$2,001-$2,500	78.55	5.36	83.90
$2,501-$3,000	80.00	7.14	87.14
Over $3,000	140.00	16.00	156.00
Weighted Average MB/PC	54.29	4.27	58.56

Source: Dataquest (September 1998)

A Quick Observation Regarding PC Servers

While collecting data for this Perspective, Dataquest also collected some standard configuration data for PC servers. A quick examination of the results indicates that the approach presented in this Perspective is not transferable to servers. The typical server has a standard base configuration of 64MB on the product specification sheet. Although on paper, servers may be intended to be configured with 64MB, Dataquest believes most servers are bought with additional memory at the time of sale as a packaged deal—effectively creating a much larger standard configuration. Dataquest estimates that the average server ships with nearly 100MB of main memory. Another difference from the desktop PC arena is that the memory is likely to be EDO and not SDRAM.

Dataquest Perspective

What does this analysis mean for DRAM manufacturers and PC OEMs? For DRAM manufacturers, a look at the configurations of the $1,500-plus machines should be reassuring. The last two years have been rotten for DRAM manufacturers, but demand hasn't been the issue. The overabundance of capacity and the pricing free fall it has enabled have been the drivers of the down market. The DRAM companies looking for higher margins have pinned their hopes on 64Mb and higher-density PC100 SDRAM. If the demand for these parts was ever in question, a look at the memory configurations of the higher-end price points should alleviate this concern.

For PC OEMs, and any other purchasers of DRAM, the pricing free fall has been a windfall. If they have a concern, it is what will happen when the next DRAM up-cycle begins. The erosion in PC average selling prices is likely to continue as the sub-$1,000 PC is replaced by the sub-$750 and then the sub-$500-PC, all dragging the PC sweet spot along with them. The challenge this situation creates is how to configure these low-priced PCs. This has not been a huge concern as DRAM and microprocessor prices have been steadily falling, but once the DRAM market turns, the issue is sure to become a much bigger one.

One last comment on MB/PC: Is 58.56MB the right answer to the MB/PC question? No. Is it close? Dataquest believes so. It is likely that 58MB is on the high side, but probably not by much.

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Perspective

Personal Computer Semiconductors and Applications Worldwide

Vendor Analysis

Intel Eyes the Market for High-End Microprocessors

Abstract: *PC vendors have been forced to reduce system prices as the market for $2,000 personal computers reaches saturation. Lower prices drive PC unit demand, but adversely affect processor revenue. To offset this decline in average selling price, Intel must find new markets for its microprocessors. This report examines the candidates for continued growth.*
By Nathan Brookwood

Introduction

Intel Corporation's phenomenal success in capturing 94.9 percent of the 1996 market for the microprocessors used in personal computers created a serious problem for the company's planners. For years, Intel had grown by finding more and more personal computer buyers, each willing to pay about $200 for the Intel x86 processor inside the PC system. The 65 million chips for which the company had collected $14.675 billion in 1996 represented 94.9 percent of all spending for processors for Windows-based computers. But now, Intel had gained all the market share it could gain, and to continue its growth, it needed to expand the size of the personal computer market even more or find other markets to pursue.

In the past, Intel drove market growth by increasing system performance, while holding prices relatively steady. The company was running out of buyers that could afford $2,000 personal computers. Eventually market dynamics would drive system prices down, which in turn would pressure microprocessor prices. The first signs of this tendency appeared in 1997, when growth in unit shipments (47 percent, to 95.2 million units) dramatically outpaced growth in revenue (29 percent, to $18.89 billion). Intel faced the prospect of eroding market share in the key market that fueled its rapid growth and awesome profitability. As shown in Table 1, Dataquest

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estimates that Intel's dollar share of the personal computer microprocessor market peaked at 94.9 percent in 1996 and will fall to just over 80 percent in 2002. This decline might have begun even sooner, had it not been for a series of missteps on the part of Intel's major x86 competitors, Advanced Micro Devices Inc. and Cyrix Corporation. Although Intel capitalized on such missteps, its paranoid view of the market would not allow it to assume the competition would remain forever at bay. AMD's recent inroads at Compaq Computer Corporation, IBM, and Hewlett-Packard Company demonstrate the wisdom of this perspective.

In addition to the loss of market share, Intel will also experience erosion in the average selling price (ASP) of the personal computer microprocessors it sells. For the overall PC market, Intel's ASP will fall from $190 in 1997 to $153 in 2002. This effect will be more pronounced on the desktop than in mobile applications. Although competitive pressures play a role, most of the erosion results from a shift in the mix of personal computer system sales. The market will flip-flop, from the point in 1997 when 68 percent of units sold for more than $1,500 to a point in 2002 when 70 percent of units will sell for less than $1,500. These less expensive systems utilize less expensive processors, thus forcing the ASP down. The microprocessor revenue generated by these lower-priced systems will increase from 16 percent to 42 percent of the total during the period.

Changes in Intel's market share within specific PC system price bands further complicate the picture. The company got off to a slow start in the sub-$1,000 arena, but we expect Intel's share in this segment to grow from 45 percent in 1997 to 50 percent in 2002. Conversely, its share in the rapidly growing $1,000-$1,500 segment will fall from 72 percent to 65 percent, as competitors gain credibility. Intel can retain most of its traditional share (99 percent) of processors used in high-end personal computers, but this segment will shrink dramatically over the period. All in all, Intel is likely to experience a drop in share from 95 percent to 80 percent of all PC-related x86 microprocessor revenue over the period. This loss of share means that Intel's revenue for PC microprocessors will grow at only a 7 percent CAGR over the period, from $15.2 billion to $21 billion, as shown in Table 1, while the overall segment grows at a 10 percent rate from $16.3 billion to $26.2 billion.

Table 1
x86 PC Microprocessor Revenue, 1996 to 2002 (Millions of Dollars)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%)
Intel x86	12,426	15,227	16,677	17,490	18,392	19,322	20,966	7
Non-Intel x86 PC	670	1,143	1,811	2,483	3,200	4,062	5,190	35
Total x86 PC	13,096	16,369	18,488	19,973	21,592	23,384	26,157	10
Intel Dollar Share (%)	94.9	93.0	90.2	87.6	85.2	82.6	80.2	-

Source: Dataquest (August 1998)

Intel Can No Longer Live by PCs Alone

Clearly, Intel needed to look to new markets to fuel continued growth. But where could it find another market that matched its technological and marketing skills? The embedded microprocessor market presented one such opportunity. Shipments of embedded processors dwarf those of computational units (199 million embedded units versus 103 million computational devices in 1997), and Intel accounted for a piddling 6 percent of the market. Unlike the general-purpose devices that go into personal computers, embedded processors go into fixed-function applications, such as controlling laser printers, communications systems, and video games. Unfortunately, despite its enormous unit volume potential, the embedded market provides only moderate revenue opportunities. It generated sales of only $2.4 billion in 1997. ASPs for embedded processors are less than 1/20th those found in the computational market.

The engineers who design embedded systems can usually calculate precisely how much computing power they need to accomplish a given task and are unwilling to spend very much for "headroom" above their projected needs. (A laser printer with a four-page-per-minute engine cannot print five pages per minute if a faster, more expensive processor is used in place of less costly alternatives.) This buying psychology differs from that used when personal computer buyers select machines without specific knowledge of the tasks such machines may be called on to perform, thus making performance headroom an appealing insurance policy. Table 2 illustrates the enormous disparity in pricing and overall revenue between the processors used for computational applications (sometimes referred to as "general-purpose" processors) and those used in embedded applications.

Table 2
Computational and Embedded Microprocessor Market Statistics, 1996 to 1997

	1996	1997
All Microprocessor Shipments (Millions of Units)	258.5	302.7
Compute Microprocessors Shipments (Millions of Units)	85.2	103.5
Embedded Microprocessors Shipments (Millions of Units)	173.4	199.2
Compute Microprocessor Share (%)	33	34
All Microprocessor Revenue ($M)	27,390	31,503
Compute Microprocessors Revenue ($M)	25,109	29,147
Embedded Microprocessors Revenue ($M)	2,281	2,356
Compute Microprocessor Share (%)	92	93
All Microprocessors ASP ($)	106	104
Compute Microprocessors ASP($)	295	282
Embedded Microprocessors ASP ($)	13	12
Ratio of Compute to Embedded	22.4	23.8

Source: Dataquest (August 1998)

Intel's planners needed to continue their search for a large market that could afford to pay a lot for powerful microprocessors. They turned to the high end of the computing market, the servers and workstations that make up just a tiny portion of computing system unit shipments. Unlike the embedded market, with its high volume of low-priced devices, the high-end computing market consists of a low (by Intel standards) number of high-priced devices. As Table 3 shows, the small number of computational microprocessors consumed by these high-end markets account for 42 percent of overall microprocessor revenue, $12.3 billion in 1997, growing to $16.4 billion in 2002. Much of this revenue presently goes to vendors other than Intel, which made the market even more attractive to Intel's strategists.

Table 3
Computational Microprocessor Revenue, 1996 to 2002 (Billions of Dollars)

All MPU Revenue	1996	1997	1998	1999	2000	2001	2002	CAGR (%)
Total PC MPU	13.5	16.7	18.8	20.3	21.9	23.6	26.4	10
Total WS MPU	1.4	1.6	2.5	3.0	3.6	4.0	4.4	23
Total Server MPU	10.3	10.7	10.6	10.7	10.9	11.4	12.0	2
All MPU Revenue	25.1	29.0	31.9	34.0	36.4	39.0	42.7	8

Source: Dataquest (August 1998)

Until recently, a variety of technological and marketing barriers precluded Intel's successful entry into the high end of the market. Changes (some wrought by Intel itself) improve the likelihood that Intel can surmount these barriers with its current assault. The barriers fall into three major areas:

- Software: The huge base of Windows-based software titles that kept the better-performing RISC architectures of the 1980s from gaining any momentum on the desktop provided no assistance for any assault on the workstation or server market. With the advent of Windows NT, Intel and Microsoft Corporation began to breach these walls. Together, they apply relentless pressure that allows them to work their way up into the middle of the high end, previously off limits. Their inexpensive, commodity-oriented hardware and software captures the less challenging applications that previously provided easy targets for the more expensive RISC platforms, driving the latter into an ever-decreasing niche, where performance technical requirements are high but opportunities are hard to find.
- Performance: The use of the highly advanced manufacturing technology and the adoption of many design tricks pioneered by the mainframe and RISC communities allowed Intel to narrow the gap between the performance of its chips and that of the proprietary alternatives. These proprietary processors are sold in tiny volumes, but cost substantially more to manufacture, and need to absorb far more development expense on a per-unit basis.
- Price: Unlike the volume-driven PC market, the high-end market survives by charging relatively high prices for units sold in relatively low volumes. Intel's desktop processor business model uses continual price reductions to push large numbers of processors into the market. Even

chips that start at very high prices rapidly fall to more modest ones; witness the 300-MHz Pentium II introduced at $1,980 in April 1997, but which fell to $700 in November and now sells for $209. Intel needed a firewall that would allow it to pursue its traditional strategies on the desktop and still charge premium prices for products targeted at workstation and server markets. The introduction of the "slot 2" Pentium II processors, officially known as "Pentium II Xeon," provides just such a firewall. Intel modifies its standard products to provide a bit more performance (10 to 20 percent, on average), and then charges from five to 20 times as much for them. Even with such substantial markups, the systems based on these Intel parts still provide a compelling economic advantage over Intel's more proprietary competitors.

Together, these changes in the relevance and maturity of Windows NT, the narrowing performance gap between x86 processors and the fastest proprietary devices, and Intel's introduction of market-specific processor packages form the foundation for Intel's assault on the high end of the computer market.

Sizing the High-End Processor Market

The very high ASPs (even by Intel standards) that processors used in servers and workstation command makes them an even more interesting target. Many of these proprietary devices are manufactured by captive semiconductor operations in mainframe companies and never appear on the open market. Thus, they remain uncounted by organizations such as Dataquest or World Semiconductor Trade Statistics Association. In this report, Dataquest estimates their value by comparing the results of our top-down processor consumption market model with the bottom-up statistics we collect from semiconductor vendors. The difference between these two correlates closely with our estimates for proprietary enterprise and departmental servers, as will be noted later. Table 4 outlines these calculations.

The ASP of microprocessors used in servers currently exceeds that used in personal computer markets by a factor of 10 ($1,690 versus $173 in 1997), but Dataquest anticipates that this multiple will shrink as the market becomes increasingly commoditized. By 2002, the server average will have dropped to $672, at a point when PC microprocessors sell for $134. Just as an increase in the mix of low-priced personal computers has pulled down personal computer ASPs from historic levels, so too will the large increase in inexpensive "workgroup servers" lower ASPs for the server market overall. From 1997 to 2002, the price of processors for servers targeted at enterprise applications will decline from just over $3,819 to $2,323. Prices of processors aimed at midrange, departmental applications will fall more gently, from $860 to $561. Prices of processors for workgroup servers will shrink from $552 to $259. Even with this erosion, the opportunity still remains quite attractive for any semiconductor manufacturer with the resources to tackle the market.

Table 4
Top-Down and Bottom-Up Computational Microprocessor Market Estimates, 1996 to 1997

	1996 Units (K)	1996 Revenue ($M)	1996 ASP ($)	1996 Units (K)	1997 Revenue ($M)	1997 ASP ($)
Top-Down	85,456	25,109	293.83	104,509	29,011	277
Bottom-Up	83,908	16,668	198.65	103,156	21,407	207
Invisible Portion	1,548	8,441	5,454.31	1,353	7,604	5,618

Source: Dataquest (August 1998)

Dataquest's Client/Server Computing Worldwide program expects that the market for server systems of all types will grow at a 5 percent rate over the period from 1998 to 2002, from $51.4 billion to $62.5 billion. Revenue associated with the microprocessors that power these servers will grow at only a 2 percent rate, from $10.6 billion to $12 billion over the same period. Although such growth would be unremarkable at best, the manner in which Dataquest actually measures this market distorts the results and makes the growth rate look far higher. Neither Dataquest nor other statistics-gathering organizations can capture the largely proprietary production of processors going into today's mainframes. As these proprietary system products decrease in volume over the next five years, Dataquest can capture the value of the third-party processors that power their replacements. In other words, we cannot capture the erosion of the proprietary processors, but we can capture the growth of the commodity ones. Consequently, microprocessors for servers will *appear* to grow at a 16 percent rate over the forecast period. Intel's share of the (more broadly defined) market will grow from 26 percent in 1997 to 60 percent in 2002. This translates into an impressive 21 percent compound growth rate for Intel's revenue in this market. Table 5 summarizes this situation.

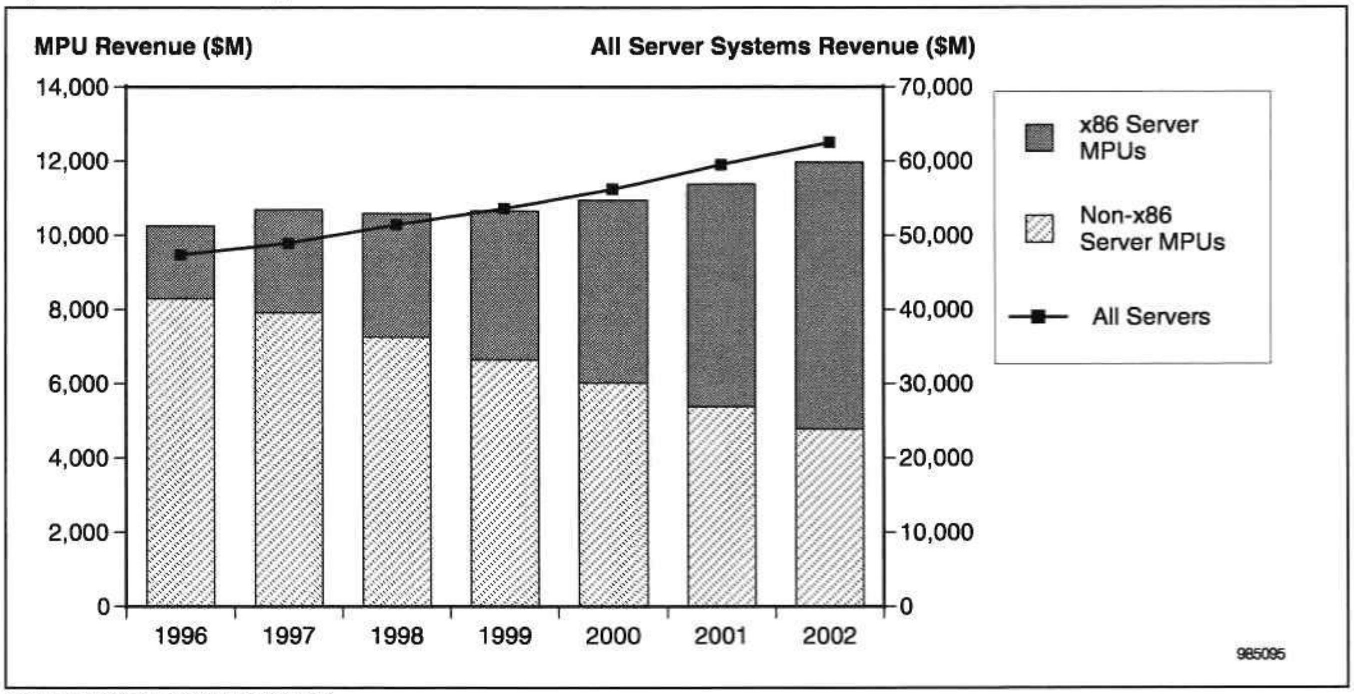
Table 5
Microprocessor Revenue for Servers, 1996 to 2002 (Millions of Dollars)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%)
All Server MPU Revenue	10,254	10,687	10,589	10,659	10,948	11,383	11,970	2
Proprietary & Other MPU Revenue	6,600	6,084	5,124	4,296	3,581	2,967	2,440	-17
All *Visible* MPU Revenue	3,654	4,602	5,464	6,363	7,366	8,416	9,530	16
x86 Server MPU Revenue	1,959	2,776	3,333	4,020	4,929	6,000	7,189	21
x86 Share of All Server MPU Revenue	19	26	31	38	45	53	60	
x86 Share of Visible Server MPU Revenue	54	60	61	63	67	71	75	

Source: Dataquest (August 1998)

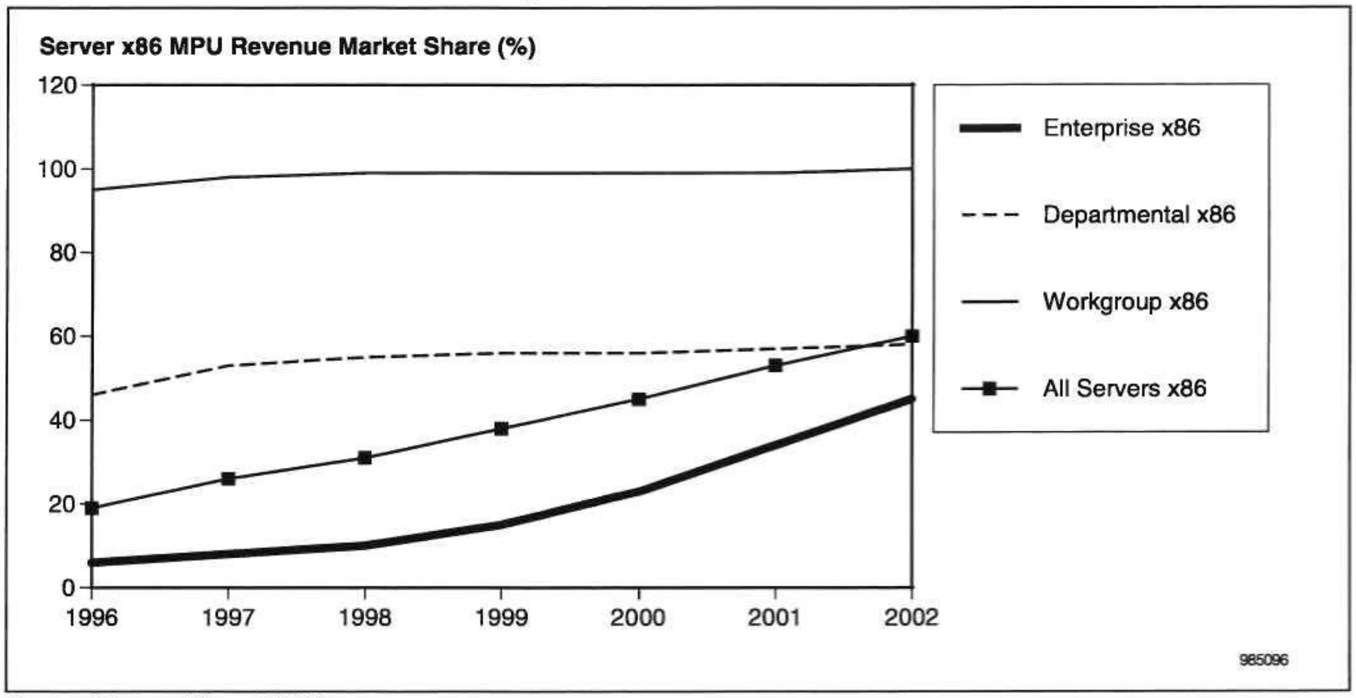
Figure 1 illustrates overall server revenue, the value of the processors going into those servers, and the growing proportion of this revenue we expect Intel to capture in this market. As noted in Figure 2, the x86 already dominates the low-end workgroup segment. In the departmental segment, Intel already accounts for more than half of the processor revenue. But in the large and pricey enterprise segment, Intel presently lays claim to less than 10 percent of current revenue and has ample growth opportunities.

Figure 1
System and Microprocessor Revenue for Servers, 1994 to 2002



Source: Dataquest (August 1998)

Figure 2
X86 Revenue Share within Each Segment of the Server Market, 1994 to 2002



Source: Dataquest (August 1998)

Intel's Projected Growth in the Workstation Market

The same factors that drive Intel's growing share of server markets also are at work in the workstation market. Unit growth of UNIX-based workstations has stalled, while growth accelerates for x86-based workstations running Windows NT. Traditional vendors hold the high end of the market, but watch their shares of entry-level and midrange systems erode. The Pentium II Xeon line, with its unique "slot 2" connector, allows Intel to garner premium prices for products that offer a bit more performance than its higher-volume, lower-cost desktop products deliver. These Xeon products cannot match the performance of the fastest proprietary RISC processors, but they come close enough for many users, and they sell at prices dramatically lower than the proprietary systems. These factors will allow x86-based workstations to increase their share of the market from 37 percent in 1997 to 88 percent in 2002. As expensive proprietary workstations give way to inexpensive x86-based systems, workstation system ASPs will plummet at a 14 percent compound rate and workstation processor ASPs will fall by 3 percent per year. In other words, as workstations become less proprietary, the processor will grab a larger portion of their overall cost of materials.

A portion of the growth in workstation shipments stems from the definitions market research companies such as Dataquest use when collecting data on the workstation market. Prior to the advent of Windows NT, the software gulf between personal computers and workstations was so wide that users of one type of device rarely migrated to the other. This situation allowed vendors such as Sun Microsystems Inc. to sell inexpensive SPARC-compatible workstations along with their more powerful models, while PC vendors could offer beefy versions of their PC products to users pushing the machines to their limits. Windows NT blurs the distinctions between these product classes and lets users deploy the same application packages in both environments. Therefore, users can migrate easily between workstation-class systems and personal computers. In the Wintel world, a low-end workstation gets counted as a personal computer and a high-end PC, marketed as a workstation, gets counted as a workstation. In effect, Windows NT workstation growth comes at the expense of both proprietary workstations and high-end personal computers.

Unit shipments of RISC-based workstations began to shrink in 1997 and will continue their slow decline in years to come, as shown in Table 6. System revenue plateaued at $12.3 billion, as the increase in x86-based units at far lower ASPs barely offset the shortfall from declining RISC-based sales at much higher prices. Dataquest expects this system pricing disparity (about $13,000 for RISC-based products versus $6,000 for the x86 versions, as indicated in Table 7) to continue, as the surviving RISC products get driven further and further up-market, into an ever-decreasing niche. The growth in x86 workstation unit shipments at more or less constant prices drives an eightfold increase in x86 workstation revenue from $419 million in 1997 to $3.5 billion in 2002 (see Table 8). In contrast to the server market, where low-end "workgroup" servers drag average prices down, low-end x86 workstations fall out of the workstation definition and do not impact average prices. Consequently, x86 workstation systems sell at relatively constant prices during this period, as do the processors that power them. As the mix of x86 versus RISC workstations shifts more and more toward the lower-priced x86 units, the ASP of all workstations falls dramatically. The prices of these systems and these processors remain high by comparison with traditional PC markets and look even more attractive in light of the price erosion in those markets.

Table 6
Workstation System Shipments, 1996 to 2002 (Units)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%)
RISC Workstations	736,521	648,899	619,326	573,184	539,133	496,680	449,837	-7
x86 Workstations	118,100	378,453	918,007	1,592,977	2,192,301	2,638,459	3,143,962	53
Total	854,621	1,027,352	1,537,332	2,166,161	2,731,434	3,135,139	3,593,799	28

Source: Dataquest (August 1998)

Table 7
Workstation System ASP, 1996 to 2002 (Dollars)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%)
RISC Workstations	15,665	15,541	14,379	13,799	13,112	12,695	12,290	-5
x86 Workstations	6,450	6,022	5,561	5,502	5,333	5,115	4,882	-4
All Workstations	14,391	12,034	9,113	7,698	6,868	6,316	5,809	-14

Source: Dataquest (August 1998)

Table 8
Workstation Microprocessor Revenue, 1996 to 2002 (Millions of Dollars)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%)
RISC Workstation MPUs	1,244	1,165	1,497	1,296	1,135	991	850	-6
x86 Workstation MPUs	129	419	1,021	1,753	2,455	2,969	3,530	53
All Workstation MPUs	1,373	1,584	2,518	3,049	3,590	3,960	4,380	23

Source: Dataquest (August 1998)

Intel's Overall Market Position

Intel's overall share of the computational microprocessor market will increase from 63 percent to 74 percent as the company extends its presence in workstation and server processor markets over the next five years. As it gains share at the high end, it will lose share at the low end, but the gains more than offset the losses. As noted earlier, a portion of its new revenue will come at the expense of proprietary processors that presently go uncounted by Dataquest. All signs will point to an expansion of the market, but in reality, units and revenue will just move from vendors that we cannot track to ones we can. The money will end up in Intel's treasury, regardless of how we count it. To the extent the current set of high-end system vendors merely replace their current proprietary products with new systems based on more standard hardware, their revenue may not reflect this subtle change in system composition. Their gross margins most likely will, because these vendors will add less value to the systems they sell and will most likely see margins fall. Some vendors will adapt their business models to such new realities and generate more profits than ever before. Others will cling to their earlier models and watch their profitability erode until they figure it out.

Over the next five years, computational microprocessor unit volumes will more than double, from 105 million units to 219 million, a 16 percent CAGR, but revenue will grow at only an 8 percent CAGR, from $29 billion to $42.7 billion. Intel's unit growth will lag the industry at 13 percent CAGR, but its move up-market will drive above-average revenue growth of 11 percent per year, from $18.4 billion in 1997 to $31.7 billion in 2002. It is difficult to predict the impact Intel's move into high-end markets will have on the company's overall profitability. Dataquest estimates that the margins on these new products will be higher than those Intel has achieved on the desktop, and certainly better than what could be achieved on the desktop going forward, as prices continue to erode.

As Intel captures share in the high-ASP, low-volume portion of the market, its x86 competitors will take share in the low-ASP, high-volume desktop segment. Much of this business will be transacted at prices lower than those Intel has accepted in the past, and Dataquest expects that Intel will continue to leave such opportunities to others. Intel might decide to pursue such business in the future, either to absorb excess capacity or to thwart competitive inroads. Such a move would dramatically slow the growth of the x86 competitors, but would have only a small impact on Intel's growth. (The competitors can report high growth rates because they are measuring from a small base.)

Over the next five years, the value of all microprocessors used in computational applications will increase about 8 percent per year, from $29 billion to $42.7 billion in 2002. Intel's overall growth will outpace the industry, as the company increases its microprocessor revenue in these markets from $18.4 billion to $31.7 billion, an 11 percent growth rate. More than half of Intel's overall growth ($7.5 billion out of a total of $13.3 billion) will come from sales of processors for workstations and servers, where profit margins should be even higher than Intel achieved in its traditional desktop and mobile markets. Intel can gain share at the high end of the market, driving increased unit shipments of workstations and servers, while ASPs for these products decline. In fact, end users and Intel will be the principal beneficiaries of Intel's increased participation in these markets. System vendors find their profit margins squeezed, as the high-end hardware that traditionally supplied much of their profit becomes just another commodity, in much the same manner as desktop systems have lost much of their differentiation and profit potential over the past 10 years.

Dataquest Perspective

The success of Intel's attempt to expand into these high-end markets is by no means assured. The proprietary solutions that now dominate enterprise server markets are mature, proven, and stable. The sophisticated users that deploy and operate these systems examine their reliability and scalability at least as closely as their acquisition costs. A wide gulf separates Windows NT from the proprietary incumbents in this regard. Many hardware and software elements must be filled in before these markets can take such products seriously. The recent delays in Windows NT 5.0 and Intel's own 64-bit Merced program illustrate the complexity of the undertaking and the high standards customers apply to vendors that serve these markets. IBM, HP, Digital Equipment Corporation (now a part of Compaq), and Sun all have earned membership rights in this exclusive club. With one obvious exception, these vendors offer both proprietary and x86-based solutions. Each would prefer to market additional proprietary systems to its own customer base. Each will use its x86-based systems to attempt to pry customers away from the others' proprietary systems and will work to enhance such x86-based products until they meet the market's stringent requirements. If Intel and Microsoft can supply the appropriate raw materials, each system vendor will work to pry loose the other system vendors' proprietary customers. In the process, each will lose the customers it had for its own proprietary systems. When the process is complete, only a few proprietary systems will remain standing, and the commoditization of the high end will be complete.

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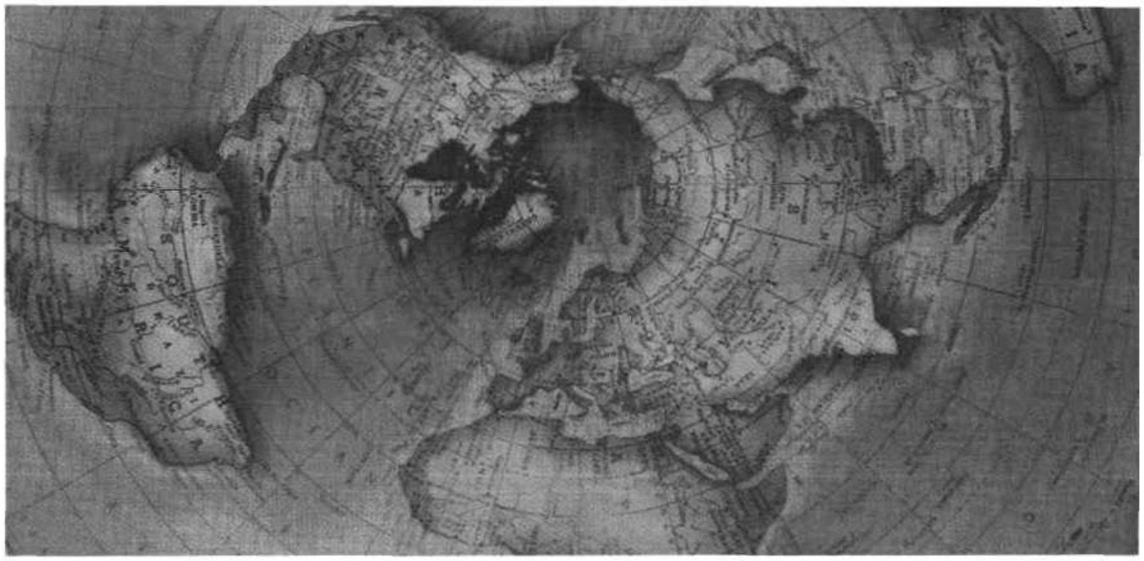
Perspective



Personal Computer Semiconductors and Applications Worldwide

Market Analysis

Guess Who's No. 1 in Computational Microprocessors?

Abstract: *Dataquest tallies the shipments and revenue for key x86 suppliers during the first half of 1998. A decline in overall average selling prices (ASPs) for these devices reflects the general malaise the market has experienced of late.*
By Nathan Brookwood

The Envelope, Please ...

Those who have to peek at Tables 1 through 4 to answer the above question have not been paying attention to Dataquest's recent reports. Those who were surprised that Intel so handily retained its No. 1 ranking have been paying too much attention to the reports that the sub-$1,000 personal computer has forever changed the landscape. Intel Corporation's dollar share of all computational x86 sales fell by more than a point, from 94.1 percent in the first quarter to 92.9 percent in the second; and its unit share fell even more, from 89.1 percent to 84.6 percent. Of course, even if these trends continue for many more quarters (and Dataquest believes they will), few observers will lose sleep wondering if Intel might be pushed out of its No. 1 position. Our limited data on sales volumes at specific price points precludes a detailed analysis of each vendor's position in the various market segments. Anecdotal evidence, along with overall average selling prices (as shown in Table 5), suggests that Advanced Micro Devices Inc., Cyrix Corporation, and IBM have made their greatest inroads at the low end of the market. Success here corresponds to winning the "Miss Congeniality" award at a beauty pageant; it is not what the contestant hoped to achieve, but it's better than no award at all.

The ASP data reflects the overall state of the personal computer industry. This average fell from $202 for all of 1997 to $178 for the first half of 1998.

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The plethora of sub-$60 processors sold by AMD and Cyrix certainly contributed to this drop, but the dearth of high-end desktop systems has also had an impact. To highlight this issue, Dataquest has backed out its estimate for Intel's "other computational"-related x86 sales from the overall figures, as revealed in Tables 6, 7, and 8. These "other computational x86" chips are targeted at workstations and servers and sell for much higher prices than traditional desktop and mobile processors. In the first half of 1998, these sales (mostly Pentium Pros, but also a smattering of Pentium II Xeon and high-end Pentium II processors) averaged almost $400 per device. This means prices for Intel's remaining Pentium, Pentium II, and Celeron processors averaged $180 during the first half of the year, down slightly from the $190 average for all of 1997. Dataquest believes AMD's increased presence in the market contributed to the *rise* in Intel's ASP from the first to the second quarter. AMD siphoned off (at distress prices) roughly a million units that otherwise might have been sold by Intel, thereby reducing its own ASP instead of Intel's. Dataquest projects that increasing sales of Pentium II Xeon processors in the second half of the year will offset the declines Intel experienced in the first half and stabilize Intel's ASP at or near traditional levels.

Table 1
Computational x86 Microprocessor Shipments, Q1/98 and Q2/98 (Units)

	Q1/98	Q2/98	Q3/98	Q4/98	1997	Year-to-Date 1998
AMD	1,500,000	2,700,000	-	-	8,108,000	4,200,000
Cyrix	840,000	850,000	-	-	3,700,000	1,690,000
IBM	500,000	600,000	-	-	1,700,000	1,100,000
Intel Total	23,173,537	22,745,292	-	-	83,791,000	45,918,829
All Compute x86	26,013,537	26,895,292	-	-	97,299,000	52,908,829

Source: Dataquest (September 1998)

Table 2
Computational x86 Market Share by Units, Q1/98 and Q2/98 (Percent)

	Q1/98	Q2/98	Q3/98	Q4/98	1997	Year-to-Date 1998
AMD	5.8	10.0	-	-	8.3	7.9
Cyrix	3.2	3.2	-	-	3.8	3.2
IBM	1.9	2.2	-	-	1.7	2.1
Intel Total	89.1	84.6	-	-	86.1	86.8

Source: Dataquest (September 1998)

Table 3
Computational x86 Microprocessor Revenue, Q1/98 and Q2/98 (Millions of Dollars)

	Q1/98	Q2/98	Q3/98	Q4/98	1997	Year-to-Date 1998
AMD	169	220	-	-	682	389
Cyrix	66	65	-	-	310	131
IBM	43	49	-	-	151	92
Intel Total	4,441	4,386	-	-	18,559	8,827
All Compute x86	4,718	4,721	-	-	19,702	9,438

Source: Dataquest (September 1998)

Table 4
Computational x86 Market Share by Revenue, Q1/98 and Q2/98 (Percent)

	Q1/98	Q2/98	Q3/98	Q4/98	1997	Year-to-Date 1998
AMD	3.6	4.7	-	-	3.5	4.1
Cyrix	1.4	1.4	-	-	1.6	1.4
IBM	0.9	1.0	-	-	0.8	1.0
Intel Total	94.1	92.9	-	-	94.2	93.5

Source: Dataquest (September 1998)

Table 5
Computational x86 Microprocessor Average Selling Price, Q1/98 and Q2/98 (Dollars)

	Q1/98	Q2/98	Q3/98	Q4/98	1997	Year-to-Date 1998
AMD	112.67	81.48	-	-	84.11	92.62
Cyrix	78.00	77.00	-	-	83.78	77.50
IBM	85.00	82.00	-	-	88.82	83.36
Intel Total	191.63	192.83	-	-	221.49	192.22
All Compute x86	181.36	175.52	-	-	202.49	178.39

Source: Dataquest (September 1998)

Table 6
Intel Computational x86 Microprocessor Shipments, Q1/98 and Q2/98 (Units)

	Q1/98	Q2/98	Q3/98	Q4/98	1997	Year-to-Date 1998
Intel PC	21,915,327	21,494,924	-	-	80,157,000	43,410,251
Intel Other Computational	1,258,210	1,250,368	-	-	3,634,000	2,508,578
Intel Total	23,173,537	22,745,292	-	-	83,791,000	45,918,829

Source: Dataquest (September 1998)

Table 7
Computational x86 Microprocessor Revenue, Q2/98 (Millions of Dollars)

	Q1/98	Q2/98	Q3/98	Q4/98	1997	Year-to-Date 1998
Intel PC	3,907	3,920	-	-	15,227	7,827
Intel Other Computational	533	466	-	-	3,332	1,000
Intel Total	4,441	4,386	-	-	18,559	8,827

Source: Dataquest (September 1998)

Table 8
Computational x86 Microprocessor Average Selling Price, Q1/98 and Q2/98 (Dollars)

	Q1/98	Q2/98	Q3/98	Q4/98	1997	Year-to-Date 1998
Intel PC	178.29	182.35	-	-	189.96	180.30
Intel Other Computational	424.00	373.00	-	-	916.90	398.58
Intel Total	191.63	192.83	-	-	221.49	192.22

Source: Dataquest (September 1998)

The same market-segment view of Intel's sales can also be applied to the overall computational x86 market. Dataquest assumes that Intel's share of the x86 devices sold into "other computational" segments (workstation and server) is arbitrarily close to 100 percent, which makes for a rather boring table. But in the x86 PC arena, when we compare the portion of Intel's x86 sales going into desktop and mobile markets with the sales of AMD, Cyrix, and IBM into these same markets, Intel's share drops slightly from its share in the overall computational x86 market. Tables 9 and 10 show that under these tighter definitions, AMD captured 10.5 percent of the units in the second quarter, and 5.2 percent of revenue for such units. These figures are up significantly from the first quarter and may mark the beginning of a turnaround for AMD.

Table 9
Computational x86 Personal Computer Market Share by Units, Q1/98 and Q2/98 (Percent)

	Q1/98	Q2/98	Q3/98	Q4/98	1997	Year-to-Date 1998
AMD	6.1	10.5	-	-	8.7	8.3
Cyrix	3.4	3.3	-	-	4.0	3.4
IBM	2.0	2.3	-	-	1.8	2.2
Intel PC	88.5	83.8	-	-	85.6	86.1

Source: Dataquest (September 1998)

Table 10
Computational x86 Personal Computer Market Share by Revenue, Q1/98 and Q2/98 (Percent)

	Q1/98	Q2/98	Q3/98	Q4/98	1997	Year-to-Date 1998
AMD	4.0	5.2	-	-	4.2	4.6
Cyrix	1.6	1.5	-	-	1.9	1.6
IBM	1.0	1.2	-	-	0.9	1.1
Intel PC	93.4	92.1	-	-	93.0	92.8

Source: Dataquest (September 1998)

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Perspective

Personal Computer Semiconductors and Applications Worldwide

Market Analysis

A Review of Taiwan's Motherboard Industry

Abstract: *This Perspective examines Taiwan's motherboard manufacturing development in 1997. Taiwan's PC industry continues to dominate the country's electronics equipment production. Products such as monitors, notebook PCs, and motherboards continue to flood the worldwide market. Dataquest expects Taiwan to maintain its world lead and high-growth pace in motherboard manufacturing.*

By Jerry Yeh

An Overview

Taiwan has been the fastest-growing motherboard manufacturing base in the world since 1991. Taiwan's motherboard shipment reached U.S.$4.5 billion in 1997, from U.S.$3.4 billion in 1996. Although Taiwan's motherboard revenue was affected by the Asian financial crisis, it was driven by the strong European market and surged in the fourth quarter of 1997. Total shipments reached 47,515,000 units in 1997, including domestic and offshore shipment. Despite Intel Corporation's strategy, Socket 7 remains in high demand. Socket 7 motherboard is still the mainstream product, and its life cycle was prolonged in 1997.

A Note on Taiwan's Motherboard Data

By Dataquest's worldwide definition, offshore shipments and revenue are excluded in Taiwan's motherboard statistics. Because of the Asian financial crisis and its impact on global logistics strategy trends, Dataquest will examine motherboard manufacturers' overall performance, including all domestic and overseas shipments. Therefore, in this Perspective, offshore shipments for Taiwan's motherboard manufacturers are included. This is a country view for this particular Perspective. In the process of conducting

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data collection and preparing motherboard statistics information, Dataquest will sometimes consolidate or revise a particular company's data and differentiated data according to the region in which the equipment was produced.

Taiwan Motherboard Manufacturer Ranking

A Ranking of Taiwan's Motherboard Manufacturers

Table 1 shows the ranking of Taiwan's motherboard revenue from 1996 to 1997. Asustek Computer Inc. was the leading manufacturer in 1997. With more than U.S.$682 million worth of shipments, Asustek won the top position and surpassed the 1996 winner—Acer. The company's brand-name strategy and high-quality products gain the highest profit among all motherboard manufacturers in Taiwan. Acer Computer International Inc. was the No. 2 motherboard manufacturer, with a total U.S.$590 million worth of shipment. The company's motherboards are produced for its brand-name PCs and OEM.

First International Computer Inc. ranked No. 3 in 1997. Its total revenue in 1997 was U.S.$420 million. GVC Corporation ranked No. 4, racking in U.S.$237 million. The company expects to shift its motherboard production to an offshore site soon in 1998. Gigabyte Technology Co. Ltd. captured the No. 5 position, with a total U.S.$235 million revenue. The company expects to start OEM/ODM production. Mitac International Corporation captured the No. 6 position in 1997, with its revenue totaling U.S.$208 million. Universal Scientific Industrial Co. Ltd. (USI) made the No. 7 spot, with revenue totaling U.S.$205 million. The company relies heavily on OEM/ODM production. Elite Group Computer System Co. won the No. 8 position, generating a U.S.$192 million revenue in 1997. Its OEM/ODM production is expected to increase in 1998. Micro Star International Co. Ltd. ranked ninth, with revenue totaling U.S.$145 million. SOYO Computer Inc. made the No. 10 spot by generating a U.S.$102 million revenue in 1997. The company will expand its brand-name production. Tables 1 and 2 present Taiwan's motherboard revenue and shipments, respectively, for the top 10 manufacturers in 1996 and 1997.

Taiwan's Motherboard Shipments by Region

Although Taiwan's motherboard revenue was affected by the Asian financial crisis, it was driven by a strong European market and surged in the fourth quarter of 1997. Taiwan's domestic and offshore motherboard shipments reached 47,515,000 units in 1997. A robust European demand for PCs drove the motherboard sales, which absorbed 40 percent of all Taiwanese shipments in 1997. Although the Americas' demand is healthy, it could not surpass that of Europe. Taiwanese shipments to Asia/Pacific was down by 1.6 percent because of the region's financial crisis that plagued Malaysia, Indonesia, and Thailand. China remained a strong demand in 1997, as well as a strong local applications market. In 1998, Asia/Pacific and South America are expected to become a main battle field for Taiwanese motherboard manufacturers. Figure 1 illustrates Taiwan's motherboard shipments by region in 1996 and 1997.

Table 1
Taiwan's Motherboard Revenue: A Comparison of Top 10 Manufacturers, 1996 and 1997 (Millions of U.S. Dollars)

199 Rank	1997 Rank	Company	1996	1997	Change (%) 1996 to 1997	1997 Share (%)
2	1	Asustek	447	682	52.5	15.0
1	2	Acer	521	590	13.2	13.0
3	3	FIC	350	420	20.0	9.3
6	4	GVC	164	237	44.5	5.2
5	5	Gigabyte	172	235	36.6	5.2
7	6	Mitac	142	208	46.5	4.6
8	7	USI	130	205	57.7	4.5
4	8	Elite	229	192	-16.2	4.2
10	9	Micro Star	124	145	16.7	3.2
13	10	SOYO	85	102	20.0	2.3
		Total Top 10 Companies	**2,364**	**3,015**	**27.5**	**66.5**
		Total Taiwan's Motherboard Revenue	**3,417**	**4,532**	**32.6**	**100.0**
		Top 10 Companies' Percentage of Total	**69.2**	**66.5**	**-3.8**	**1.5**

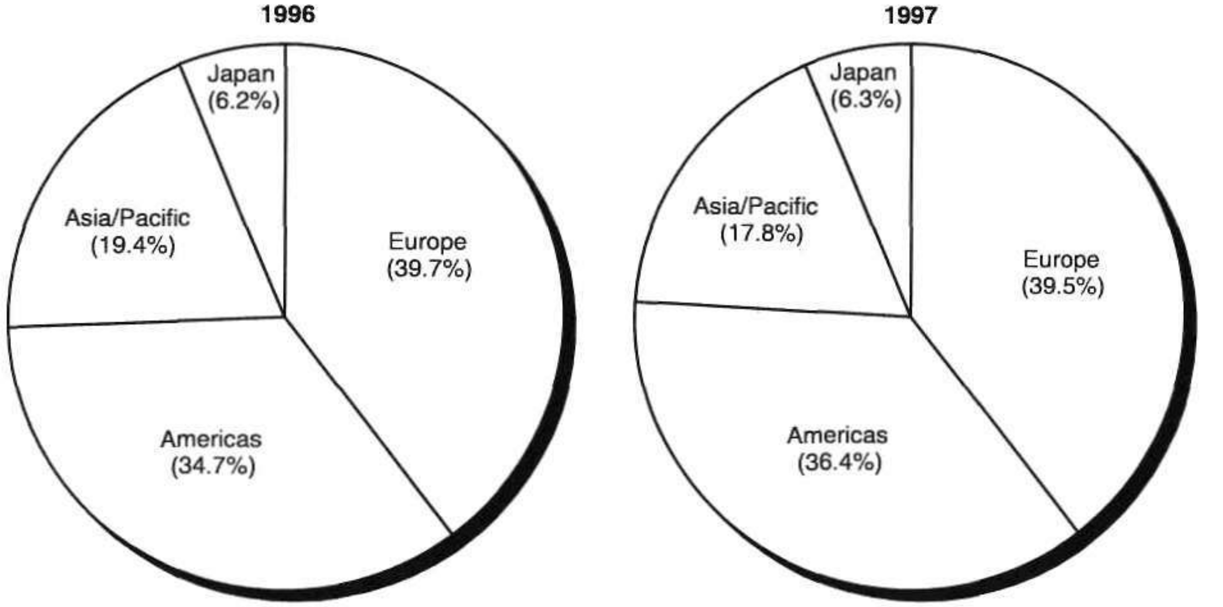
Source: Dataquest (August 1998)

Table 2
Taiwan's Motherboard Shipments: A Comparison of Top 10 Manufacturers, 1996 and 1997 (Thousands of Units)

1996 Rank	1997 Rank	Company	1996	1997	Change (%) 1996 to 1997	1997 Share (%)
3	1	Asustek	3,280	5,965	81.9	12.6
1	2	Acer	4,878	5,775	18.4	12.2
2	3	FIC	3,600	4,550	26.4	9.6
5	4	Gigabyte	1,805	2,856	58.2	6.0
6	5	GVC	1,645	2,538	54.3	5.3
7	6	Mitac	1,450	2,180	50.3	4.6
8	7	USI	1,316	2,124	61.4	4.5
4	8	Elite	2,435	1,824	-25.1	3.8
10	9	Micro Star	1,310	1,680	28.2	3.5
13	10	SOYO	860	1,400	62.8	2.9
		Total Top 10 Companies	**22,579**	**30,892**	**36.8**	**65.0**
		Total Taiwan Motherboard Shipment	**36,258**	**47,515**	**31.0**	**100.0**
		Top 10 Companies' Percentage of Total	**62.3**	**65.0**	**4.4**	**0.1**

Source: Dataquest (August 1998)

Figure 1
Taiwan's Motherboard Shipments by Region, 1996 and 1997 (Percent)



Source: Dataquest (August 1998)

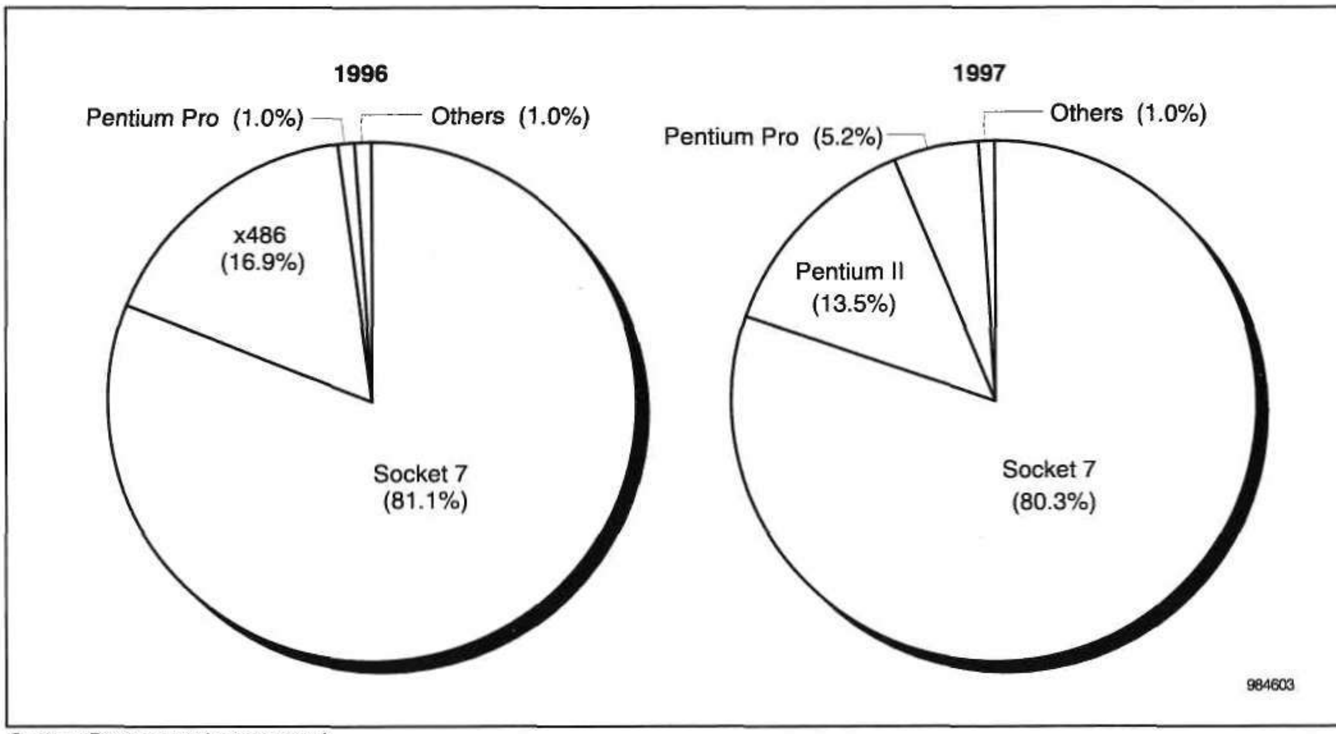
Taiwan Motherboard Shipments by CPU Type

Despite Intel's CPU road map, Socket 7 remains in high demand. The Socket 7 motherboard—accommodating Intel's Pentium series, Advanced Micro Devices Inc.'s K6 series, National Semiconductor Corporation's 6x86 series, and IDT C6+—is still the mainstream product in 1997, accounting for 80.3 percent of all shipments in 1997. With the support of Intel's competitors and major chipset suppliers, Socket 7's life cycle was prolonged in 1997. Pentium II accounted for 13.5 percent of Taiwan's motherboard shipments in 1997. With Intel's aggressive promotion of its Pentium II motherboard, Taiwanese motherboard manufacturers will increase Pentium II motherboard shipments in 1998. Figure 2 illustrates Taiwan's motherboard shipments by CPU type in 1996 and 1997.

Fast Shifting to Offshore Shipment, but the Pace Slowed in 1997

About 42 percent of total Taiwan's motherboard shipments came from offshore production in 1996. Taiwan's shift to offshore shipment was rapid for years, but the pace slowed in 1997 because many of the Taiwanese motherboard manufacturers were actively preparing to go public on the stock market in 1997. Withdrawing from offshore production to local production could help manufacturers gain more profit and obtain large OEM orders. Except for Asustek and USI, most of the Taiwanese motherboard manufacturers have facilities in other Asia/Pacific countries, particularly in China. For example, major Taiwanese players in China are FIC, GVC, and Elite. Although domestic shipment reached 62 percent of all shipments in 1997, the high ratio of domestic shipments represents manufacturers' short-term strategy. Dataquest believes that offshore shipments will increase dramatically after these manufacturers have gone public. Figure 3 compares the domestic and offshore shipments of Taiwanese motherboard makers.

Figure 2
Taiwan's Motherboard Shipment by CPU Type, 1996 and 1997 (Percent)

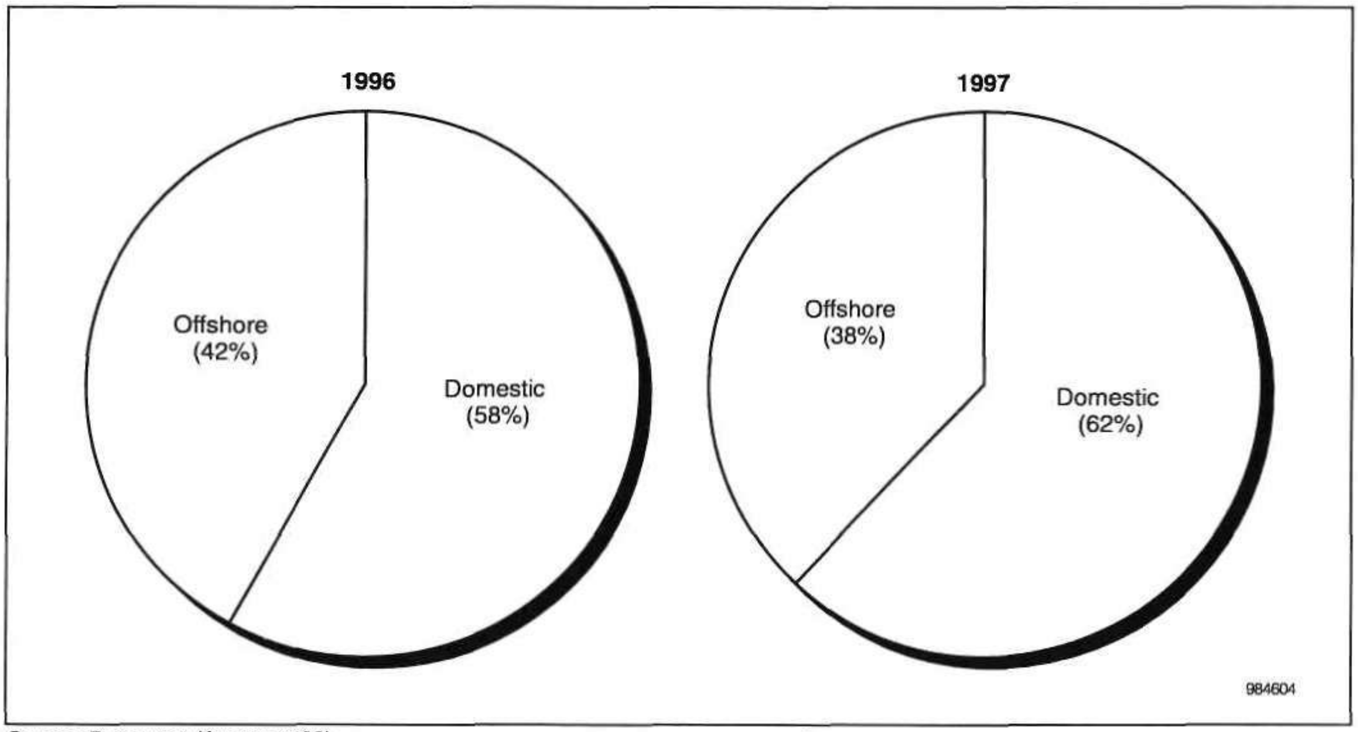


Source: Dataquest (August 1998)

Dataquest Perspective

To challenge motherboard competition and market demand, Taiwan's motherboard manufacturers increase barebone system shipments. Companies also enter into different fields, such as notebook and CD-ROM. Taiwan's motherboard shipments are expected to increase in 1998; however, the revenue growth may be slow because of the increasing market presence of low-priced PCs. After more than decades of efforts to develop its own information technology (IT) industry, Taiwanese companies have created an enviable success. Taiwan's government and many aggressive industry leaders have also played an important role. Taiwan is on the path to succeed in establishing an integrated IT industry by 2002—not just in semiconductors, but also in motherboards.

Figure 3
Taiwan's Motherboard Shipments, Domestic and Offshore, 1996 and 1997 (Percent)



Source: Dataquest (August 1998)

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Perspective

Personal Computer Semiconductors and Applications Worldwide

Market Analysis

A Review of Taiwan's Motherboard Industry

Abstract: *This Perspective examines Taiwan's motherboard manufacturing development in 1997. Taiwan's PC industry continues to dominate the country's electronics equipment production. Products such as monitors, notebook PCs, and motherboards continue to flood the worldwide market. Dataquest expects Taiwan to maintain its world lead and high-growth pace in motherboard manufacturing.*
By Jerry Yeh

An Overview

Taiwan has been the fastest-growing motherboard manufacturing base in the world since 1991. Taiwan's motherboard shipment reached U.S.$4.5 billion in 1997, from U.S.$3.4 billion in 1996. Although Taiwan's motherboard revenue was affected by the Asian financial crisis, it was driven by the strong European market and surged in the fourth quarter of 1997. Total shipments reached 47,515,000 units in 1997, including domestic and offshore shipment. Despite Intel Corporation's strategy, Socket 7 remains in high demand. Socket 7 motherboard is still the mainstream product, and its life cycle was prolonged in 1997.

A Note on Taiwan's Motherboard Data

By Dataquest's worldwide definition, offshore shipments and revenue are excluded in Taiwan's motherboard statistics. Because of the Asian financial crisis and its impact on global logistics strategy trends, Dataquest will examine motherboard manufacturers' overall performance, including all domestic and overseas shipments. Therefore, in this Perspective, offshore shipments for Taiwan's motherboard manufacturers are included. This is a country view for this particular Perspective. In the process of conducting

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data collection and preparing motherboard statistics information, Dataquest will sometimes consolidate or revise a particular company's data and differentiated data according to the region in which the equipment was produced.

Taiwan Motherboard Manufacturer Ranking

A Ranking of Taiwan's Motherboard Manufacturers

Table 1 shows the ranking of Taiwan's motherboard revenue from 1996 to 1997. Asustek Computer Inc. was the leading manufacturer in 1997. With more than U.S.$682 million worth of shipments, Asustek won the top position and surpassed the 1996 winner—Acer. The company's brand-name strategy and high-quality products gain the highest profit among all motherboard manufacturers in Taiwan. Acer Computer International Inc. was the No. 2 motherboard manufacturer, with a total U.S.$590 million worth of shipment. The company's motherboards are produced for its brand-name PCs and OEM.

First International Computer Inc. ranked No. 3 in 1997. Its total revenue in 1997 was U.S.$420 million. GVC Corporation ranked No. 4, racking in U.S.$237 million. The company expects to shift its motherboard production to an offshore site soon in 1998. Gigabyte Technology Co. Ltd. captured the No. 5 position, with a total U.S.$235 million revenue. The company expects to start OEM/ODM production. Mitac International Corporation captured the No. 6 position in 1997, with its revenue totaling U.S.$208 million. Universal Scientific Industrial Co. Ltd. (USI) made the No. 7 spot, with revenue totaling U.S.$205 million. The company relies heavily on OEM/ODM production. Elite Group Computer System Co. won the No. 8 position, generating a U.S.$192 million revenue in 1997. Its OEM/ODM production is expected to increase in 1998. Micro Star International Co. Ltd. ranked ninth, with revenue totaling U.S.$145 million. SOYO Computer Inc. made the No. 10 spot by generating a U.S.$102 million revenue in 1997. The company will expand its brand-name production. Tables 1 and 2 present Taiwan's motherboard revenue and shipments, respectively, for the top 10 manufacturers in 1996 and 1997.

Taiwan's Motherboard Shipments by Region

Although Taiwan's motherboard revenue was affected by the Asian financial crisis, it was driven by a strong European market and surged in the fourth quarter of 1997. Taiwan's domestic and offshore motherboard shipments reached 47,515,000 units in 1997. A robust European demand for PCs drove the motherboard sales, which absorbed 40 percent of all Taiwanese shipments in 1997. Although the Americas' demand is healthy, it could not surpass that of Europe. Taiwanese shipments to Asia/Pacific was down by 1.6 percent because of the region's financial crisis that plagued Malaysia, Indonesia, and Thailand. China remained a strong demand in 1997, as well as a strong local applications market. In 1998, Asia/Pacific and South America are expected to become a main battle field for Taiwanese motherboard manufacturers. Figure 1 illustrates Taiwan's motherboard shipments by region in 1996 and 1997.

Table 1
Taiwan's Motherboard Revenue: A Comparison of Top 10 Manufacturers, 1996 and 1997 (Millions of U.S. Dollars)

199 Rank	1997 Rank	Company	1996	1997	Change (%) 1996 to 1997	1997 Share (%)
2	1	Asustek	447	682	52.5	15.0
1	2	Acer	521	590	13.2	13.0
3	3	FIC	350	420	20.0	9.3
6	4	GVC	164	237	44.5	5.2
5	5	Gigabyte	172	235	36.6	5.2
7	6	Mitac	142	208	46.5	4.6
8	7	USI	130	205	57.7	4.5
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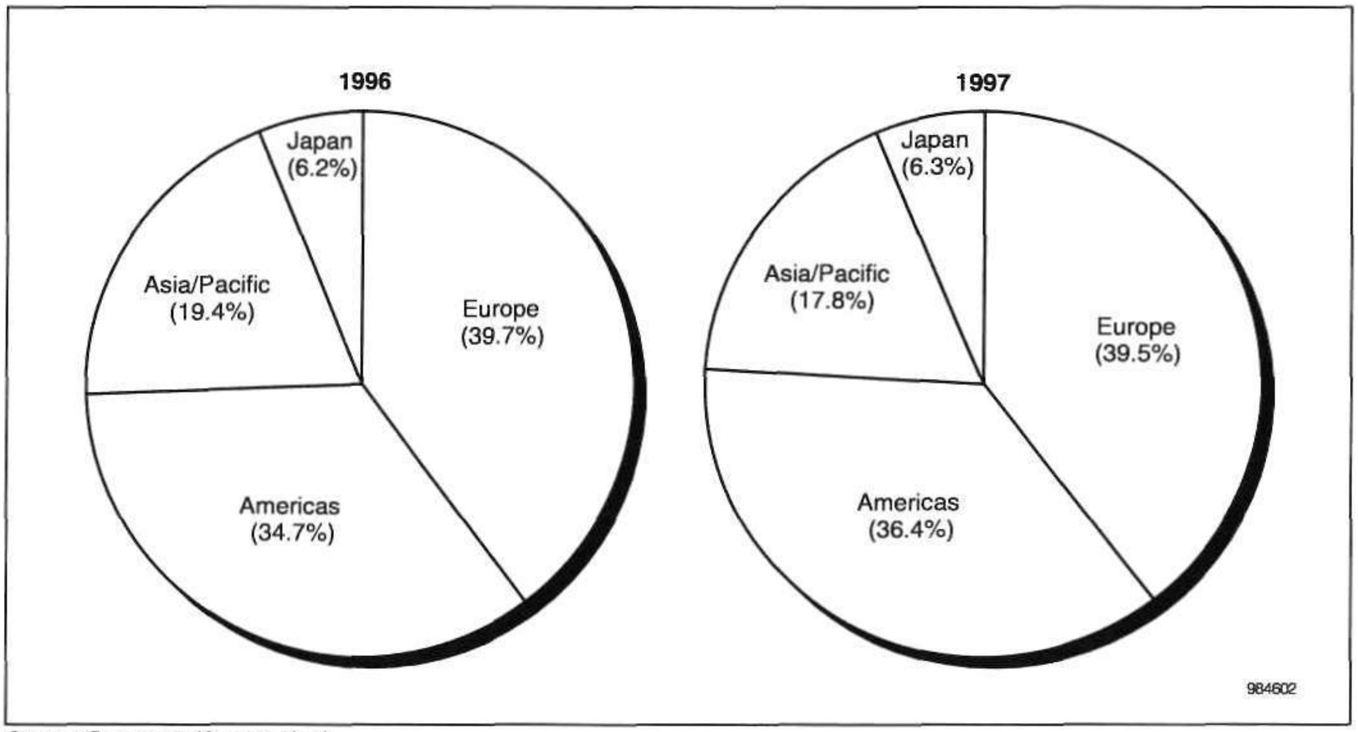

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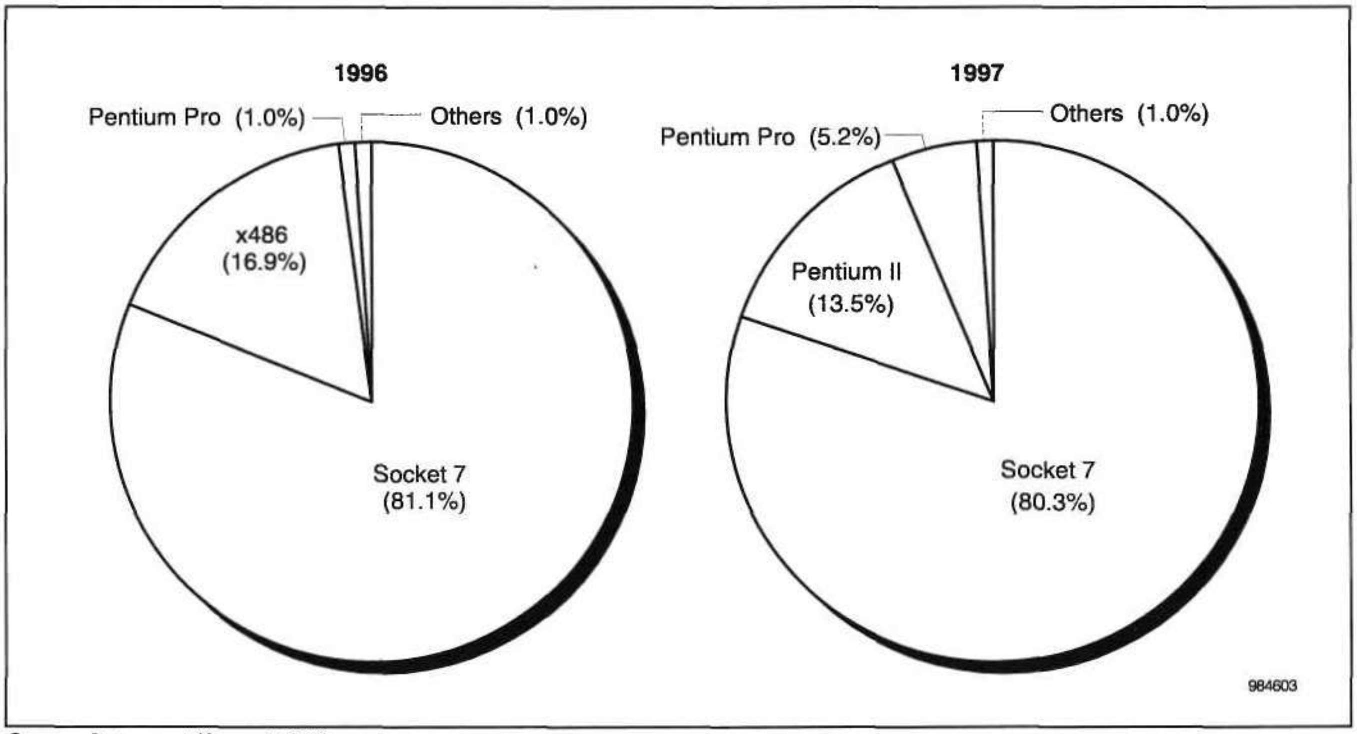

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Dataquest Perspective

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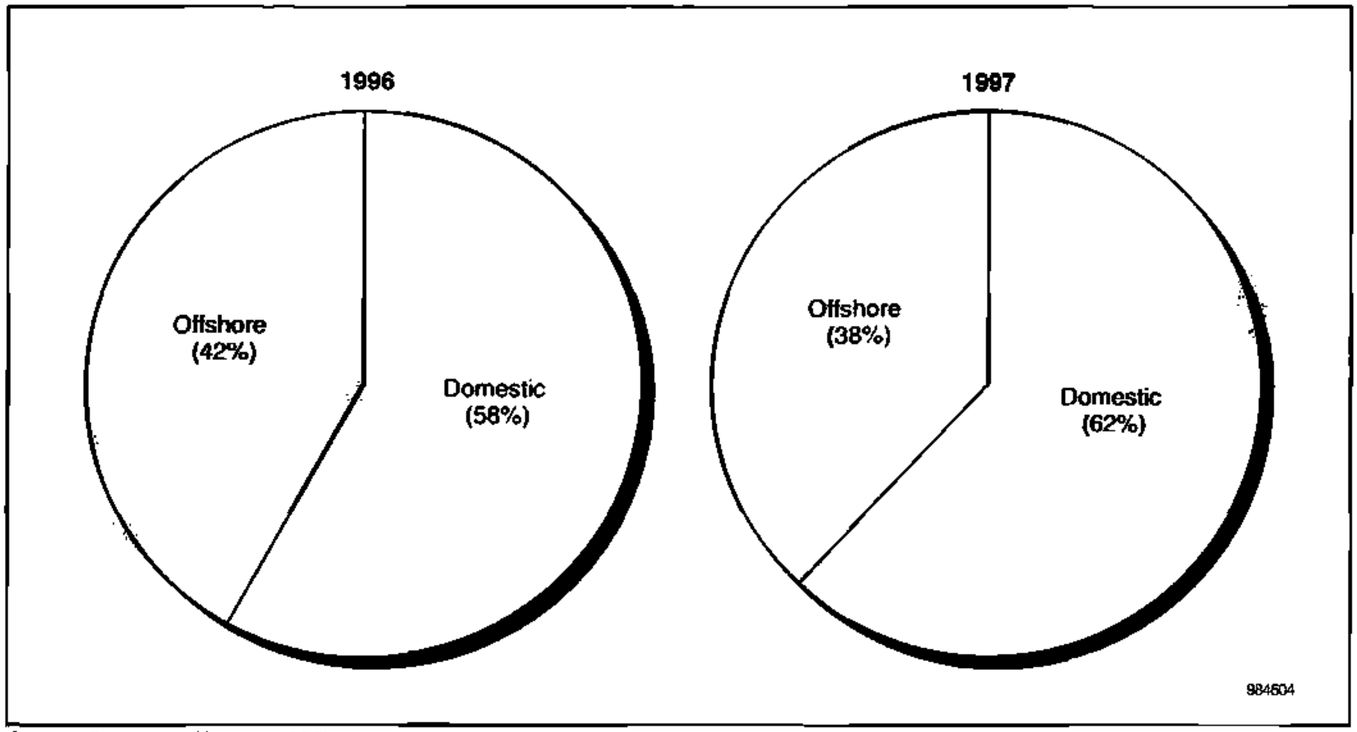

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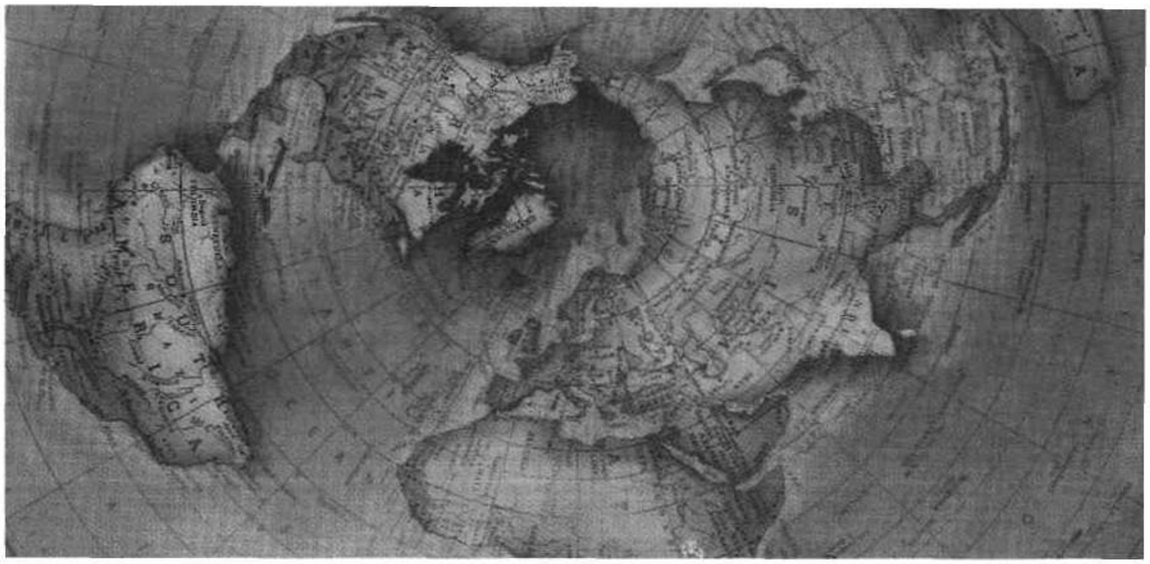
Perspective



Personal Computer Semiconductors and Applications Worldwide

Technology Analysis

How Many Microprocessors Does It Take to Surf the Net?

Abstract: *Dataquest examines what all those microprocessors hidden in the Internet's infrastructure actually do, by following the path of a data packet through the Internet. This report uses 30 years of history in computing and communications to extrapolate the outlook for the next 30 years.*
By Nathan Brookwood

Dataquest Has a New Neighbor

Two years ago, Cisco Systems Inc. purchased a 139-acre site that partially abuts Dataquest's San Jose headquarters. One year ago, it began construction of a 19-building, 3.3 million-sq. ft. campus, to augment the 1.7 million sq. ft. of office space it has built over the past four years. In much the same way as Cisco's products stream data into the high-capacity communications lines that drive the Internet, the company's construction proceeds in a highly pipelined manner. Specialized crews move from building to building. It took 12 months for the company to fill the construction pipeline. The site preparation crew has progressed to Building No. 13, immediately behind Dataquest. As employees move into Building No. 1, landscapers plant trees by Building No. 2, painters and electricians complete Building No. 3, and so on. For the next 18 months, new buildings will emerge at the rate of one per month, even though it takes 12 months to complete each of the buildings.

As this Dataquest analyst looked up from the Dataquest Interactive (DQi) display on the computer screen in his office and watched the bulldozers reshape the landscape, he realized that his research activities and Cisco's construction efforts were highly intertwined. The need to build out Internet bandwidth, facilitating access to Web sites such as DQi, drives much of Cisco's growth. Cisco's routers consume large numbers of high-end

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embedded microprocessors, as Dataquest noted in an earlier report, *Pushing the Envelope: Performance-Starved Embedded Applications* (MCRO-WW-DP-9708).

Dataquest anticipates that Internet service providers (ISPs) will purchase $4.3 billion of communications hardware in 1998. This revenue figure is projected to show a compound annual growth rate (CAGR) of 22 percent through 2002, as indicated in Table 1. Table 2 shows semiconductor consumption in LANs and routers. Networking hardware sold to ISPs and corporations is projected to consume almost $4 billion worth of semiconductors in 1998, growing to $6.2 billion in 2001. Overall, companies building networks for their own use, or to carry other companies' traffic, spent about $5.8 billion on routers in 1997, as detailed in Table 3. These devices come with hefty price tags. ISPs and corporations deploy $75,000 routers in the same casual manner as Cisco drops 150,000-sq. ft. buildings onto San Jose's landscape.

Why does the Internet need so much hardware to transport data from an office in San Jose to the Web site of Gartner Group Inc. in Colorado? And why, given the explosive growth of the Internet, does Dataquest project flat sales for the high-end routers that power today's Internet and absorb so many high-end embedded processors?

Table 1
Sales of Internet Access Equipment to ISPs (Millions of Dollars)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Access Concentrators	420.8	643.5	1,093.1	1,511.3	2,002.4	2,485.7	3,045.7	36
Remote Access Servers	96.5	68.0	121.9	126.4	125.5	120.1	108.1	10
100-Mbps Ethernet Hubs	5.4	9.1	9.4	11.9	15.6	20.6	23.9	21
100-Mbps Ethernet Switches	119.6	593.3	1,100.0	1,601.9	1,930.8	2,115.8	2,181.6	30
10-Mbps Ethernet Hubs	2.1	1.7	1.3	1.1	1.0	0.8	0.8	-14
10-Mbps Ethernet Switches	97.3	117.4	160.7	160.4	181.5	215.6	241.7	16
Route Switch (Layer 3 Switches)	-	154.4	244.0	388.0	611.1	885.3	1,099.9	48
High-End Routers	794.9	810.0	868.2	963.4	1,048.2	822.4	804.0	0
Midrange Routers	248.8	205.2	174.3	167.9	164.2	142.7	152.2	-6
Branch Office Routers	219.4	258.5	257.8	325.6	416.4	485.7	505.2	14
Frame Relay	65.4	88.5	112.7	122.7	124.2	117.2	109.0	4
ATM Backbone Switches	20.4	50.5	60.6	89.1	114.9	133.9	154.0	25
FDDI Switches	123.7	60.6	119.3	129.9	120.0	90.4	65.6	2
FDDI Hubs	45.3	23.1	22.6	19.5	16.3	11.3	7.7	-20
Total	**2,259.6**	**3,083.8**	**4,345.9**	**5,619.1**	**6,872.1**	**7,647.5**	**8,499.4**	**22**

Source: Dataquest (June 1998)

Table 2
Semiconductor Consumption in LANs and Routers (Millions of Dollars)

Application	Device Category	1996	1997	1998	1999	2000	2001	CAGR (%) 1996-2001
Router	MPU/MCU	102.2	122.8	170.0	220.4	281.4	341.5	27.3
Router	System Functions	207.3	243.3	322.7	419.0	513.7	624.7	24.7
Router	ASSP	57.1	68.5	90.8	117.6	144.0	174.7	25.1
Router	ASIC	149.8	173.6	230.0	298.1	364.8	442.7	24.2
Router	Other	512.4	462.7	518.6	639.2	757.2	776.4	8.7
Router	Subtotal Router	821.9	828.8	1,011.3	1,278.6	1,552.3	1,742.6	16.2
LAN	MPU/MCU	199.8	246.0	312.8	381.0	454.6	527.9	21.5
LAN	System Functions	1,077.5	1,364.9	1,634.6	1,872.3	2,039.1	2,180.1	15.1
LAN	ASSP	675.2	844.2	980.9	1,106.5	1,206.4	1,294.5	13.9
LAN	ASIC	401.8	519.5	651.8	762.5	827.8	878.5	16.9
LAN	Other	949.9	885.2	1,014.9	1,271.3	1,583.0	1,737.8	12.8
LAN	Subtotal LAN	2,227.2	2,496.1	2,962.3	3,524.6	4,076.7	4,445.8	14.8
All	**Total LAN/Router**	**3,049.1**	**3,324.9**	**3,973.6**	**4,803.2**	**5,629.0**	**6,188.4**	**15.2**

Source: Dataquest (September 1997)

Life in the Pre-Microprocessor Era

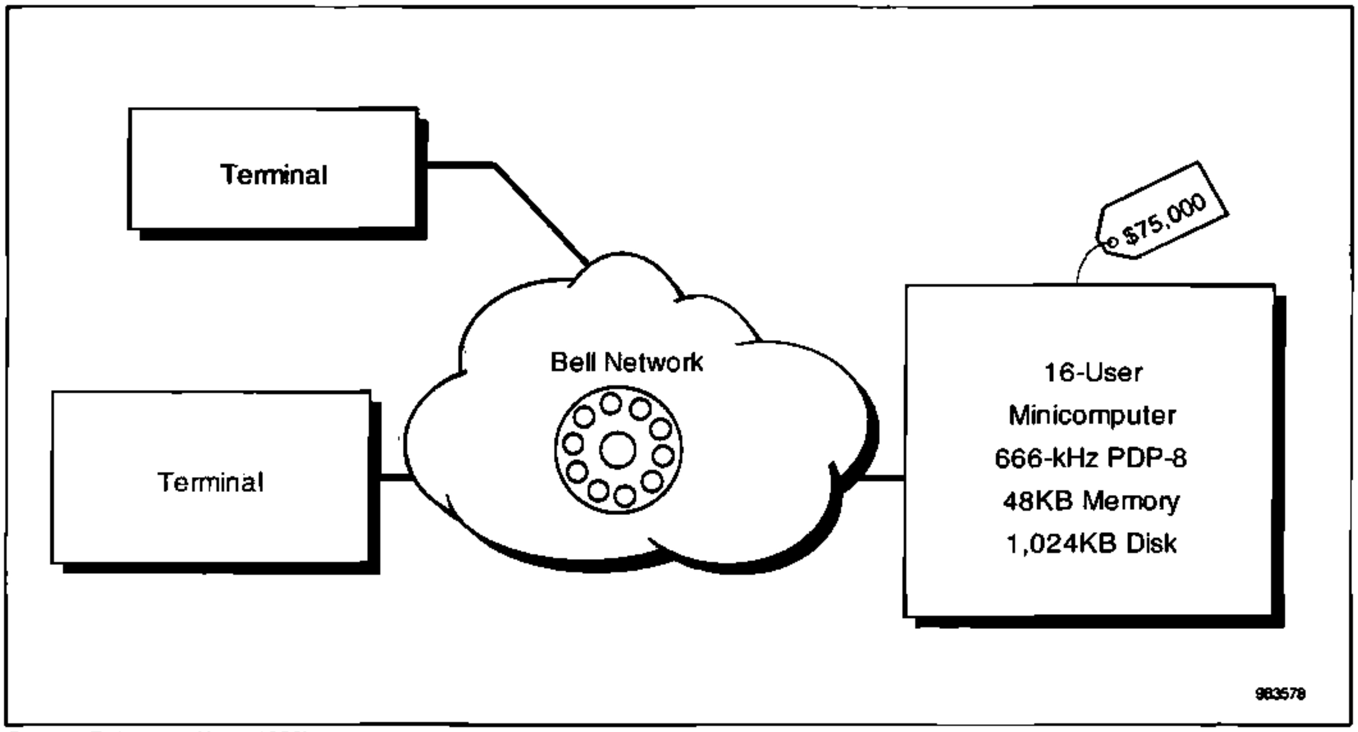
The analyst could recall an earlier time, when data traveled with far less electronic assistance, albeit at somewhat lower transmission rates. In 1968, long before becoming an analyst, he had often accessed a time-shared minicomputer located in Maynard, Massachusetts, from his home a few miles away. The minicomputer, a 48KB PDP-8, with almost a megabyte of hard disk storage, ran at 660 kHz, sold for approximately $75,000, and supported 16 simultaneous users. It was considered a bargain in its day. His teletype terminal contained an incredible array of gears and linkage arms, printed at 10 characters per second, and sold for $800. The telephone company (there was only one) had not yet replaced the area's mechanical crossbar switch with a more modern equivalent (its 40-year depreciation cycle had a few more years to run). He could hear the switch click as it connected his rotary-dial phone with the remote computer. Figure 1 illustrates how things worked in this much simpler era.

Table 3
The 1997 Router Market

	Revenue ($M)	Units (K)	ASP ($)
High-End	2,556.80	34.1	74,979
Midrange	1,483.00	110.6	13,409
Branch Office	1,731.70	792.3	2,186
Total	**5,771.50**	**937.0**	**6,160**

Source: Dataquest (June 1998)

Figure 1
Data Communications Network, Circa 1968



Source: Dataquest (June 1998)

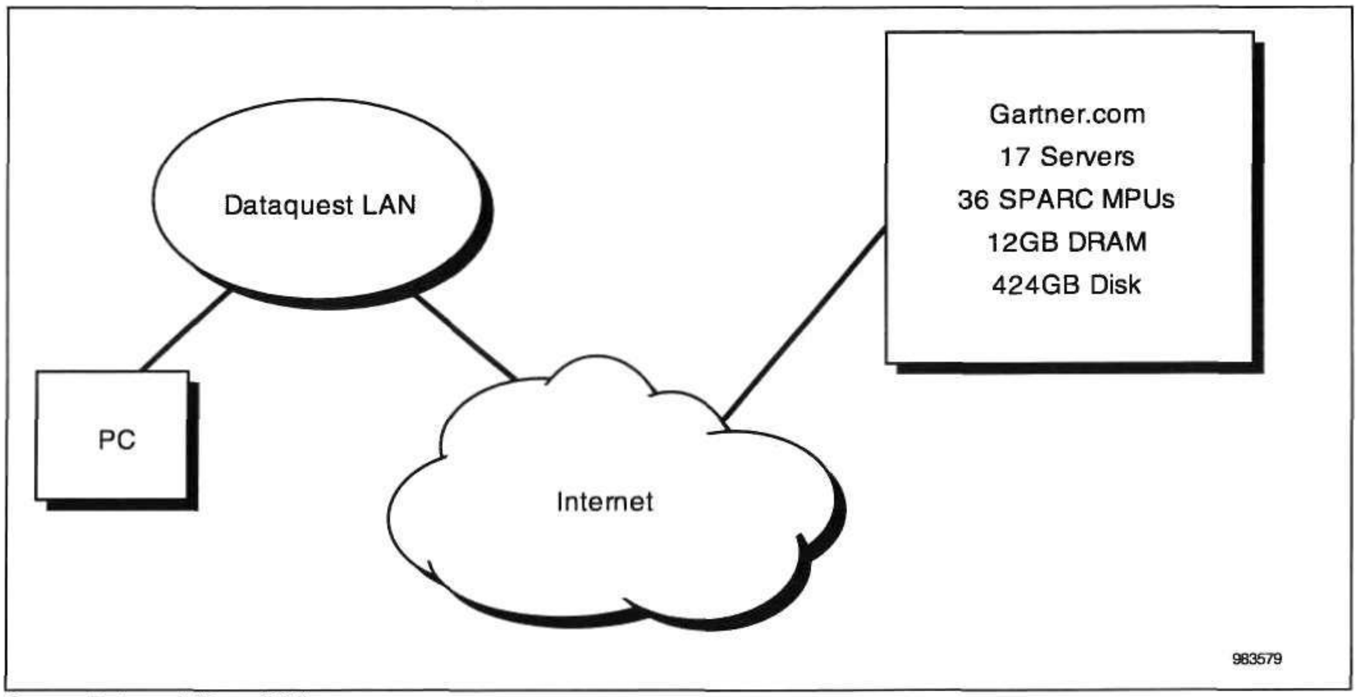
Back then, as the analyst depressed the keys on his keyboard, gears whirred. Mechanical brushes swept a rotating disk and generated the bits for each character going down the line. A 110-bps modem, for which the telephone company charged $35 per month, converted the bits into tones and pushed them into the network. (Forget autodial; that was not available at any price.) At the other end of the line, a modem attached to the minicomputer converted the data back into bits. The minicomputer's main (and only) processor converted these bits into characters. To accomplish this, it set aside its computing activities 550 times each second and checked each incoming data line for the bits that made up a character. This task alone consumed over 20 percent of the 660-kHz processor's power, but the alternative (to implement this activity in hardware) would have been prohibitively expensive. 100 milliseconds after a key was depressed, the character arrived at the host system. Software at the host accepted the character, generated a response, and sent its output down the same torturous path back to the terminal. At best, this round-trip took 200 milliseconds (100 each way), and usually a lot longer. When all went well, the entire ensemble chugged along at the impressive rate of 10 characters per second. In the course of the entire transaction between terminal and minicomputer, only one programmable device (the minicomputer's processor) ever touched the data.

It cost a lot to build programmable devices prior to the invention of the microprocessor. Consequently, not many programmable devices were built, and not many semiconductor devices were needed to build them. Dataquest estimates that 1968 worldwide semiconductor revenue totaled approximately $1.47 billion. In the following 30 years, innovations such as the microprocessor allowed the industry to maintain a 16.6 percent CAGR, leading to total revenue of $147 billion in 1997.

How It's Done Now

In an attempt to understand why today's data networks require so much more hardware than those of yore, the analyst undertook a bold experiment. He allowed himself to be digitized and entered his personal computer. There he hopped onto the packet that signaled the click of his mouse and traveled through the computer, through Dataquest's LAN, and through the Internet, until he arrived at the Gartner Web site (www.gartner.com). On his arrival, he immediately boarded an outbound packet and returned via the Internet to his system's display monitor, where he appeared briefly as "nbrookwood.gif." Once back in San Jose, he exited the system and was restored to his original carbon-based life form. Figure 2 illustrates his overall journey, which consumed a total of 82 milliseconds. Table 4 identifies the major stops along the way. The remainder of this document reflects his observations regarding the microprocessors, microcontrollers, and unusual ASICs he saw on his journey through a small portion of today's electronic universe.

Figure 2
Data Communications Network, circa 1998



Source: Dataquest (June 1998)

Inside the Computer and in the LAN

A microcontroller inside the mouse transmits the click to the specialized microcontroller on the PC motherboard that communicates with the keyboard and mouse. Following a brief stopover in the system's DRAM, the system's powerful x86 processor stuffs the click into a data packet and hands it to the system's Ethernet adapter, which pushes it onto a 10-Mbps switched Ethernet connection. A few hundred microseconds after the mouse clicked, the message signaling that event heads out of the PC onto Dataquest's LAN.

Table 4
The Packet's Itinerary

Hop	Transit Time (ms)	Elapsed Time (ms)	IP Address	Function	Equipment	Owner	Location	MPU Configuration
1	0	0	-	LAN Switch	Kalpana	Dataquest	San Jose	MIPS
2	1	1	206.79.111.239	Router	Cisco 2500	Dataquest	San Jose	68030
3	0	1	206.79.141.165	Firewall	Sun Ultra 1	Dataquest	San Jose	UltraSPARC
4	1	2	206.79.141.97	Router	Cisco 4500	Dataquest	San Jose	68030
5	2	4	206.40.94.93	Router	Cisco 2500	Exodus	Santa Clara	68030
6	0	4	207.82.200.77	Switch	Cisco 5500	Exodus	Santa Clara	MIPS
7	2	6	207.82.200.1	Core Router	Cisco 7513	Exodus	Santa Clara	MIPS R4000
8	0	6	209.1.169.17	Core Router	Cisco 7513	Exodus	Santa Clara	MIPS R4000
9	0	6	209.1.169.146	Border Router	Cisco 7505	Exodus	Santa Clara	MIPS R4000
10	1	7	209.1.169.234	Inter-Packet Exchange (IPX)	Cisco 7505	BBN	Santa Clara	MIPS R4000
11	1	8	4.0.1.62	Backbone	Cisco 7505	BBN	Oakland	MIPS R4000
12	15	23	4.0.1.134	Backbone	Cisco 7505	BBN	Denver	MIPS R4000
13	0	23	4.0.52.5	Backbone	Cisco 7505	BBN	Denver	MIPS R4000
14	18	41	4.0.208.254	IPX	Cisco 7505	BBN	Denver	MIPS R4000
15	0	41	204.131.250.41	Border Router	Cisco 7505	SuperNet	Denver	MIPS R4000
16	0	41	-	LAN Switch	Cabletron 9000	SuperNet	Denver	i960
17	0	41	205.168.252.209	Firewall	Sun Ultra 1	Gartner	Denver	UltraSPARC
18	0	41	-	LAN Switch	Xyplex 3140	Gartner	Denver	68060
19	0	41	204.133.127.68	Host	Sun Ultra 1	Gartner	Denver	UltraSPARC

Source: Dataquest (June 1998)

It takes roughly 50 microseconds for the packet to travel over the local Ethernet cable to a nearby wiring closet. There, a Kalpana Ethernet switch quickly shuttles it onto an upstream Ethernet connection to a small Cisco 4500 router in an adjacent building. Kalpana pioneered the switched Ethernet concept, and its boxes use ASICs that quickly move data between upstream and downstream connections. Shortly after Dataquest acquired its network, Cisco acquired Kalpana, as it has acquired many other successful networking startups. Traces of the Kalpana genealogy can be found in Cisco's newer Catalyst Ethernet switches. Traces of some Kalpana progenitors will likely find their way into the massive complex rising out of the dust behind Dataquest.

The 4500 router, controlled by a 40-MHz Motorola 68030 with 16MB of DRAM, collects traffic from all of Dataquest's on-site systems. Cisco still builds and markets systems that use these 68030 processors, although this chip ceased to be interesting in desktop applications more than six years ago. (Unlike the more fickle computational microprocessor market, where products come and go in two- or three-year cycles, some embedded design wins last forever.) The 4500 passes the packet to a Sun UltraSPARC workstation (150-MHz MPU, 512MB DRAM) that serves as a firewall. Firewalls monitor all packets passing between internal systems and the outside world and trap those that might cause trouble or compromise security. Most networks connected to the Internet use firewalls to preserve their own integrity. The UltraSPARC forwards the packet to a Cisco 2500 (containing a 20-MHz 68030 and 8MB of DRAM), which in turn pushes it onto a T-1 carrier line operating at 1.54 million bits per second. Lines such as this usually rent for $2,500 per month and link many buildings like Dataquest's to telephone central offices or to other building sites on a point-to-point basis. Local carriers charge for such lines by the mile and view such services as a healthy source of revenue. Dataquest's relatively short T-1 circuit is fairly inexpensive as communications channels go. No wonder the telecommunications companies (telcos) resist digital subscriber line (DSL) offerings that can provide the same bandwidth at prices well below $100 a month.

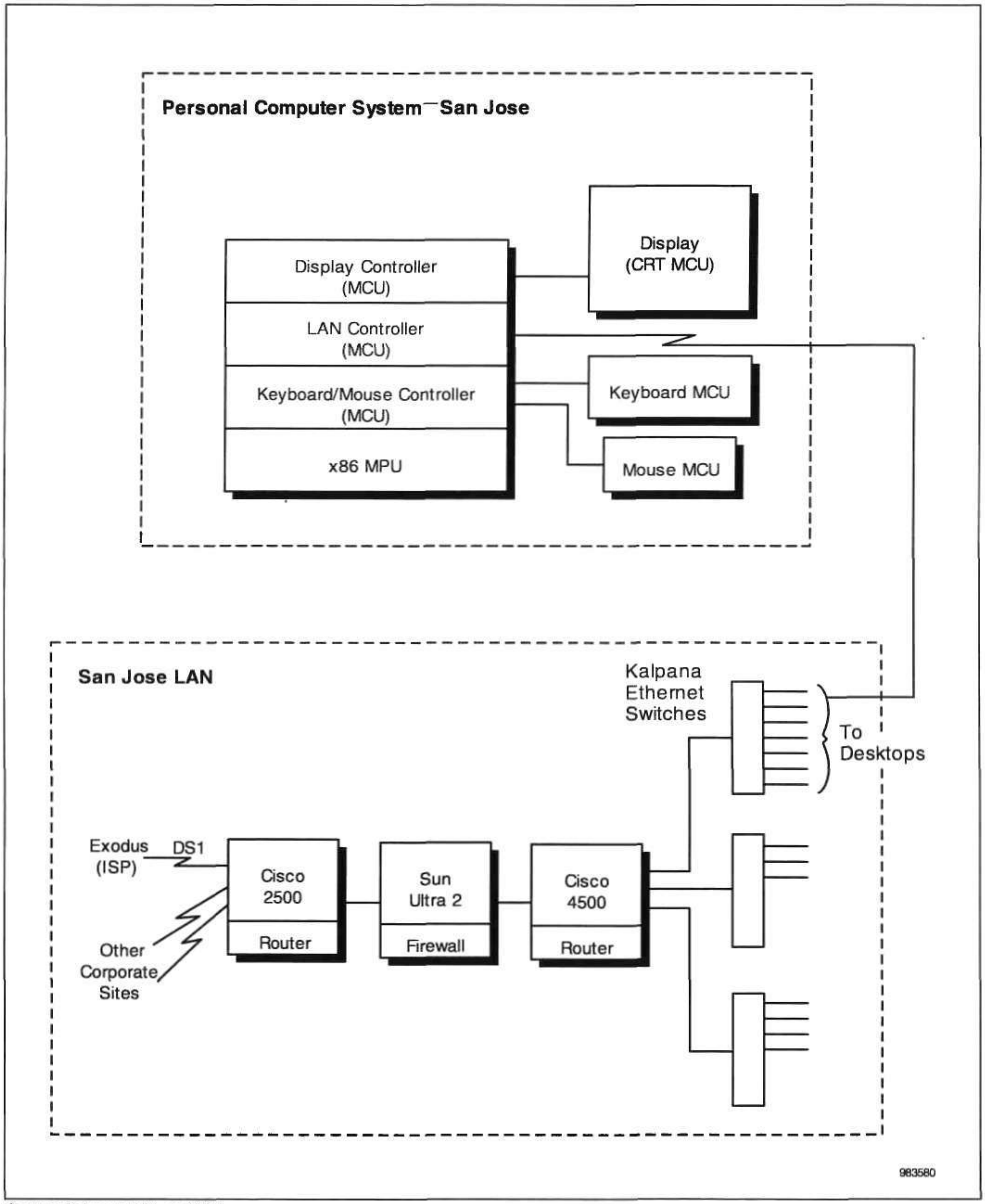
It has taken roughly 2 milliseconds for the packet containing the click to travel less than 200 yards from the mouse to the edge of the building. Eleven microcontrollers and four microprocessors have nudged it along the way. Figure 3 traces its path up to this point.

Through the Internet

It takes another 2 milliseconds for the packet to travel the few miles between Dataquest and Exodus Communications Inc., Dataquest's ISP. Many corporate Web sites (but not Dataquest's) physically reside at the Exodus site in Santa Clara, where they have affordable access to the high-speed links that tie Exodus to other Internet carriers.

The packet enters the Exodus on-site LAN via a Cisco 2500 router. The 2500 passes it to a Cisco 5500 Ethernet switch that aggregates data traveling to and from Exodus' on-site clients. The 5500, descended from the Kalpana switch mentioned earlier, contains a MIPS microprocessor, but depends on custom ASICs to accomplish most of its work. From the 5500, the packet travels to the Exodus "core" router, a massive Cisco 7513, which directs it toward one of several "border" routers that connect Exodus with the rest of the Internet. The core router knows the shortest path to 204.133.127.68, more commonly known as www.gartner.com, will pass through another ISP, BBN-Planet. It directs the packet along that path, toward an Exodus router linked to the BBN-Planet network. To minimize message transit delays, most large ISPs maintain direct high-speed links to other large ISPs, in an arrangement referred to as "peering." Often, a dedicated node, known as an Internet Packet eXchange (IPX) point, serves as the go-between. The packet flows through the Exodus/BBN IPX and speeds down a fiber-optic link to a nearby BBN-Planet point of presence (POP). During the 3 milliseconds it spent in the Exodus facility, seven high-performance MIPS microprocessors and one 68030 gently nudged it through the various hardware interfaces.

Figure 3
Inside the Personal Computer and LAN



Source: Dataquest (June 1998)

The packet, now in the care of BBN-Planet, speeds to Oakland over a 45-Mbps DS3 link. There, it hangs a sharp right at the local BBN-Planet router (another Cisco 7500) and heads east toward Denver. Yet another Cisco 7500 links BBN-Planet with SuperNet, the site in Denver where Gartner.com physically resides. Within each 7500, at least three MIPS R4000 microprocessors touch the packet. Other processors in each system busy themselves shuttling packets on and off other lines attached to the system. The trip through BBN-Planet covers almost 1,000 miles, touches 16 MIPS microprocessors—some running as fast as 200 MHz—and takes a total of 34 milliseconds. About half of this time was consumed in the long link between Oakland and Denver, while the remainder was spent in local traffic after the packet arrived at the Denver IPX. Figure 4 depicts the path the packet takes through the Internet.

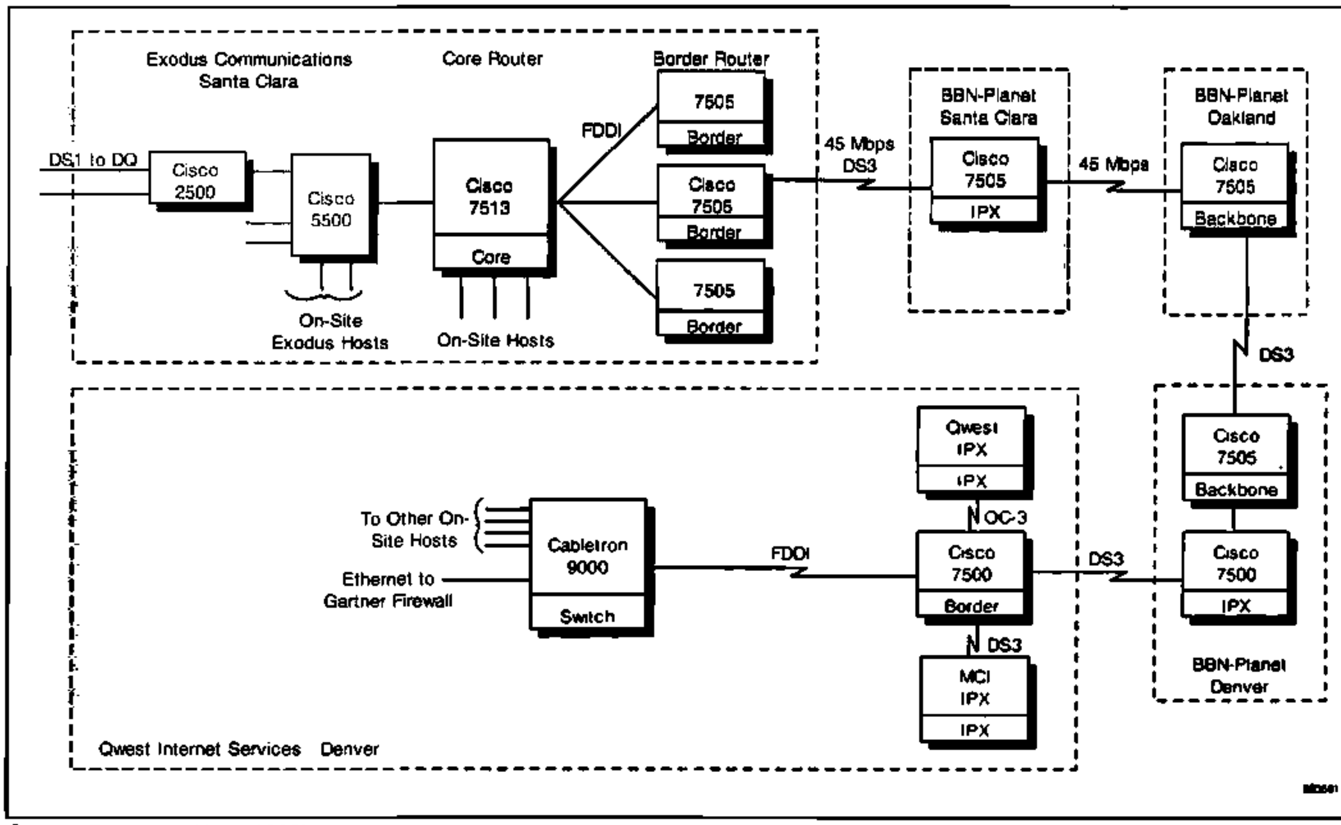
Finally, the packet arrives at SuperNet, an ISP that, like Exodus, specializes in hosting Web sites physically colocated on its premises. Over 100 companies maintain Web sites at SuperNet, each in its own caged and secure area. Three high-speed fiber-optic connections enter the site via yet another Cisco 7500 router. Two DS3 (45-Mbps) links tie SuperNet to BBN-Planet and MCI Communications Corporation; a third links SuperNet to Qwest Communications International Inc., the long distance company that recently acquired SuperNet. Qwest employs packet switching, like that used within the Internet, to achieve substantially lower long distance costs than traditional carriers for voice communications. Qwest brings some of this packetized voice traffic into its Denver site via an OC-3 (155-Mbps) link.

After the long run of MIPS-based Cisco routers that carried the packet along the Internet backbone, the packet encounters some different architectures. SuperNet uses a Cabletron Superswitch 9000 (formerly known as MMAC-Plus) to distribute data to its many on-site hosts, in much the same way that Exodus uses a Cisco 5500. The Cabletron system contains almost a dozen Intel 960 microprocessors on its varied interface boards. (Dataquest always wondered who bought all those Intel 960s, which have survived in the market for a long time but which have been overshadowed by Intel's huge x86 microprocessor shipments.) As it leaves the Cabletron switch, the packet formally crosses the border into Gartner.com. It took less than 1 millisecond for the packet to traverse SuperNet's switching equipment, and it used six microprocessors en route. The one-way trip through the Internet took a total of 39 milliseconds and required 30 microprocessors along the way.

Arriving in the Promised Land: Gartner.com

After meandering through the Internet for what seemed like an eternity, but actually measured 39 milliseconds, the packet signaling the mouse click arrived at the front door of Gartner.com. A Sun UltraSPARC firewall inspects it and passes it into the site. A massive Xyplex 3140 switches it to one of the 17 hosts that make up the Gartner Web site. Six of the machines front-end the site and manage the interactions with the thousands of Gartner clients that visit the site each day. The remainder work behind the scenes, storing, searching, and accessing the vast array of research materials created by Dataquest and Gartner analysts.

Figure 4
The Long Voyage through the Internet

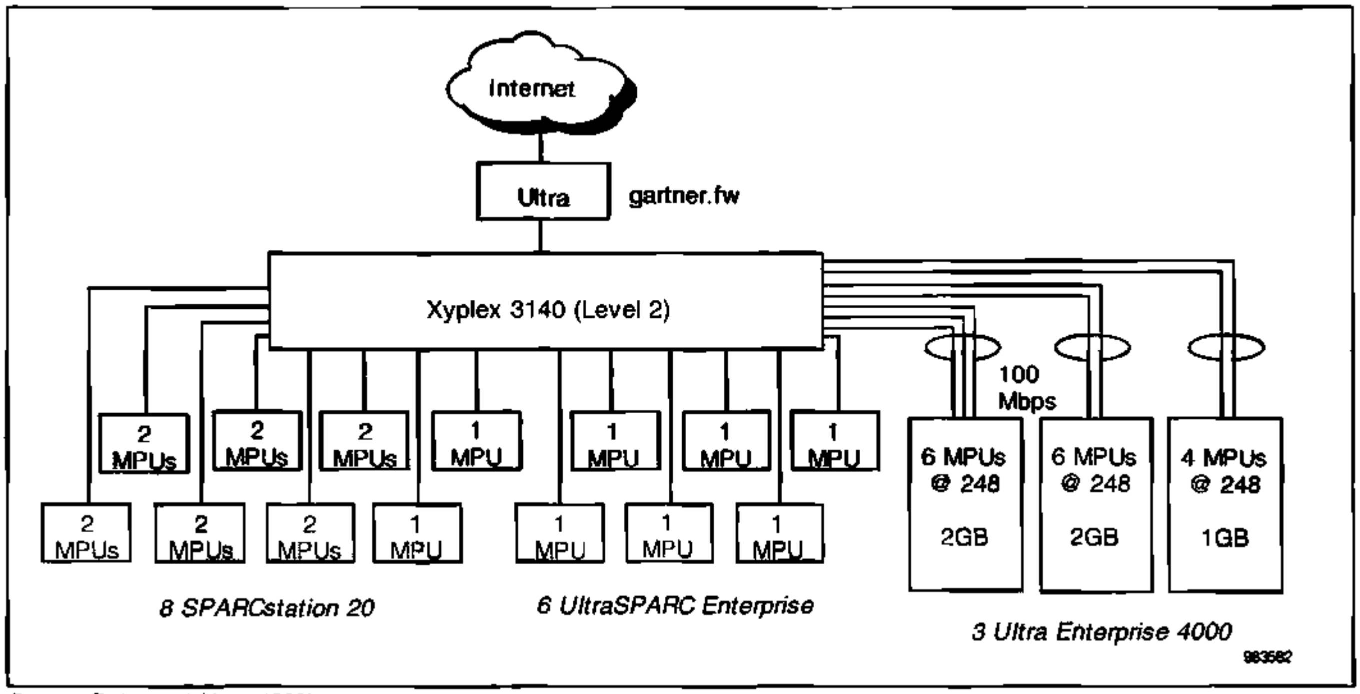


Source: Dataquest (June 1998)

Gartner.com, as illustrated in Figure 5, contains enough Sun hardware to have funded at least one sales representative's child's college education. These hosts, named Gartner1 through Gartner17, with the obvious omission of Gartner13, all run under Sun's Solaris operating system. The cadre includes eight dual-processor SPARCstation 20s, six uniprocessor UltraSPARC workstations, and three large UltraSPARC 4000 Enterprise servers. The three large servers contain a total of 16 248-MHz UltraSPARC II microprocessors, 5GB of main memory, and 213GB of redundant arrays of disk storage (RAID).

At last, the packet with the mouse click arrives at its final destination. The UltraSPARC processor channels it to a waiting program, and the system performs the action that was requested back in San Jose. The host directs its stream of data toward the browser running back in California, and the sought-for answer winds its way back. Six SPARC microprocessors at Gartner.com, along with two Motorola 68060's in the Xyplex switch, touched the packet as it traversed the site. Between the click of the mouse in San Jose and the activation of the program at Gartner.com, a total of 41 milliseconds have elapsed. Of course, the response must still travel back to California, a trip that will take it by all the same places.

Figure 5
The Systems That Constitute www.gartner.com (204.133.127.68)



Source: Dataquest (June 1998)

Another 40 or so milliseconds transpire as the packet returns to the analyst's desktop computer. The response passes through the UltraSPARC firewall, by the 68060s in the Xyplex switch, past the 960s in the Cabletron switch, past the MIPS processors in the Cisco 7500 routers that line the path between Denver and Santa Clara, back to the 68030 in the Cisco 2500 at Exodus, across the T-1 link to the Cisco 2500 at Dataquest's site, through the UltraSPARC firewall, through the Cisco 4500, through the LAN, and into the PC, where one last microcontroller transforms it from bits in the system's memory to glowing pixels on the computer's screen.

Like so many long journeys, the return covers familiar territory and seems to go by much faster than the outbound trek, but both took similar amounts of time, according to the clock on the wall. All together, 42 distinct microprocessors handled the packet along its journey, many touching it on both outbound and inbound legs of the trip.

The Microprocessor's Role in Communications Equipment

As noted throughout this travelogue, high-end routers, mostly Cisco high-end routers, play a key role in moving data within today's Internet. It was not just a coincidence that we saw so many Cisco products and so few from other vendors. As Table 5 illustrates, Cisco dominates this market segment the way Intel dominates compute microprocessors and Microsoft dominates operating systems.

The need for Internet bandwidth grows constantly, but the forecast in Table 1 indicates that sales of these powerful routers will plateau at current levels.

Table 5
Top Five Companies' Worldwide High-End Router Market Share, First Quarter 1998

	Manufacturer Revenue ($M)	Unit Shipments (K)	Revenue Market Share (%)	Unit Shipment Market Share (%)
Cisco Systems Inc.	313.9	6.7	82.9	82.4
Bay Networks Inc.	48.0	0.6	12.7	7.6
Network Systems Corporation	5.3	0.1	1.4	0.8
Cabletron Systems Inc.	3.6	0.2	0.9	2.7
Hypercom Network Systems	3.5	0.4	0.9	5.0
Others	4.2	0.1	1.1	1.5
Total	**378.5**	**8.1**	**100.0**	**100.0**

Source: Dataquest (June 1998)

The rationale behind this forecast reflects a trend that will impact this and other microprocessor applications over the next five years. The combination of increased line speeds and decreased diversity of network protocols will drive the routing function, which traditionally has been handled by powerful microprocessors and sophisticated real-time software, into special-purpose ASICs that require far less processor and software intervention. Cisco's switches—the Catalyst 5500 and the more recent Catalyst 8500—along with switches from other vendors like Bay Networks Inc., Cabletron Systems Inc., and Xyplex Networks, will absorb more and more of the traffic now handled primarily by routers.

This trend manifests itself in the dramatic 48 percent CAGR of "route switches," otherwise known as "layer 3 switches." The term "layer 3" refers to the network layer of the International Standards Organization's (ISO) networking model. In this model, traditional switching functions (such as the Kalpana switch sitting at Dataquest) operate at the physical link layer (layer 2) and network routing (such as the Internet Protocol, or IP) operates at layer 3. These ASIC-intensive route switches, although somewhat less flexible than traditional routers, provide far greater performance at the same or lower cost as their predecessors and will increasingly be deployed in lieu of high-end routers. This phenomenon first affects those routers dealing only with on-site traffic, where bandwidth requirements are greatest and interfaces to external communications facilities are least important. Later, as route switches gain increased communications flexibility and sophistication, the trend may spread to border router configurations as well. As this trend plays out, one of the last price-insensitive applications for high-end embedded processors will slowly fade from the scene.

Other attributes also differentiate the needs of the communications market from other microprocessor applications:

- Little if any need for floating point hardware—The high-end MIPS processors used in Cisco's systems all contain powerful floating-point engines that are never used. Almost any other use of the silicon dedicated to these operations would benefit network equipment providers more than the current scheme. Even as the high-end router market transitions to more switch-like devices, midrange products and route-switch devices will need more powerful microprocessors. Vendors should consider offering versions of their high-end products without floating point capability, especially if they can redeploy the silicon for a more beneficial purpose.
- Very long product cycles—Unlike desktop computers that often become obsolete in just a few years, many communications devices go on and on forever. Network equipment purchasers tend to be extremely conservative in their buying practices. They often pay tens or hundreds of thousands of dollars per month for the lines they rent, and they don't want some newfangled microprocessor to mess up their network. Consequently, Cisco still uses 68030s in some low-end systems, while Cabletron continues with the i960.

Dataquest Perspective

As we compare the manner in which data flowed through an early network in 1968 with the way it flows today, several important trends emerge:

- A simple transaction then took at least 200 milliseconds, even when the physical distances traveled were short. Today it takes less than half that time for a more complex message to travel a considerably greater distance. An inexpensive terminal then cost about $800 and operated at 10 characters per second. Today's inexpensive Internet devices cost a similar amount (before adjusting for inflation) and operate at speeds up to 5,600 characters per second (over ordinary phone lines, given 56K modems).
- The installed base of computers then totaled fewer than 10,000 systems. Today it totals more than 300 million systems.
- The worldwide semiconductor industry revenue in 1968 totaled approximately $1.47 billion. Thirty years later, it has grown to $147 billion, a 100-fold increase. This translates into a CAGR of 16.5 percent over the period and supports the "general wisdom" that the semiconductor industry's long-term growth is measured in the mid-teens.

At many points over the past 30 years, prophets of doom declared that the gravy days were over and growth would soon decelerate. In retrospect, it is easy to see what such observers missed. In 1968, the Internet was barely a gleam in Vinton Cerf's eye. Bill Gates had yet to write his first program or make his first million. Were representatives from the 1968 computer cognoscenti to be transported into the future (1998) and given the opportunity to review Dataquest's latest microprocessor market statistics, they would not believe that the world could find uses for so many processors. The recent slowdown of the semiconductor market has led some to once again question whether the incredible course of the modern microelectronic era is finally running out of steam. The applications and devices that will drive the continued growth of the electronics industry may not always be visible, even to its most far-sighted participants, but barring the collapse of human ingenuity, they too will emerge.

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Perspective

Personal Computer Semiconductors and Applications Worldwide

Market Analysis

Rumors of the Deaths of the Graphics and Audio Add-In Board Markets Are Greatly Exaggerated

Abstract: *The PC add-in board markets for graphics and audio features are under fire. This document provides forecasts for the PC graphics and PC audio board markets as well as an analysis of how vendors can weather the current storm and position their product lines for the future.*

By Geoff Ballew

Introduction

Changes in the PC market inevitably create change in the markets for PC add-in boards. Falling prices for PCs resulted in price erosion for the PC graphics and PC audio add-in board markets, too. Average selling prices (ASP) went down sharply and will go lower before recovering. Dataquest forecasts a recovery to begin in late 1999 and gain strength in 2000.

The term "board" is used throughout this Perspective to describe a printed circuit board with components for adding peripheral functions to a PC. It is interchangeable with the term "card," for example, graphics card or audio card. Also, the term "audio board" is interchangeable with sound board or sound card.

Graphics Will Fare Better than Audio

The graphics add-in board market continues to suffer from the price pressure on PCs and the current value proposition for 3-D graphics in corporate environments. Price erosion has paralleled falling prices in the PC market. Before the emergence of Segment 0 PCs as viable products, few graphics

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vendors introduced add-in boards at a $99 street price. Today, major graphics board vendors need a new, compelling $99 board in their bag of tricks in the same way the PC OEMs need a Segment 0 offering in their own product lines.

The graphics board vendors do have some opportunities on the horizon to raise their ASPs. These opportunities are tied to the increasing chip-level integration for core logic and microprocessor products as well as the opportunity to differentiate on performance.

Chip-level integration trends will rob the add-in board market of some of its unit growth, but the business it will steal is not the high-margin business that board vendors crave. Graphics logic integrated into the core logic chipset or even into the microprocessor will appeal mostly to the bottom third of the market. The reason for this is simple: Whatever level of performance can be integrated, savvy chip vendors can deliver greater performance in a separate chip. This of course depends on that fact that PC users can distinguish the performance difference and associate some value with it. For 3-D graphics on the average business desktop today, that is not the case. Dataquest forecasts that new applications will emerge because they always do. Human beings interact in a 3-D environment, so it only makes sense that the human/computer interface will evolve to take advantage of that. The fact that this software is not here right now indicates that the opportunity for a strong recovery will be pushed into 1999.

The long-term opportunity to sell graphics chips and graphics add-in boards is predicated on the ability of vendors to differentiate their products on performance. 3-D graphics offers vendors incredible headroom to increase the performance of their products without reaching the limit of a human being's ability to perceive a difference. Today's graphics chips could get 1,000 times faster and still have more than another thousand-fold opportunity to boost performance. The value proposition to PC users will determine how much vendors at both the chip level and board level can charge for their products, but the opportunity to sell will exist.

AGP Upgradability

Graphics boards always face competition from graphics chips soldered directly to the motherboard. This is a classic cost-versus-flexibility trade-off. Typically, it is less expensive to implement graphics on the motherboard than it is to put that same graphics solution on an add-in board. However, in that case the opportunity to change the graphics solution without redesigning the motherboard is severely limited. Some graphics chip vendors have pin-compatible products within a product family, but no two vendors use the same pin-out.

AGP adds an additional twist to the flexibility versus cost formula. AGP is a point-to-point interface, so there is only one AGP "slot" on PCs. If a PC motherboard has an AGP graphics chip soldered to it, there cannot be an additional socket to accept an AGP add-in board. If the PC user wants to upgrade the graphics, a PCI board must be installed and the benefits of AGP will be lost. This is a dubious upgrade at best. Previous bus architectures did not have this issue, and the industry recognizes the need for change. Three-point AGP is a solution for allowing a motherboard AGP device and an AGP socket to accept an add-in board. The limitation will be that the motherboard AGP device must be disabled for the add-in board to be used, but the solution would allow an AGP upgrade. The problem with three-point AGP is technical complexity. Core logic products supporting three-point AGP should debut in 1999, but motherboard designers may have difficulty designing robust products because of technical issues.

Flexibility in changing the graphics subsystem is valuable to PC OEMs in two ways. First of all, it allows OEMs to redefine their product configuration more easily for either product enhancement if a new graphics product is introduced or risk management in the case of supply or quality issues surrounding the graphics component. The second benefit is the opportunity to upgrade the graphics. This benefit grows in importance as the industry relies more heavily on build-to-order (BTO) or channel-configuration business practices. A PC vendor can offer an graphics upgrade to encourage the PC buyer to spend more money. Dataquest believes that upgrades at the time of order are very profitable for the PC vendor and add considerably to the overall margin the vendor makes on that sale.

The major consequence of AGP's upgradability issues is that PC OEMs have the incentive to continue using add-in boards even as the variety of more highly integrated options increases. This benefits only the middle and high-end segments of the board markets because the low-end boards will face steeper competition in the form of more highly integrated core logic and microprocessor options.

Graphics Board Forecast

The graphics board forecast covers all discrete graphics board products that include VGA, 2-D graphics, and 3-D graphics acceleration. Dataquest believes that the graphics board market will grow on a unit basis, albeit at a slower pace than the overall PC market. The low end of the graphics market will gradually be absorbed by integrated graphics solutions on the motherboard. Segment 0 PCs offered by top-tier OEMs will overwhelmingly use motherboard graphics. The remaining (and growing) units in the graphics board market will move up in the value chain, and ASPs will rise from 1999 to 2000, reversing the current trend of declining ASPs. Table 1 shows the new forecast. Figure 1 presents this data graphically.

Major Risk Factors

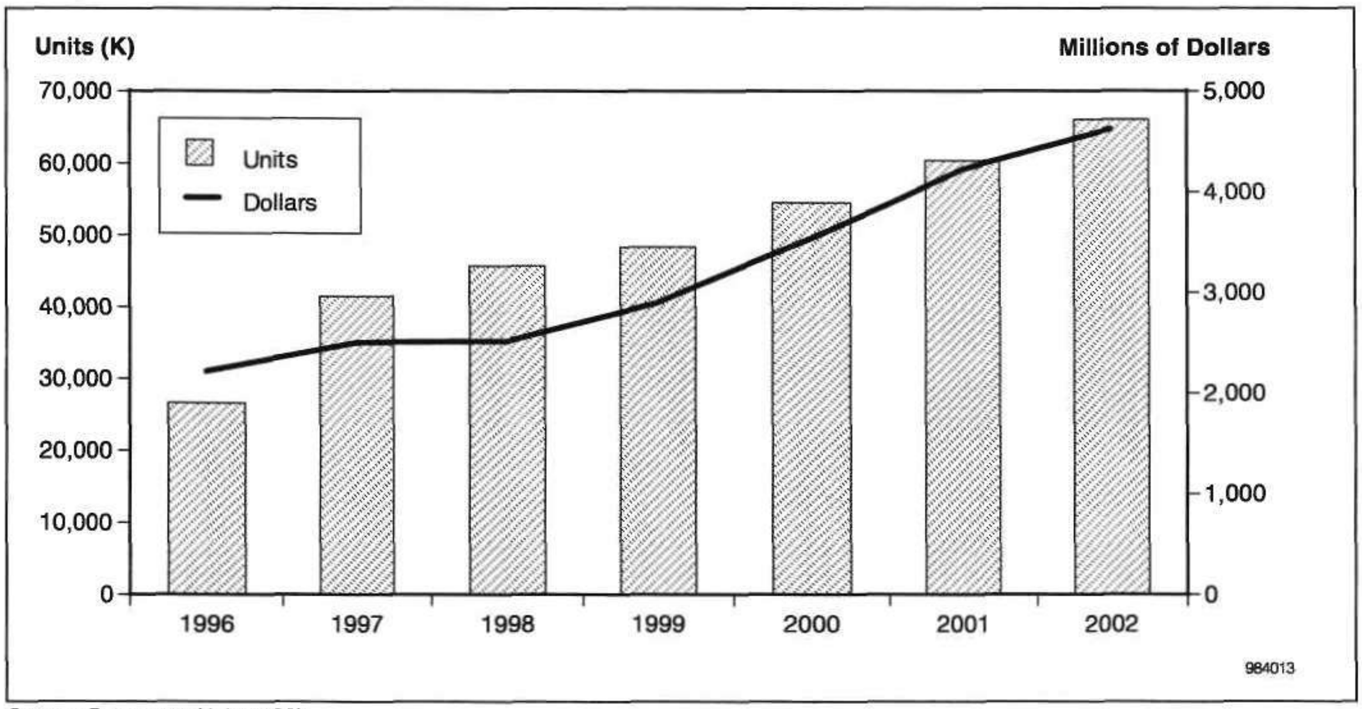
This forecast is predicated on the continued and regular growth of graphics performance as well as the evolution of business software that creates a superior value proposition for 3-D graphics in mainstream business computing. If one of those two requirements fails to materialize, the graphics board ASPs are unlikely to rise because only very attractive pricing will convince buyers to demand new products rather than mature products. In that scenario, any vendor that attempts to maintain pricing on old products will lose business to whichever vendors break from the pack and reduce their prices as manufacturing costs decline.

Table 1
PC Graphics Board Forecast

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Graphics Board Shipments								
2-D+Video Boards (Units K)	19,963	14,496	6,853	2,416	0	0	0	-100
2-D+3-D+Video Boards (Units K)	6,654	26,922	38,831	45,905	54,441	60,339	66,071	20
Total (Units K)	**26,617**	**41,418**	**45,684**	**48,321**	**54,441**	**60,339**	**66,071**	**10**
Deskbound PC Shipments (Units K)	58,062	66,285	75,561	86,393	101,486	117,599	134,760	-
Effective Attach Rate (%)	46	62	60	56	54	51	49	-
Graphics Board Revenue								
2-D+Video Boards ($M)	1,397	507	110	31	-	-	-	-100
2-D+3-D+Video Boards ($M)	820	1,995	2,408	2,869	3,539	4,224	4,625	18
Total ($M)	**2,218**	**2,502**	**2,517**	**2,900**	**3,539**	**4,224**	**4,625**	**13**
Graphics Board ASP								
2-D+Video ($)	70	35	16	13	-	-	-	-100
2-D+Video+3-D ($)	123	74	62	63	65	70	70	-1
ASP ($)	**83**	**60**	**55**	**60**	**65**	**70**	**70**	-

Source: Dataquest (July 1998)

Figure 1
PC Graphics Board Forecast



Source: Dataquest (July 1998)

Upside demand factors include the small probability that three-point AGP will not work at all, the risk that chip-level integration of graphics logic into core logic products and microprocessors will not be compelling, and the possibility that new business applications for 3-D graphics will emerge sooner than Dataquest currently forecasts, spurring a flurry of upgrades and heightened demand for leading-edge 3-D graphics boards.

Audio Add-In Board Vendors Face Challenges

The audio add-in board vendors face several challenges in increasing their revenue. The historical drivers of audio board sales are not keeping pace with the overall PC market, and a host of new chip solutions will make motherboard solutions more attractive.

Audio boards have typically been used in consumer-oriented PCs because that market offers a much clearer value proposition for audio in general, but particularly for advanced audio features and higher quality. Audio boards have shipped in high volume to both PC OEMs as well as retail distribution, either as discrete boards or bundled with other multimedia peripherals such as CD-ROM drives in "multimedia upgrade" kits. Sales of multimedia upgrade kits have declined now that most consumer-targeted PCs include fast CD-ROM drives and advanced audio features. Sales of DVD-ROM upgrade kits may boost overall sales of multimedia upgrade kits, but are not likely to drive sales back to the unit volumes of the early 1900s. The reasons for this are the low prices for new PCs and the difficulty of installing the upgrades. If a consumer buys a new PC, he or she gets a faster processor, bigger hard disk drive, and other benefits without the hassle of installing the multimedia upgrade components or the expense of professional installation.

New chip-level audio products will increase the appeal of motherboard audio implementations. The venerable single-chip ISA-based audio solution will die a slow death as it represents a low-cost but complete solution with proven legacy software compatibility. Core logic products featuring AC-link interfaces will grow in popularity through 1999 and 2000, making mainstream audio features very inexpensive to add to a system as AC-97 codecs will fall below a dollar in cost. Advanced software running on the host CPU or even a DSP shared between audio and modem functions could provide virtually all other requirements, at the opportunity cost of using those hardware resources, whether CPU or shared DSP, for audio functions. In this scenario, audio add-in boards must provide a clear value proposition and will be less likely to appeal to an average PC buyer. The market will slowly make the transition to the higher-value products as low-end products disappear.

Branding will continue to be very important for the audio board market as products move up in the value chain. Retail presence and strength of brand name are critical as the slowing unit growth squeezes the profitability of second- and third-tier vendors.

Audio Board Forecast

Table 2 presents Dataquest's latest audio board forecast. Figure 2 presents the same information graphically.

Table 2
PC Audio Board Forecast

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Audio Board Shipments								
8-Bit (Units K)	97	0	0	0	0	0	0	NA
16-Bit (Units K)	17,261	20,869	21,509	23,587	23,006	23,816	23,945	3
Greater than 16-Bit (Units K)	-	-	40	80	160	320	640	NA
Total (Units K)	**17,358**	**20,869**	**21,549**	**23,667**	**23,166**	**24,136**	**24,585**	**3**
Deskbound PC Shipments (K Units)	58,062	66,285	75,561	86,393	101,486	117,599	134,760	-
Effective Attach Rate (%)	30	31	29	27	23	21	18	-
Audio Board Revenue								
8-Bit ($M)	1.5	0	0	0	0	0	0	NA
16-Bit ($M)	971	925	856	1,004	1,126	1,143	1,101	4
Greater than 16-Bit ($M)	-	-	6	14	32	64	128	NA
Total ($M)	**972**	**925**	**862**	**1,018**	**1,158**	**1,207**	**1,229**	**6**
ASP ($)	**56**	**44**	**40**	**43**	**50**	**50**	**50**	**-**

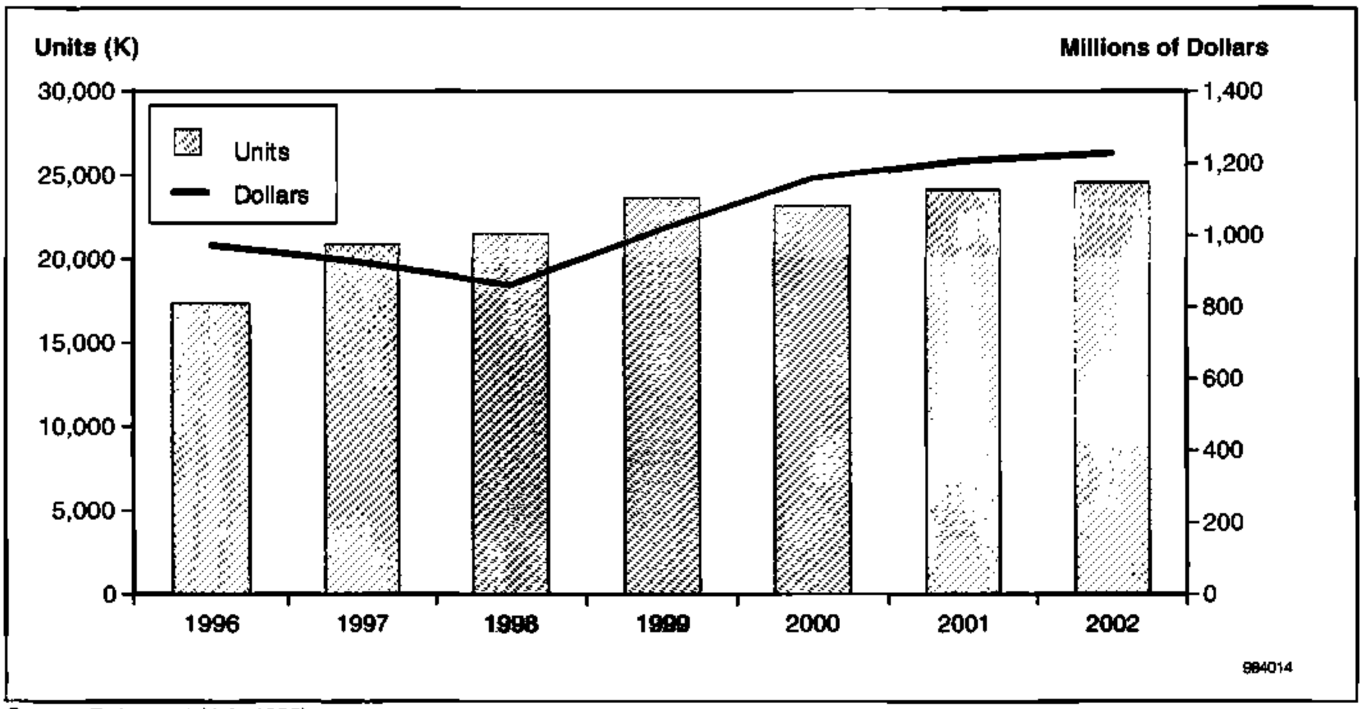
NA = Not applicable
Source: Dataquest (July 1998)

Dataquest Perspective

Vendors of PC graphics and PC audio boards face a challenging time for the next 12 months, but a recovery period is within sight. The markets for add-in boards will emerge from that recovery period with different dynamics and lower long-term opportunity for growth, but will be more profitable than they are today. The low end of the market will be "integrated away" as increasing levels of integration for semiconductor products and efforts by OEMs to reach new, lower PC price points will cause the low-end board market to evaporate.

The new market dynamics impact board vendors as well as semiconductor vendors. Board vendors will need strong brand identity and the ability to deliver boards with the latest graphics and audio chipsets in a timely fashion. Aging board-level products that fall too close to the features and performance of motherboard resources will be tough to sell at any price that recoups direct costs. PC OEMs need to leverage the brand name of the add-in boards to justify the cost of those boards in the system. PC vendors using BTO manufacturing practices will rely on add-in board branding to "upsell" the PC buyer at the time of order. Chip vendors must please two customers, the add-in board vendors and the PC OEMs for motherboard implementations. Chip vendors that cannot compete for motherboard design wins will find it difficult to compete profitably as the list of chip vendors shrinks. Niche markets will continue to exist, but the "Last Chance Saloon" market for low-end chip products on low-end board products will not.

Figure 2
PC Audio Board Forecast



Source: Dataquest (July 1998)

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Perspective

Personal Computer Semiconductors and Applications Worldwide

Market Analysis

The USB Market Begins Not with a Bang, but a Whimper

Abstract: *The Universal Serial Bus has been slow to penetrate the market, but this year's planned release of Windows 98 should finally get the bus rolling.*
By Nathan Brookwood

Waiting for the Bus

For the past 18 months, the computer industry has been standing at the Universal Serial Bus (USB) stop, waiting for a bus that has yet to arrive. Some have begun to question whether it ever will arrive. The Universal Serial Bus peripheral market, which many expected to start with a bang, has instead begun with a whimper. Dataquest anticipates that the pieces that will enable the start of the USB transition are finally falling into place, although momentum will still be slow to build. Peripheral vendors that have successfully avoided USB until now should reassess their strategies. Semiconductor vendors that have added USB to their microcontroller offerings may finally begin to see some return on their investment. System vendors may miss an opportunity to stress "ease of use" if they do not move aggressively to incorporate USB into their product lines for basic peripheral connectivity.

Intel began to include USB hardware support in its PC core logic in 1996, and other chipset vendors soon followed suit. Most personal computers sold over the past 18 months have included USB features. At the end of 1997, the installed base of personal computers able to host USB peripherals stood at more than 58 million units. Sadly, at year's end, there were fewer than 0.5 million USB devices to attach to that installed base, leaving most USB ports on host systems lonely and unoccupied. Sales should increase 20-fold, to 10 million USB devices, in 1998, and fivefold more, to 50 million units in

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1999. Even with this dramatic rate of growth, it will take until 2001 for the industry to sell more devices to plug into USB (195 million) than hosts that can accept multiple USB devices (152 million). The bang that will be heard in 1999, probably through a set of USB-enabled digital speakers, will be that of the USB market finally beginning to explode.

What's All the Fuss About?

The Universal Serial Bus greatly simplifies the problem of connecting inexpensive, low-to-moderate performance peripherals to a personal computer. Current techniques, including the use of one parallel and two serial ports, along with a variety of in-the-box add-in cards, constrain many users, and thus restrain market growth. Those who do not believe Dataquest should just ask any PC user who has tried to install two printers, or a printer and a scanner, on one system.

USB allows users to attach up to 127 devices to a PC in almost any combination. If an application calls for 10 printers and four keyboards, it can have them. Individual devices can be plugged and unplugged from the system dynamically. Some devices, such as keyboards, rarely get used in this manner. Others, such as cameras, personal digital assistants, and some infrequently used peripherals, benefit greatly from this feature. Devices can be cascaded in a hub-and-spoke arrangement, with a maximum of five hubs between the system host (known as the "root hub") and an end point of the network. Connections between hubs, or between a hub and a peripheral, can be up to 5 meters in length; this means that all 127 devices must reside within a radius of 30 meters (about 100 feet).

USB peripherals can transfer data at either 12 million bits per second (that is, a little faster than standard Ethernet) or 1.5 million bits per second. The lower speed permits the use of less expensive interfaces and is used primarily in cost-sensitive devices such as keyboards and mice. Devices that need only limited electrical power (typically less than 2.5W) can obtain this power from the bus and need no additional power supply. This approach reduces the product's materials cost and allows a single version to be shipped anywhere in the world, without regard to the electrical supply characteristics at that destination. It also simplifies many regulatory and safety rating issues that otherwise impede product developers and restrain market growth. Devices that ordinarily attach to external power sources (such as monitors) serve as powered USB hubs and supply current to the bus-powered devices in the configuration.

USB is often compared with, or confused with another emerging serial interface, IEEE 1394, or Firewire. IEEE 1394 provides far greater bandwidth (200 million bits per second, evolving to 400 million and 800 million over time), at far greater cost. USB interfaces add little (if any) incremental cost to a basic peripheral, while IEEE 1394 can add $10 to $20. Dataquest anticipates that both architectures will coexist into the indefinite future. The infrastructure development for IEEE 1394 lags that of USB by 12 to 18 months, pushing serious deployment of IEEE 1394 well into 1999 or the year 2000.

Why USB Failed to Take Off in 1997

Conceptually, few would argue with USB's major goals of simplifying the connection of low-speed peripherals to a computer system and adding a true "plug-and-play" capability to peripheral installation. But they could, and did, argue about the price. Although Macintosh zealots had long pointed to that system's ability to daisy-chain its mouse and keyboard cables using Apple's desktop bus, PC vendors were reluctant to pay a premium for the early USB-enabled keyboards and mice. It was a clear illustration of an existing and adequate solution precluding the emergence of a more elegant, but marginally more expensive, solution. This Dataquest analyst learned long ago that buyers appreciate elegance in product design but refuse to pay any premium for it.

Operating system support, or the lack thereof, also hindered the market's development. USB connectors first appeared on systems in 1996, but Microsoft provided no USB support in Windows 95 until early 1997, with its OEM Service Release (OSR) 2.1, available only on personal computers shipped after that date. Even with the OSR 2.1 release, Windows USB support is still far from complete, but at least now, adventurous users have some limited ability to install early USB devices.

Just as Windows 95 delayed the start of the USB market, Windows 98 should finally jump-start its development. Windows 98 provides complete USB support, including features for streaming video and streaming audio that are needed for cameras and speakers. Microsoft has yet to nail down a specific release date for Windows 98, but most forecasters anticipate that it will arrive toward the middle of the year, if Bill Gates and the Department of Justice can settle their long-term disagreements. Users of Microsoft's Windows NT operating system will have to wait a little longer for USB support; it will not show up until NT 5.0, scheduled for 1999.

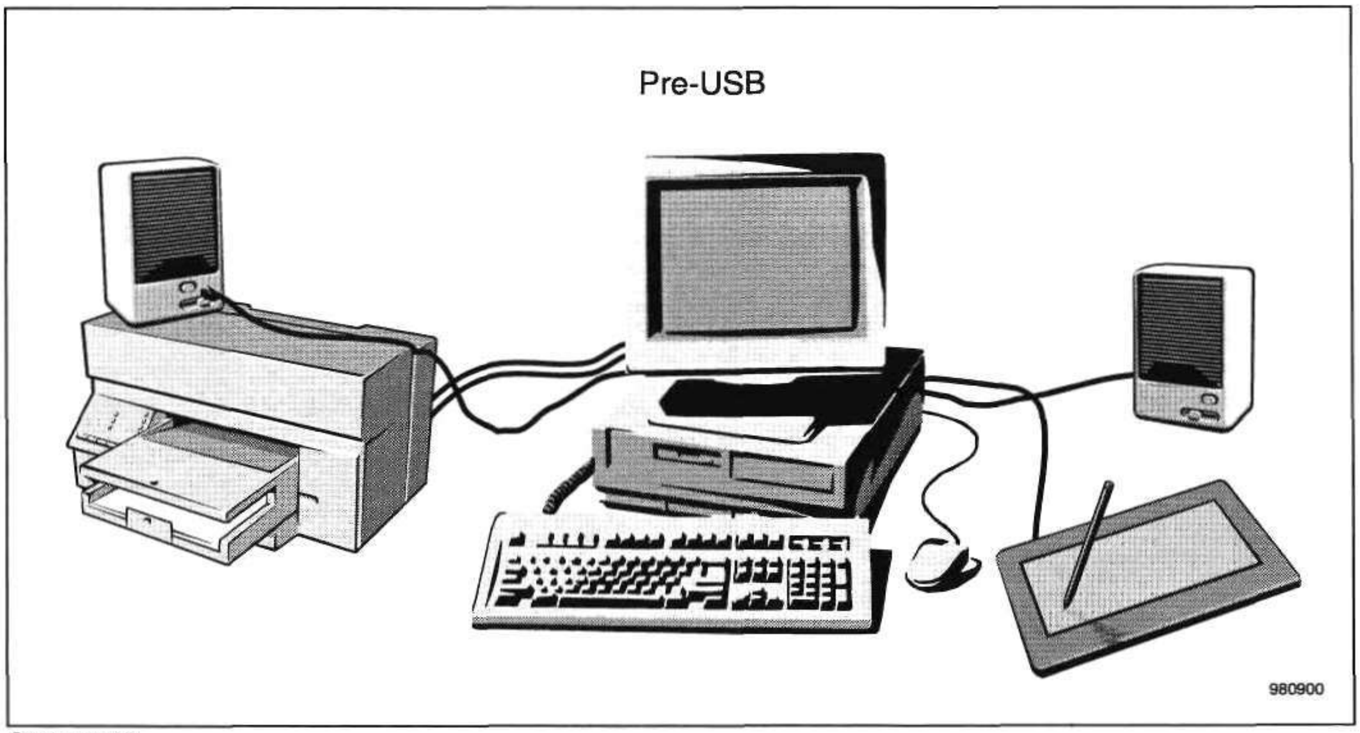
The availability of operating system software would be of little interest if USB peripherals continued to be offered only at premium prices. Here, too, Dataquest expects much progress. Several microcontroller vendors have added USB features to their products at little or no incremental cost, compared with the earlier, non-USB versions. (The added USB value allows them to maintain the average selling price they charged for the version with fewer features.)

Just to ensure that PC vendors get the USB message, Microsoft's PC98 specification requires that no major system component be implemented via an ISA-compatible add-in card. This requirement forces vendors wishing to sport the "Designed for Windows 98" logo on their systems to use either PCI or USB to attach standard peripherals. This provision primarily affects sound cards and modems, the last major categories of ISA peripherals. Change is in the wind.

A Call to Arms

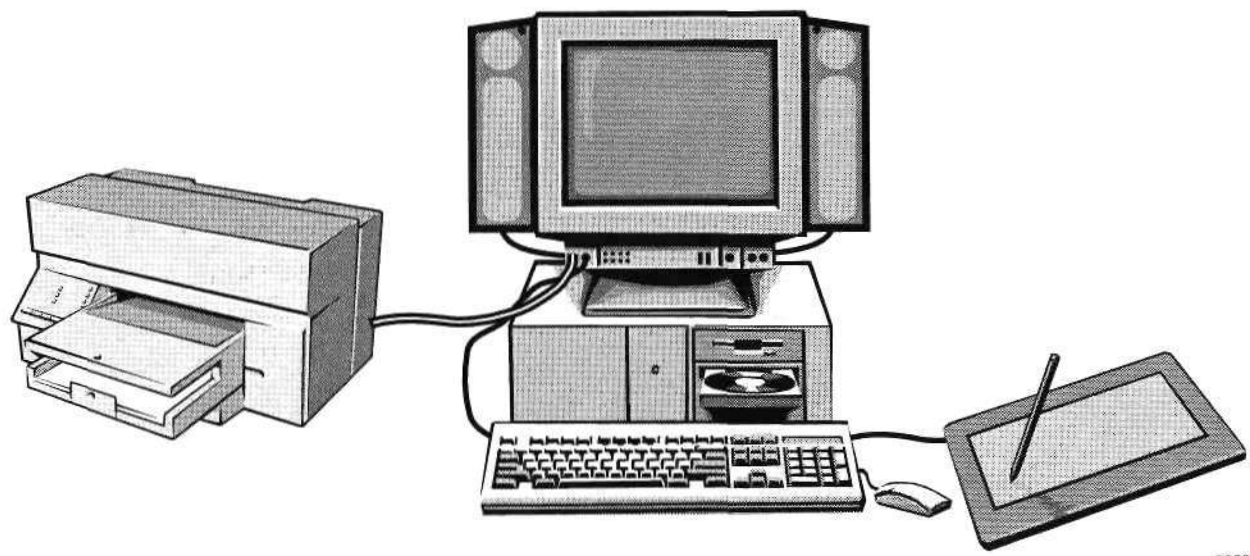
Even with the efforts of Microsoft and Intel, Dataquest expects that most USB ports will remain unoccupied, at least through 1999. Early adopters seek USB only when current interfaces prove inadequate, as is the case for digital cameras, scanners, and high-speed modems. None of these represents vast market opportunities in the near term. Inertia limits the migration of mainstream peripherals. USB makes it easier to connect printers, keyboards, and mice to a computer system and greatly reduces the rat's nests of wires that populate most users' offices, but it does not cause printers to print better, or users to type faster, or mice to point more accurately. Consequently, systems vendors feel little pressure to migrate these basic peripherals from their current attachment mechanisms to USB. Figure 1 illustrates the tangle of wiring found in many offices today. Figure 2 shows how the same equipment can be connected via USB. Dataquest knows of no major system vendor planning to emphasize the "ease of use" aspects of USB by offering USB-connected monitors, keyboards, mice, printers, and speakers. To date, one brave vendor has offered one such configuration for sale in one geographic market. Systems vendors (you know who you are) are letting a potentially valuable marketing opportunity go to waste.

Figure 1
Today's Wiring for PC Peripherals



Source: Intel

Figure 2
Using USB to Attach PC Peripherals



Source: Intel

USB Forecast

Most purchasers of USB peripherals will not be wanting for a place to plug them in; rarely has the market for devices that logically must exist in pairs (or at least in a one-to-many relationship) developed in such a lopsided one-to-few manner. At this point, it is almost impossible to buy from a major vendor a PC *without* USB host connectors. The installed base of USB-enabled personal computers should exceed 136 million units by the end of 1998 and will encompass more than 500 million units by 2001. This forecast addresses only USB devices attached to personal computer hosts. USB will likely extend its reach into embedded markets; just a few weeks before this report was published, Award Software International Inc. announced the availability of USB host software for Wind River real-time embedded operating systems. More announcements are likely.

A typical personal computer today can support two USB peripherals. Unlike the traditional parallel and serial ports, which cannot be easily expanded, USB effortlessly supports up to 127 peripherals. This aspect of the USB design allows users to attach a variety of printers, scanners, and modems to their systems simultaneously, a feat that is extraordinarily cumbersome (and often impossible) with the traditional arrangement. Users wanting to connect more than two devices or wanting to access USB ports without reaching around to the (often inaccessible) back of the computer chassis can attach one or more USB hubs to their systems.

Dataquest expects hubs located in the system display housing to be the most popular, because displays have access to external power sources needed to drive downstream USB peripherals. Some keyboard vendors intend to package hubs within their devices, a somewhat problematic location because keyboards typically draw their power from the system chassis. A third class of USB hubs will be offered on a standalone basis for users that need additional USB ports but do not want to upgrade their keyboards or monitors to add this capability. Table 1 shows Dataquest's forecast.

Dataquest's USB peripheral forecast reflects the market's slow start, stemming from the factors discussed earlier. Even without a major system vendor's sponsorship, the market will begin to grow in 1998, reach respectable proportions in 1999, and finally achieve de facto status in 2000. Display devices dominate the USB forecast into the foreseeable future and will also play a central role as desktop hubs for attachment of other USB peripherals. Audio speakers play a close second, allowing vendors to offer the benefits of vastly improved audio quality, along with easier cabling, at prices comparable to today's analog speakers. Table 2 details Dataquest's estimates for each peripherals category.

USB Peripheral Outlook

USB Monitors

Dataquest expects most monitor vendors to add configurations that include USB hub capability this year. Such displays will continue to require VGA cables for their video signals and will use the USB connection both to adjust the monitor (via applets running on the host) and to provide a desktop locus to which other USB devices can be attached. These capabilities add little incremental cost to the monitor, especially considering that monitors are often the most expensive peripherals in a PC configuration. National Semiconductor Corporation, Philips Electronics N.V., and Multivideo Labs Inc. have already introduced display microcontrollers that integrate USB features. Eventually, monitor suppliers may find it economical to remove the control features and on-screen displays they now provide to allow user adjustments.

Table 1
USB Host and Hub Forecast, 1997 to 2001 (Thousands of Units)

	1997	1998	1999	2000	2001	CAGR (%) 1998-2001
Personal Computers	83,077	97,321	113,330	131,371	151,795	16
USB-Enabled PCs	58,154	77,857	101,997	124,802	151,795	25
USB PCs Installed Base	58,154	136,011	238,008	362,810	514,605	56
Monitor Hubs	294	5,109	15,467	25,812	47,587	110
Keyboard Hubs	0	115	838	1,942	4,487	239
Standalone Hubs	-	973	2,833	6,569	7,590	98

Source: Dataquest (February 1998)

Monitors are ideally situated to serve as USB hubs. They are almost always conveniently located, thus simplifying connection and disconnection of transient USB peripherals such as cameras, and they almost always contain a power supply. Table 3 provides Dataquest's estimate of the rapidly growing market for USB-enabled monitors.

Table 2
USB Peripheral Device Forecast, 1997 to 2001 (Thousands of Units)

Peripheral Category	1997	1998	1999	2000	2001	CAGR (%) 1998-2001
Monitors	392	6,812	20,623	34,415	63,449	110
Keyboards	0	767	5,585	12,945	29,915	239
Mice	0	320	3,697	8,527	18,407	286
Printers	0	271	1,031	2,747	11,031	244
Scanners	47	258	1,349	2,782	3,664	142
Speakers	0	619	12,041	27,876	51,494	337
Video Cameras	3	32	110	319	605	167
Still Cameras	10	538	1,572	2,599	4,375	101
Modems	0	9	225	1,097	3,894	652
Telephony	0	376	3,323	5,141	7,977	177
Total Devices	**452**	**10,001**	**49,557**	**98,449**	**194,810**	**169**

Source: Dataquest (February 1998)

Table 3
USB Monitor Forecast, 1997 to 2001 (Thousands of Units)

	1997	1998	1999	2000	2001	CAGR (%) 1998-2001
Monitors	78,330	90,826	103,115	114,718	126,898	12
USB Penetration (%)	0.5	8	20	30	50	-
USB Devices	392	6,812	20,623	34,415	63,449	110

Source: Dataquest (February 1998)

USB Keyboards and Mice

Keyboards, mice, and printers occupy most of the serial and parallel ports on today's systems and contribute most to the cable clutter on most desktops. Early in the USB development cycle, Dataquest had hoped that USB would remove this clutter, but the past two years have educated us in this regard. Vendors have been reluctant to migrate these peripherals to USB, given that USB offers little incremental benefit to the user in the *operation* (as opposed to the *installation*) of these devices. CMD Technology Inc. and USAR Systems have both introduced USB microcontrollers optimized for keyboard (and keyboard with hub) operation. USAR's device contains a PS/2 mouse controller that allows the end user to plug an inexpensive PS/2-style mouse into the USB keyboard. Eventually, vendors may conclude that they can save $0.50 by omitting the traditional PS/2 keyboard and mouse connectors on host systems, and these USB devices will begin to make inroads. This will be a slow process; it took six years for the industry to migrate from the five-pin

DIN PC AT keyboard connector to the six-pin mini-DIN PS/2 connector, and that transition had fewer software side effects than the shift to USB. Table 4 provides Dataquest's estimate for this market's development; we anticipate that it will be a "late bloomer."

The situation for USB mice is even more problematic, given the lower cost of these peripherals. Some vendors may seek to gain the esthetic advantages USB offers by using a keyboard with a built-in PS/2 mouse connector or with a built-in pointing device, as discussed above. Logitech and Genius already offer premium-priced USB mice. Samsung Semiconductor Inc. and Cypress Semiconductor Corporation both offer inexpensive 8-bit USB microcontrollers that provide a good fit with this low-end application.

USB Printers

Printers, like keyboards and mice, have been slow to adopt USB technology. At this time, no vendor has announced any printer with USB capability. Several manufacturers have tested USB printers at recent industry events focused on cross-platform USB compatibility testing, and Dataquest believes this capability will show up later this year on low-end inkjet and page printers. Special-purpose printers, like those used specifically to print labels, will emerge first, as vendors have struggled for years with the constraint of a single parallel port, often occupied by a general-purpose printer, on most PCs. Table 5 outlines Dataquest's expectations for this market, another "late bloomer."

Although the cost structure of most laser printers could easily adapt to a USB controller in lieu of a parallel port, most vendors in this segment plan to wait for the larger bandwidth available with IEEE 1394 interfaces before they change their products' connectivity. By using IEEE 1394, vendors hope to dramatically reduce the memory required for buffers in today's laser printers and to move most formatting into the host system. (NeXT Inc. tried this approach in 1988, but proprietary interfaces and system CPU performance limitations severely limited its success at that time.)

Table 4
USB Keyboard and Mouse Forecast, 1997 to 2001 (Thousands of Units)

	1997	1998	1999	2000	2001	CAGR (%) 1998-2001
PC Keyboards	81,796	95,935	111,705	129,447	149,576	16
USB Penetration (%)	0	0.8	5.0	10.0	20.0	192
USB Devices	0	767	5,585	12,945	29,915	239
Mice	68,343	79,881	92,436	106,591	122,710	15
USB Penetration (%)	0	0.4	4.0	8.0	15.0	-
USB Devices	0	320	3,697	8,527	18,407	286

Source: Dataquest (February 1998)

Table 5
USB Printer Forecast, 1997 to 2001 (Thousands of Units)

	1997	1998	1999	2000	2001	CAGR (%) 1998-2001
Serial Printers	37,338	42,848	45,414	49,782	51,800	7
USB Penetration (%)	0	0.5	2	5	20	-
USB Devices	0	214	908	2,489	10,360	264
Page/Laser Printers	10,479	11,294	12,292	12,900	13,412	6
USB Penetration (%)	0	0.5	1	2	5	-
USB Devices	0	56	123	258	671	128

Source: Dataquest (February 1998)

USB Scanners

Digital scanner manufacturers plan to aggressively adopt USB connectivity. Hewlett-Packard Company and Logitech (which recently sold its scanner business to Storm Technology Inc.) have already introduced USB products, and others will follow shortly. Unfortunately, the scanner market is modest in size, and thus even high levels of penetration drive only moderate volumes of USB-enabled product, as indicated in Table 6.

USB offers many benefits for scanner manufacturers and users. Current attachment mechanisms that attempt to share the computer's printer port or require an add-in SCSI adapter have proven problematic, leading to low levels of customer satisfaction, along with many product returns. Installation of USB scanners is straightforward and requires no additional hardware.

Some might argue that vendors will sell more scanners once these devices can be installed by mere mortals. Dataquest counters that some organizations will buy fewer scanners and move them from workstation to workstation as needed, once they become easier to connect and disconnect. We anticipate that reality will lie somewhere between these two points.

Table 6
USB Scanner Forecast, 1997 to 2001 (Thousands of Units)

	1997	1998	1999	2000	2001	CAGR (%) 1998-2001
Scanners	4,727	5,165	5,396	5,564	6,107	6
USB Penetration (%)	1	5	25	50	60	-
USB Devices	47	258	1,349	2,782	3,664	142

Source: Dataquest (February 1998)

USB Digital Still Cameras

USB connectivity greatly simplifies the problem of transferring images captured by a digital still camera into a personal computer, and Dataquest expects USB to gain popularity rapidly in this application. The bandwidth available to accomplish image uploading via USB vastly exceeds that which can be obtained using a conventional serial port, and USB's plug-and-play characteristics eliminate many operational problems associated with the use of RS-232 connections. Dataquest's forecast for USB-attached digital cameras is in Table 7.

USB PC Video Cameras

USB enables the construction of low-cost digital video cameras. Most USB video cameras use power supplied by the bus, further simplifying their design and reducing their cost. Eastman Kodak Company's DVC 300, one of the first USB devices to hit the market (in February 1997) typically sells for less than $150. Other vendors, including Intel Corporation, Connectix Corporation, Philips, and Sharp Electronics Corporation have since introduced their own versions. Most fall into the $100-to-$200 price range, and further cost reductions appear likely; at last fall's COMDEX show, VLSI Vision Ltd. demonstrated a digital USB camera that contained just two chips—a CMOS sensor and a microcontroller. Intel sells a non-USB version of its Create and Share camera at $299 and a USB version at $199; to date the USB version has accounted for more than 60 percent of its sales.

Despite the affordability of these devices, sales have been modest. Videoconferencing, the most obvious application for inexpensive digital video cameras, has been slow to gain acceptance. The switched telephone network severely limits frame rates and video image quality, a situation that is unlikely to change until xDSL modems proliferate in the next decade. It takes two to videoconference, further limiting market development until a critical mass of users has these cameras installed. Intel has positioned its Create and Share as an image-capture device, eliminating the need to pair them up to accomplish useful work. Creative marketing approaches like this will be needed to break the chicken-and-egg cycle of seeding the market. Dataquest's most recent forecast for PC video cameras, which drives the USB video camera forecast in Table 8, was prepared before vendors began to emphasize these nonvideoconferencing uses, and it now appears a bit conservative.

Table 7
USB Digital Still Camera Forecast, 1997 to 2001 (Thousands of Units)

	1997	1998	1999	2000	2001	CAGR (%) 1998-2001
Digital Still Cameras	2,089	5,377	6,289	7,426	8,749	18
USB Penetration (%)	0.5	10	25	35	50	-
USB Devices	10	538	1,572	2,599	4,375	101

Source: Dataquest (February 1998)

Table 8
USB PC Video Camera Forecast, 1997 to 2001 (Thousands of Units)

	1997	1998	1999	2000	2001	CAGR (%) 1998-2001
PC Video Cameras	255	319	440	638	1,008	47
USB Penetration (%)	1.0	10	25	50	60	-
USB Devices	3	32	110	319	605	167

Source: Dataquest (February 1998)

USB Computer Telephony Integration

The computer telephony integration (CTI) market provides another major opportunity for USB deployment. Two Canadian-based telephone equipment suppliers, Mitel Corporation and Nortel, have introduced desktop telephone instruments that attach to both a PBX (using normal telephone wiring) and to a personal computer using USB. Such devices permit call logging (for both inbound and outbound calls) and can greatly enhance the user's ability to manage calls on a multiline telephone set and to dial calls from an online directory. The ability of such systems to automatically generate client billing records for telephone-related activities should appeal to many professional services organizations. Dataquest expects such devices to be widely deployed within informal call centers and in small office/home office environments, as described in the document "*Planting Some Stakes—The North American CTI Market*" (VOIC-NA-DP-9702, February 1997). Table 9 shows Dataquest's expectations for this developing market.

Table 9
USB Telephony Forecast, 1997 to 2001 (Thousands of Units)

	1997	1998	1999	2000	2001	CAGR (%) 1998-2001
Computer Telephony Peripherals	268	1,010	5,603	7,188	10,305	117
USB Penetration (%)	0	37	59	72	77	-
USB Devices	-	376	3,323	5,141	7,977	177

Source: Dataquest (February 1998)

USB Modems for Cable and xDSL

The 33.6K and 56K analog modems generally available today seriously limit increased Internet utility for many current users. Many observers look to cable, Asymmetric Digital Subscriber Line (ADSL), and Symmetric Digital Subscriber Line (SDSL) modems as the ultimate solutions to this bandwidth problem. It appears likely that many of these high-speed modems will use USB to connect to the host computer. Indeed, the current approaches used to connect modems to computers cannot be extended into the performance domains of these new communications channels, thus forcing a rethinking of the connectivity issue. The serial ports commonly used as modem attachment channels lack the bandwidth needed for these new high-speed digital interfaces. Consequently, cable and xDSL modems must use the system's ISA, PCI, or USB interfaces. As Microsoft and Intel drive to remove the legacy ISA bus from new PC designs, USB emerges as the most attractive modem interface. Several cable and xDSL modems have been spotted at recent USB "plugfests," and Dataquest anticipates that USB will play a large role in future nonproprietary cable and xDSL modems.

The good news is that USB will make it very easy to hook up a computer to these emerging high-speed links. The bad news is that the availability of these services is likely to remain extremely limited until well into the next decade. Although early users rave about xDSL technology, the local telephone companies that must install the necessary equipment for deployment are still arguing with regulatory agencies about the economics of these services. This debate will continue for a year or two, and during this time, only limited deployment appears likely. Cable modems do not face the same regulatory issues, but other factors will slow their deployment, as well. Consequently, Dataquest sees only limited opportunities for sales of these high-speed devices during the forecast period. Even with a high rate of USB utilization for these devices, their absolute unit shipments remain modest, as Table 10 suggests. (Dataquest regrets that it cannot paint a rosier picture of the situation for improved bandwidth to homes. Even in the high-technology mecca of Silicon Valley, this Dataquest analyst cannot obtain such services in his home, either.)

Table 10
USB High-Speed Modem Forecast, 1997 to 2001 (Thousands of Units)

	1997	1998	1999	2000	2001	CAGR (%) 1998-2001
Cable Modems	210	567	1,191	2,024	2,935	73
ADSL Modems	95	190	570	1,140	2,280	129
SDSL Modems	20	160	490	1,225	2,573	152
Total High-Speed Modems	325	917	2,251	4,389	7,788	104
USB Penetration (%)	0	1	10	25	50	268
USB Devices	0	9	225	1,097	3,894	652

Source: Dataquest (February 1998)

USB Speakers

USB offers the potential for significantly improved audio fidelity in personal computer sound systems. The (electrically) noisy environments within a personal computer chassis greatly limit the analog signal processing needed to generate high-quality audio signals. USB speakers receive audio signals in digital form, and then perform the digital-to-analog (D/A) conversion in the more benign electrical environment within the speaker. Typically, only one speaker in the pair receives its signals in digital form, and it performs the D/A conversion for both audio channels.

Full digital audio over USB requires the use of data streaming, which in turn relies on USB's isochronous transmission feature. Unfortunately, this feature will remain unsupported until Windows 98 arrives later this year. Altec-Lansing Technologies has already introduced a hybrid USB speaker that accepts analog audio signals but uses USB for volume control and fading. Philips, Altec-Lansing, and Labtec Inc. have all announced digital USB speakers, although none expects to ship in any volume before the advent of Windows 98.

Dataquest anticipates that the improved audio quality enabled by USB will make speakers a fertile ground for USB device manufacturers, starting with high-end devices and migrating rapidly to the midrange, as well. These speakers may even find a home in low-end systems, since they eliminate the need for a separate sound card inside the system. Dataquest's speaker forecast in Table 11 examines speakers sold in the aftermarket, along with those bundled into standard configurations.

Table 11
USB Speaker Forecast, 1997 to 2001 (Thousands of Units)

	1997	1998	1999	2000	2001	CAGR (%) 1998-2001
Standalone Speakers	6,002	7,202	8,499	9,773	11,239	16
Bundled Speakers	29,077	34,062	39,666	45,980	53,128	16
Total Speakers	35,079	41,264	48,165	55,753	64,367	16
USB Penetration (%)	0	2	25	50	80	-
USB Ports	0	619	12,041	27,876	51,494	337

Source: Dataquest (February 1998)

What's a Microcontroller Vendor to Do?

The arrival of the USB bus will not toll the death of the traditional serial and parallel ports used to attach peripherals to systems, but it will pressure users of microcontrollers to revisit and update their product lines. Some designers may choose to add a separate USB controller to an existing design, but cost considerations will force most to seek newer microcontrollers that can handle USB along with the more traditional I/O interfaces.

Vendors must first decide whether they want to pursue high-volume USB applications, which typically require extremely specialized and cost-optimized solutions, or general-purpose devices that can be targeted at a variety of niche applications. In this regard, USB microcontrollers differ little from earlier technology integration opportunities that have confronted microcontroller suppliers.

Intel, NetChip Technology Inc., Texas Instruments Inc., Mitsubishi Corporation, Samsung Semiconductor, Motorola, Cypress Semiconductor, and Lucent Technologies all have added (or at least announced plans to add) USB capability to their general-purpose microcontrollers. Dataquest expects to see these devices appear in a wide variety of printers, scanners, cameras, modems, and telephones.

Others are pursuing more specialized devices. National Semiconductor, Philips, and Multivideo Labs Inc. have already introduced display microcontrollers that integrate USB features. CMD Technology Inc., and USAR Systems both offer USB microcontrollers optimized for keyboard (and keyboard with hub) operation.

As the market moves to USB, opportunities will open up for a variety of gateway and bridge devices. Legacy systems lacking chipset support for USB will require PCI add-in cards with PCI-to-USB bridges, like the ones provided by CMD. Some users will seek USB-to-serial and USB-to-parallel interfaces that allow them to attach existing peripherals to a USB network.

Vendors of core logic for personal computers and embedded systems will want to consider adding USB host support to their products. They should not underestimate the software implications of such a move, which are substantial. Award Software has focused much of its embedded marketing efforts toward this objective.

Application-specific IC (ASIC) and system-on-a-chip suppliers must also provide USB capability in their support libraries. At least two design companies, Innovative Semiconductors Inc. and Sand Microelectronics, now offer synthesizable USB cores for use in ASICs. Many other ASIC suppliers, including NEC Electronics Inc., CAE Technology, Virtual Chips Inc., LSI Logic Corporation, and Oki Semiconductor, include USB cores within their design libraries.

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Perspective

Personal Computer Semiconductors and Applications Worldwide

Market Analysis

First Quarter 1998 Financial Results Forebode a Continued Revenue Malaise in the PC Semiconductor Market

Abstract: *Financial results for the first calendar quarter of 1998 confirm what many in the industry already knew: that revenue growth is scarce in the semiconductor business these days. Inventories are up at component suppliers but are down at PC OEMs. These conditions will dominate the next two quarters in the PC semiconductor market, with little visibility into the fourth quarter of 1998.*

By Geoff Ballew

Introduction

The PC system and PC semiconductor markets are tough businesses these days, but the industry is weathering the storm reasonably well. Revenue growth is scarce, and, of the three industry segments tracked for this Perspective, microprocessors, PC peripherals, and PC systems, only the systems group posted revenue growth on a year-to-year comparison of the first quarter of 1998. The most positive comment that can be made is that chip vendors have kept their inventories under control. That control shows good management at a time when the biggest OEMs are adopting manufacturing practices that minimize inventory, pushing greater risk onto the component suppliers. Table 1 shows selected financial data from a variety of PC-related vendors, grouped by general product categories. Figure 1 shows the subtotal net sales, gross margin, and days of inventory data. The results for each major group in Table 1 are discussed in the section titled "Microprocessor Group." Figure 2 shows the gross margin data by group, and Figure 3 shows the inventory data by group.

Dataquest

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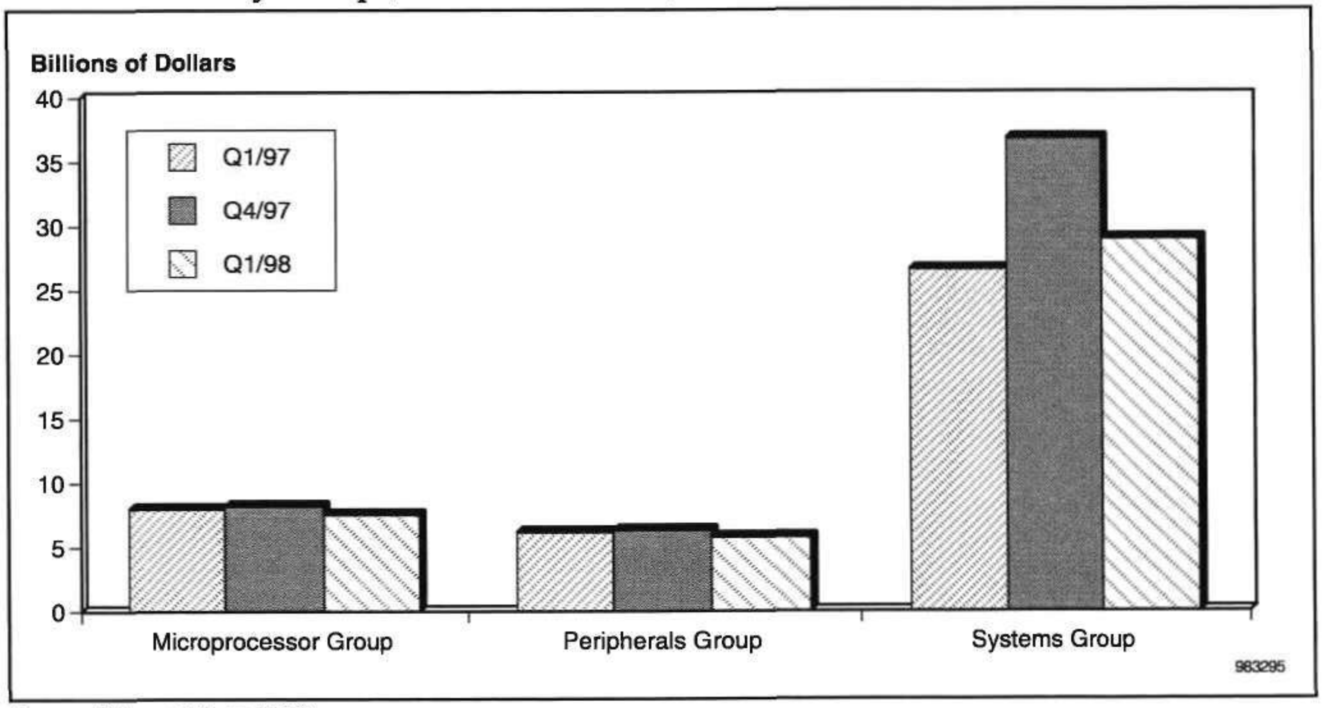
Table 1
First Quarter Financial Results of Key PC Semiconductor and PC System Vendors (Thousands of Dollars)

Category/ Company Name	Ticker Symbol	Fiscal Year End	Net Sales Q1/97	Net Sales Q4/97	Net Sales Q1/98	Growth (%) Q1/97-Q1/98	Growth (%) Q4/97-Q1/98	Gross Margin (%) Q1/97	Gross Margin (%) Q4/97	Gross Margin (%) Q1/98	Days of Inventory Q1/97	Days of Inventory Q4/97	Days of Inventory Q1/98
Microprocessors													
Advanced Micro Devices Inc.	AMD	31-Dec	551,999	613,171	540,856	-2	-12	37	30	22	39	36	34
Intel Corporation	INTC	31-Dec	6,488,000	6,507,000	6,001,000	-8	-8	64	59	54	54	57	60
SGS-Thomson Microelectronics	STM	31-Dec	940,500	1,084,400	998,300	6	-8	38	40	39	81	81	93
Subtotal			**7,980,499**	**8,204,571**	**7,540,156**	**-6**	**-8**	**59**	**54**	**50**	**57**	**59**	**62**
Peripherals													
3Com Corporation		31-May	1,462,891	1,220,253	1,250,191	-15	2	50	47	43	52	88	98
Adaptec	ADPT	31-Mar	265,240	254,163	203,600	-23	-20	58	63	59	44	59	77
ATI Technologies	ATY.TO	30-Nov	110,354	265,938	199,584	81	-25	31	36	38	54	37	65
Cirrus Logic	CRUS	30-Mar	212,900	240,843	287,844	35	20	23	39	30	71	62	46
ESS Technologies	ESST	31-Dec	81,468	70,735	52,876	-35	-25	49	-3	7	75	62	81
LSI Logic Corporation	LSI	31-Dec	308,388	323,036	324,850	5	1	47	45	44	45	52	49
National Semiconductor	NSM	31-May	680,500	719,900	650,000	-4	-10	38	39	36	52	51	65
Oak Technology	OAKT	30-Jun	50,634	49,353	35,550	-30	-28	55	53	41	51	48	39
Rockwell Semiconductor Systems	ROK	30-Sep	369,000	414,000	315,000	-15	-24	NA	NA	NA	NA	NA	NA
S3 Inc.	SIII	31-Dec	138,166	101,911	82,507	-40	-19	42	38	19	60	102	51
Texas Instruments Inc.	TXN	31-Dec	2,263,000	2,428,000	2,187,000	-3	-10	35	39	31	39	46	46
Trident Microsystems	TRID	30-Jun	46,500	26,939	28,249	-39	5	38	31	34	32	109	91
VLSI Technology	VLSI	31-Dec	177,684	193,017	141,286	-20	-27	43	45	41	51	45	57
Subtotal			**6,166,725**	**6,308,088**	**5,758,537**	**-7**	**-9**	**39**	**39**	**34**	**47**	**57**	**62**
Systems													
Compaq Computer Corporation	CPQ	31-Dec	5,272,000	7,323,000	5,687,000	8	-22	22	28	18	37	27	24
Dell Computer Corporation	DELL	31-Jan	2,588,000	3,737,000	3,920,000	51	5	22	22	22	12	7	8
Gateway 2000 Inc.	GTW	31-Dec	1,420,000	1,976,835	1,727,927	22	-13	19	18	19	25	14	12
IBM	IBM	31-Dec	17,308,000	23,723,000	17,618,000	2	-26	0	0	0			
Subtotal			**26,588,000**	**36,759,835**	**28,952,927**	**9**	**-21**	**8**	**9**	**8**	**28**	**19**	**17**

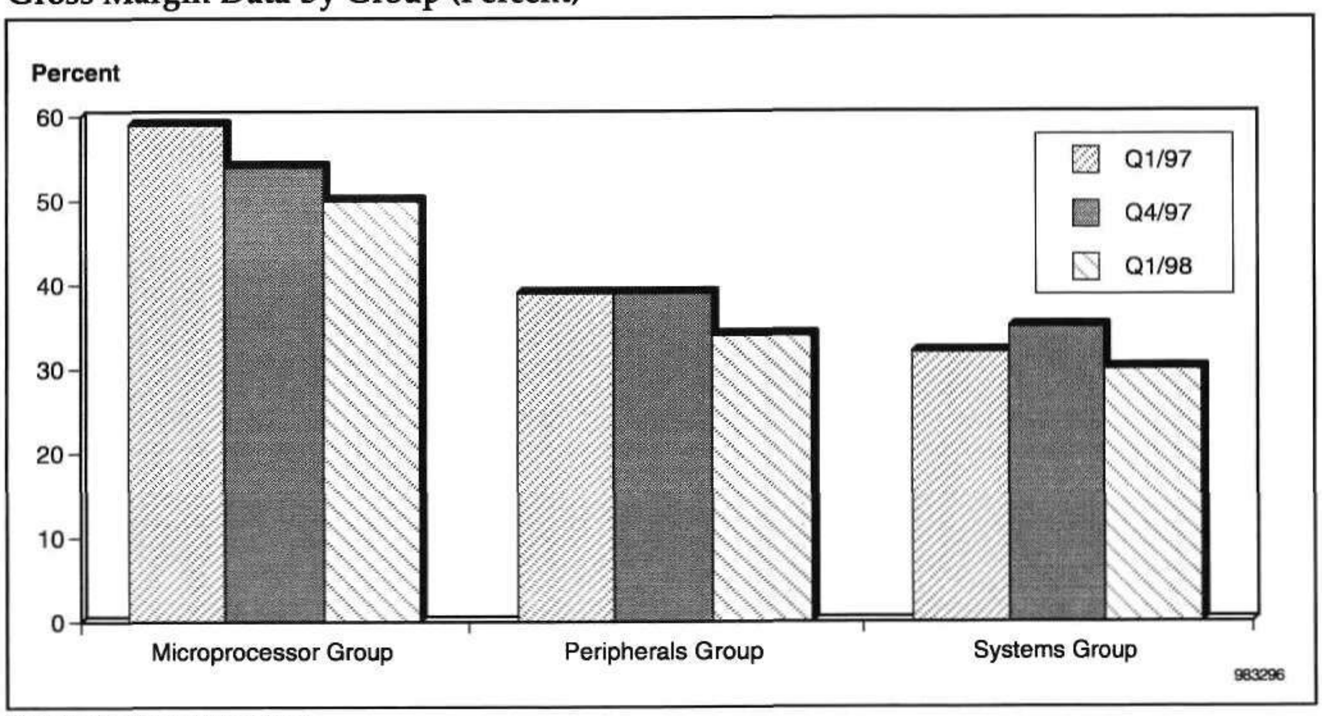
NA = Not available
Note: Days of inventory calculations for the systems group exclude IBM.
Source: Dataquest (June 1998)

Figure 1
Net Sales Data by Group (Billions of Dollars)



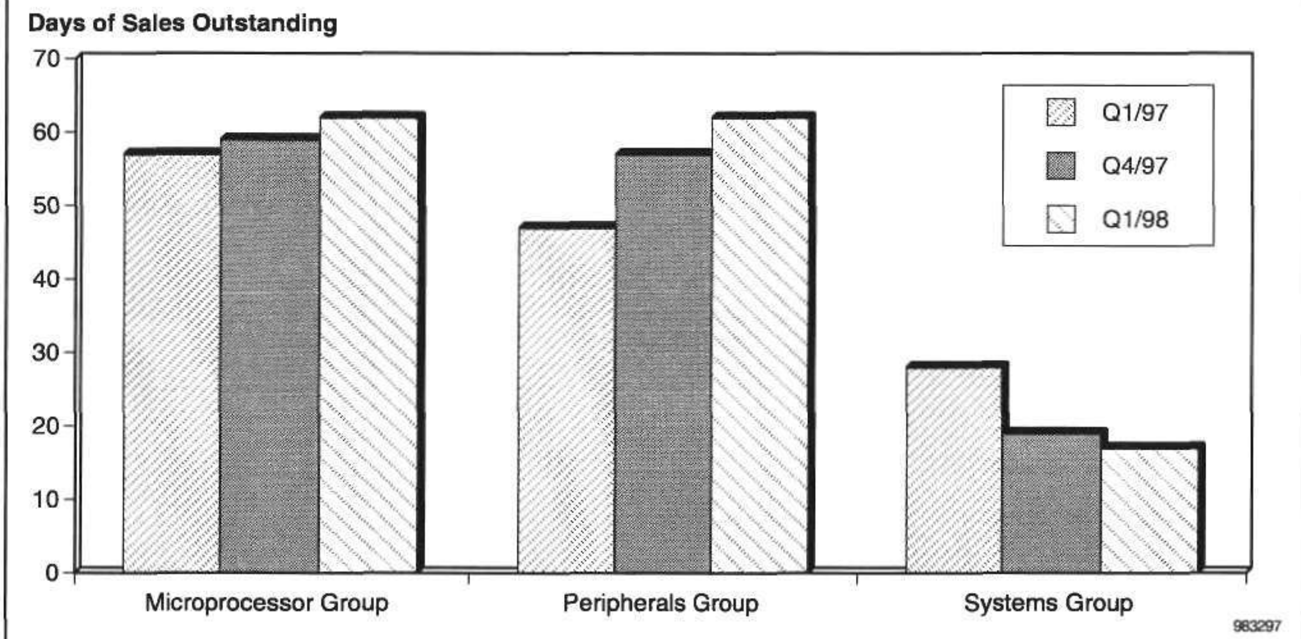
Source: Dataquest (June 1998)

Figure 2
Gross Margin Data by Group (Percent)



Source: Dataquest (June 1998)

Figure 3
Inventory Data by Group (Days of Sales Outstanding)



Source: Dataquest (June 1998)

Microprocessor Group

The end of an era has arrived as Intel faces greater obstacles to revenue growth than it has in the past. After years of successfully raising average selling prices (ASPs) for its microprocessors, the microprocessor giant finds itself staring at a flat revenue future. Revenue was down 8 percent for Intel despite higher unit shipments for a 1997-to-1998 comparison of first quarter results, largely because of market conditions rather than competitive threats.

Competition is a real issue, though, as AMD appears to have solved its manufacturing problems and prepares to bring its 3-D-enhanced K6 processor to market. AMD has its own Fab 25 as well as a manufacturing agreement with IBM, so capacity constraints should not be a limiting factor for AMD's microprocessor business.

Though it is not listed on Table 1, Integrated Device Technology Inc. is well positioned for low-end or pseudo-embedded microprocessor markets because it has an unusually small die. A small die brings obvious cost benefits and helps to differentiate this underdog in the x86 market.

Peripherals Group

The PC peripherals market faces continued price pressure that seriously dampens the prospects of revenue growth relative to last year. This is evident in the decline in gross margin. The gross margin fell 5 percentage points for the peripherals group overall and was down for nine of the 12 companies tracked compared to the first quarter of 1997.

Inventories are up in terms of days of sales, and revenue is down. Unit shipments continue to grow as PC unit shipments grow, of course, but inventory management is essential through this period as early reports of second quarter 1998 results indicate some inventory build-up in the distribution channel. Some vendors whose inventories are uncomfortably high are 3Com, Adaptec, ATI Technologies, National Semiconductor, and Trident Microsystems. S3 Inc. stands out for its success in cutting its inventory down to only 51 days of sales outstanding from 102 days at the end of fourth quarter 1997.

Systems Group

The systems group fared better than either the microprocessor or peripherals group, but the group's results are strongly colored by the sample set. The top-tier vendors in the PC market are performing better than the industry overall. The data set for this analysis includes only top-tier vendors and therefore overstates the health of the industry.

There is good news, however, as the top vendors did register growth in revenue for the first quarter of 1998 compared to the same quarter of 1997. Dell grew a whopping 51 percent year to year and even succeeded in growing revenue from fourth quarter 1997 to first quarter 1998. The fourth quarter 1997 boost was more evident in other vendors' results as sequential quarterly revenue declined for everyone except Dell.

Inventories are much lower, largely because of the changing manufacturing strategies of Compaq and the ongoing build-to-order practices of direct PC retailers Dell, and Gateway 2000 Computer Corporation Inc. Dataquest forecasts revenue growth, but the growth rate will not match unit shipment growth rates. Gross margin was steady for Dell and Gateway, which is a positive sign, but those margins hover around 20 percent, with Dell above that mark and Gateway below. Superb inventory and manufacturing logistics management is necessary to avoid production hiccups with such slim inventories and margins. Compaq's gross margin was down considerably compared to first quarter 1997 as the PC giant focused more on market share than profits. Compaq has advised investors to expect second quarter 1998 results similar to first quarter 1998 in terms of profitability.

Dataquest Perspective

Peripheral vendors face increasing levels of competition because of the many paths of integration. The looming issues of software modem, modem on audio, and peripheral integration into core logic chipsets force peripheral vendors to justify every dollar of costs against low-end solutions that are virtually free. Does the PC buyer get leading-edge performance from free peripherals? No, but in many cases the PC buyer is not demanding leading-edge performance.

Peripheral vendors must define products that are inexpensive to manufacture if they are to compete profitably through the next couple of product cycles. Pressure on PC system ASPs flows directly to the peripheral vendors because of the slim inventories of system OEMs and the fact that the hardware/software spiral is out of balance. For today's mainstream software, Windows 95 and Office 95/97, most PC peripherals are "good enough," "big enough," and "fast enough," which are all frightening phrases in the computing industry. The current levels of stagnation in demand for performance challenge peripheral chip vendors just as they challenge microprocessor vendors to define new products that can be sold profitably at lower-than-historical price points.

The bottom line for component vendors is to segment the market with two families of products, one engineered for low cost and another engineered for feature growth at traditional price points. The product engineered for low cost must be competitive on a value basis with "soft" products that are added to a system for "almost free" as well as products integrated into the core logic chipset. Hybrid solutions that combine hardware acceleration with assistance from the host CPU will be compelling in this market. Traditional products that grow in features and performance and compete for benchmark scores are important too and will be necessary for component vendors competing in the top half of the PC market.

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Perspective

Personal Computer Semiconductors and Applications Worldwide

Market Analysis

PC Revenue to Fall Short of Unit Growth

Abstract: *The impact of lower PC prices will be both positive and negative. PCs are more affordable than ever, but achieving revenue growth will prove tougher for the industry than increasing unit shipments. This document provides the latest PC and advanced desktop forecast, with specific advice for PC semiconductor vendors, and highlights the magnitude of the changes from the previous forecasts.*
By Geoff Ballew

PC Revenue Forecast Lowered (Again)

Dataquest has lowered the PC revenue forecast again for April 1998. This follows a similar reduction in revenue expectations for the fall 1997 forecast over spring 1997. Unit growth remains strong through the forecast period, however, even though the newest forecast shows lower unit shipment expectations. Lower average selling prices (ASPs) are responsible for both the lower revenue expected and the market's ability to sustain unit growth percentages in the mid teens. Table 1 shows the new PC forecast and highlights the changes from the previous forecast. Figure 1 shows the PC unit and revenue forecasts graphically.

Dataquest

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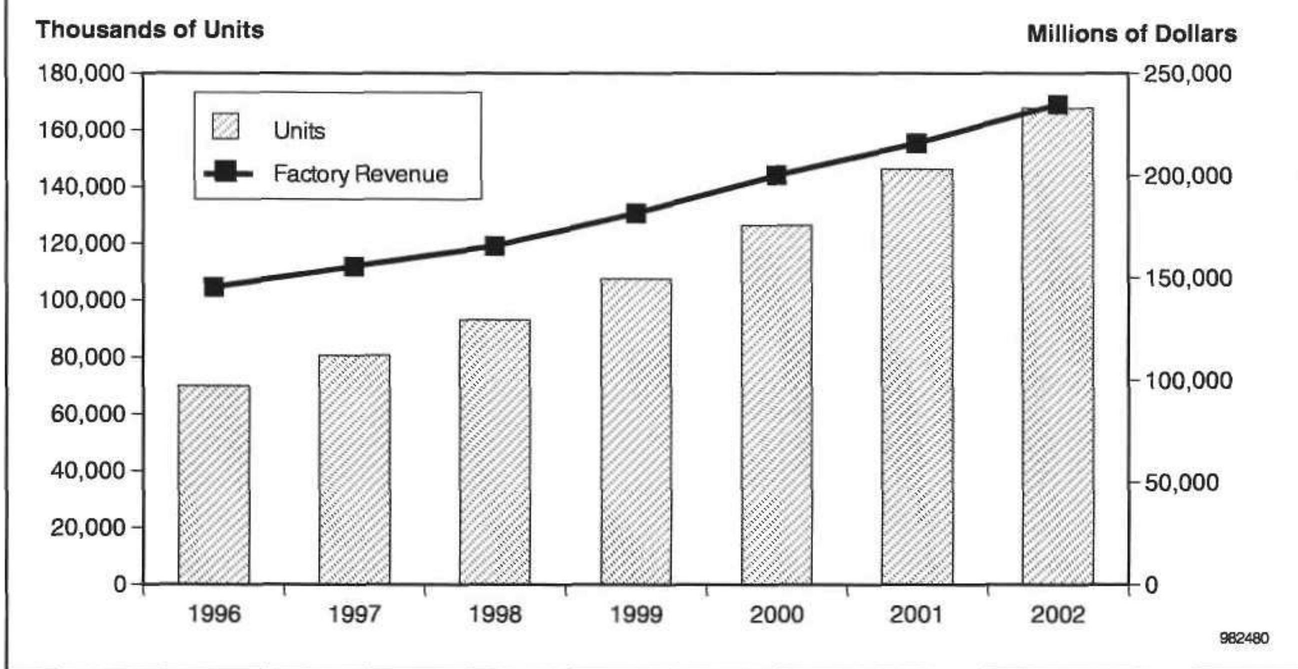
Table 1
Worldwide PC Unit Shipment, Average Selling Price, and Revenue Forecast

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Spring 1998 Forecast								
Units (K)	69,870	80,589	93,145	107,657	126,525	146,185	167,685	15.8
Unit Growth (%)	17.8	15.3	15.6	15.6	17.5	15.5	14.7	NA
ASP ($K)	2.08	1.93	1.78	1.69	1.58	1.48	1.40	-6
Factory Revenue ($M)	145,324	155,541	165,600	181,610	200,185	215,738	234,801	8.6
Revenue Growth (%)	21.0	7.0	6.5	9.7	10.2	7.8	8.8	NA
Fall 1997 Forecast								
Units (K)	70,870	83,077	97,321	113,330	131,371	151,795	-	-
Factory Revenue ($M)	150,149	165,190	186,851	215,612	243,211	277,821	-	-
Changes								
Units (K)	-1,000	-2,488	-4,176	-5,673	-4,846	-5,610	NA	NA
Percentage Change	-1.4	-3.0	-4.3	-5.0	-3.7	-3.7	NA	NA
Revenue ($M)	-4,825	-9,649	-21,251	-34,002	-43,026	-62,083	NA	NA
Percentage Change	-3.2	-5.8	-11.4	-15.8	-17.7	-22.3	NA	NA

NA = Not applicable
Source: Dataquest (May 1998)

Figure 1
Worldwide PC Unit Shipment and Revenue Forecast



Source: Dataquest (May 1998)

The forecast for advanced desktops, also known as workstations, increased for both unit shipments and revenue, in contrast to the decreases in the PC forecast. Table 2 shows the advanced desktop forecast and highlights the unit forecast changes for both traditional workstations and PC workstations. The higher unit shipments for PC workstations in part offset the declines in the PC forecast because some units were shifted from the "PC" category to "PC workstation" category. This shift added to the ASP declines of the PC market because those units carry prices higher than the average in the PC category. Shifting units from the PC forecast to the advanced desktop forecast also lowers the advanced desktop ASP because PC workstations sell for less money than the average traditional RISC workstation. Some units were also moved from the advanced desktops category to the servers category, and that caused the restatement of the 1995 and 1996 historical numbers as shown in the table. Figure 2 shows PC workstation and traditional workstation revenue and shipments.

Impact of the Sub-$1,000 PC and Intel's Celeron Family

The concept of the segment 0, or sub-$1,000, PC continues to generate intense discussion. The emergence of viable systems priced at or below $1,000 has worked to decrease PC ASPs. It has also challenged PC OEMs to define products in higher price categories that are attractive compared to the low-cost offerings. A rhetorical question: How much more powerful does a $3,000 PC need to be to justify its purchase instead of an $800 PC? The answer may lie in more rigorous segmentation of the PC product spectrum. Taking a page from Intel Corporation's move to segment the microprocessor market, where there has been little segmentation, one might conclude that PC OEMs should endorse bolder distinctions between medium-price and low-price systems. PC servers and PC workstations are already differentiated by the requirements of the end markets for those systems. Over the past year, the difference between the $1,500 desktop and the $800 desktop has been little more than timing. In other words, last year's $1,500 system is today's $800 system, with relatively few changes. This represents a perpetuation of the megahertz marketing model and will make it difficult for vendors to differentiate their products except by price. That scenario makes profit in the sub-$1,000 category hard to achieve. Differentiation through innovative design and the introduction of unique new models at or below $1,000 is the key opportunity for profitable sales at segment 0 prices. Dataquest believes new segments of the market will emerge, including a basic, easily managed PC that is replaced frequently, dubbed by Dataquest a "Model T" PC, a new type of mobile PC known as a companion notebook, and a consumer platform PC that is both digital media-centric and broadcast media-centric and more suitable for the living room than the home office.

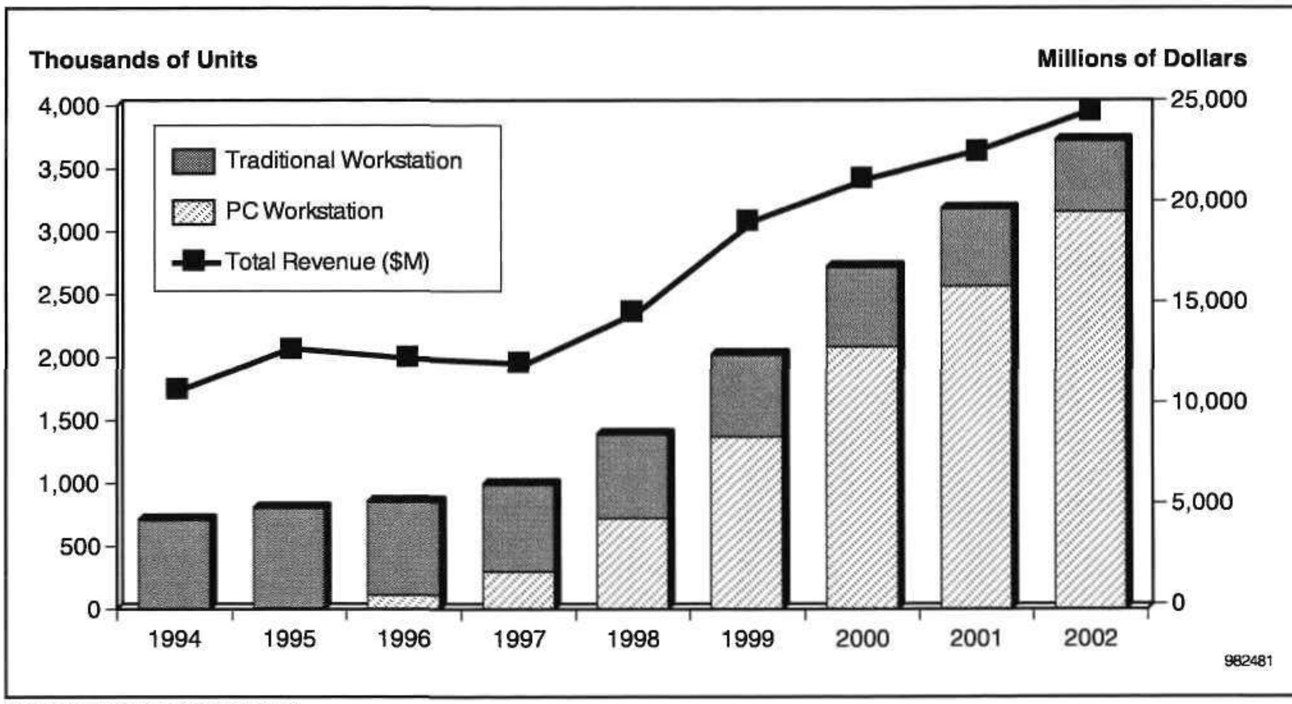
The current low prices for PCs have had very positive effects on the household penetration rate for PCs in the United States. Recent Dataquest surveys of U.S. households indicate that PC ownership is up across all income and education levels. Having a home PC is no longer the privilege of the working professional; it is becoming accessible and affordable to a broader array of households.

Table 2
Worldwide Workstation Unit Shipment, Average Selling Price, and Revenue Forecast

	1994	1995	1996	1997	1998	1999	2000	2001	2002*	CAGR (%) 1997-2002
Total Advanced Desktop Units	709,008	804,134	854,117	991,084	1,389,979	2,021,487	2,717,654	3,180,021	3,721,053	30.3
Total Advanced Desktop ASP ($K)	15.12	15.88	14.39	12.38	10.43	8.87	7.71	7.11	6.55	-12.0
Total Advanced Desktop Revenue ($M)	10,717.2	12,770.3	12,291.1	12,268.0	14,494.6	17,927.7	20,950.2	22,595.2	24,369.4	14.7
PC Workstation Units	0	10,537	115,429	301,100	722,640	1,373,016	2,086,984	2,566,991	3,157,400	60.0
PC Workstation ASP ($K)	0	11.27	6.39	6.47	6.61	6.33	5.91	5.65	5.40	-3.6
PC Workstation Revenue ($M)	0	118.8	738.1	1,948.6	4,774.0	8,688.7	12,338.0	14,497.2	17,034.3	54.3
Traditional Workstation Units	709,008	793,597	738,688	689,984	667,339	648,471	630,670	613,030	563,653	-4.0
Traditional Workstation ASP ($K)	15.12	15.94	15.64	14.96	14.57	14.25	13.66	13.21	13.01	-2.7
Traditional Workstation Revenue ($M)	10,717.2	12,651.5	11,553.0	10,319.4	9,720.6	9,239.0	8,612.2	8,098.0	7,335.1	-6.6
Changes from June 1997 Forecast										
PC Workstation Units	0	0	-2,551	40,000	135,165	344,935	544,862	716,445	NA	NA
Traditional Workstation Units	0	-47,753	-14,419	-68,812	-87,139	-102,385	-117,288	-131,308	NA	NA
Net Change in Units	0	-47,753	-16,970	-28,812	48,026	242,550	427,574	585,137	NA	NA

*The 2002 forecast and five-year CAGR shown in this table are not Dataquest's official advanced desktop forecast. The data was derived by applying the 2000-to-2001 growth rate to the 2001 forecast.
Source: Dataquest (May 1998)

Figure 2
Worldwide Workstation Unit and Revenue Forecast



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Dataquest Perspective

PC pricing has undergone a fundamental change. The sub-$1,000 PC is here to stay, and new, lower price points are bound to be met. This helps set the stage for convergence with digital consumer products and services, such as digital set-top boxes and interactive, digital television broadcasts.

The lack of segmentation between medium-price and low-price systems is changing. Intel's introduction of its Celeron processor family, a Pentium II in low-cost wrapping, is a major step toward significant differentiation at the semiconductor level for segment 0 PCs. Dataquest advises other semiconductor vendors to follow suit and introduce products tailored to the segment 0 PC market and the consumer/convergence market. These products must balance different trade-offs from those faced by more expensive, but still mainstream, PC designs. Savvy chip vendors will seize the market opportunities of both segments.

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Perspective

Personal Computer Semiconductors and Applications Worldwide

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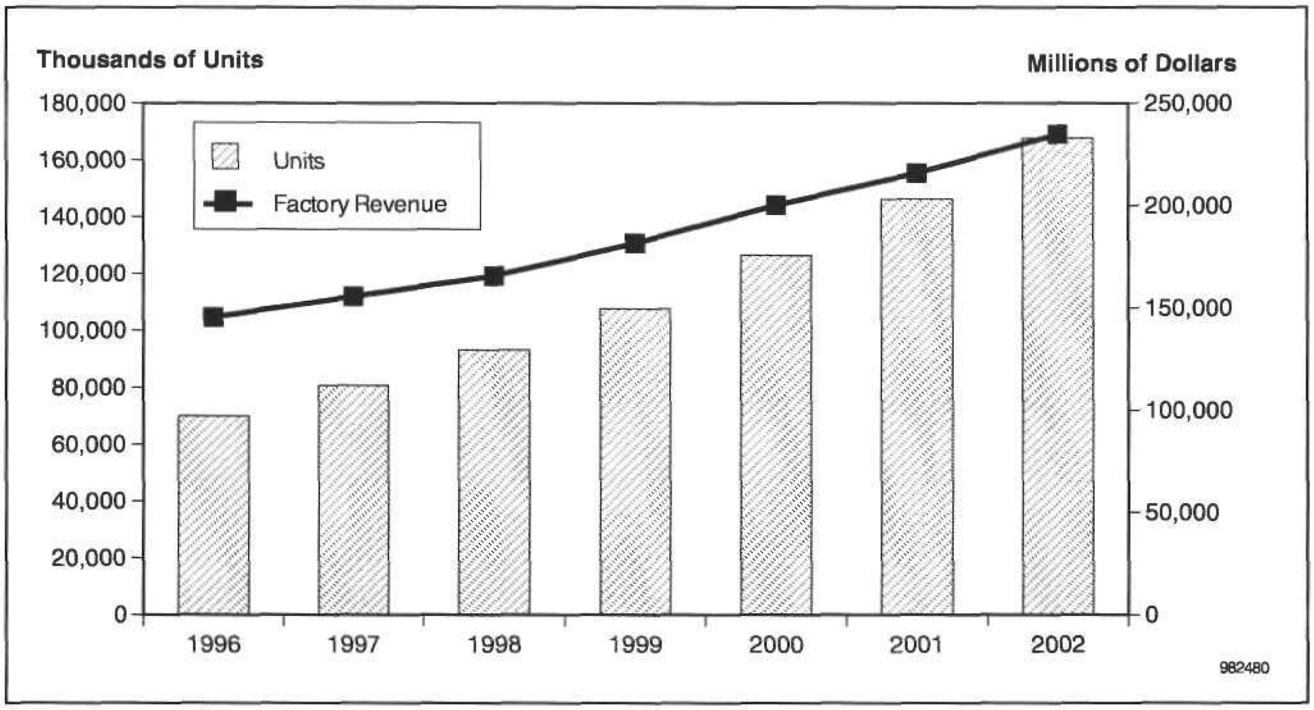

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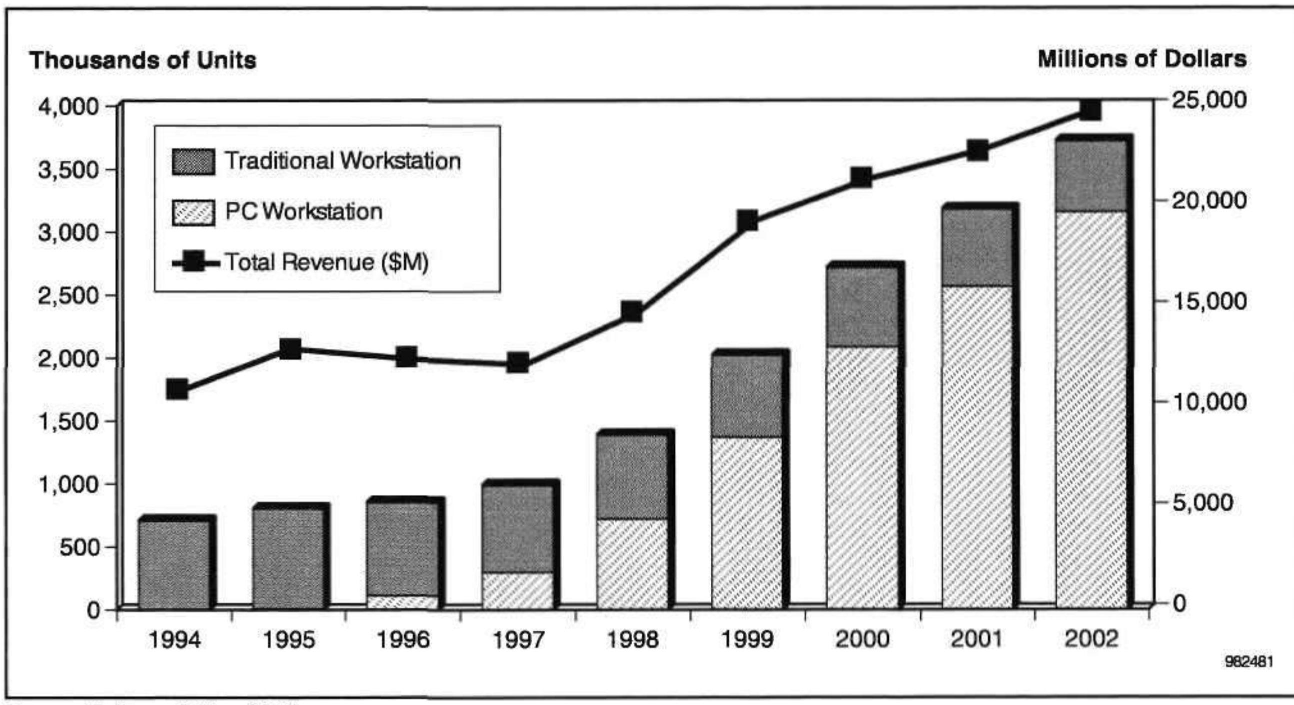
Total Advanced Desktop ASP ($K)	15.12	15.88	14.39	12.38	10.43	8.87	7.71	7.11	6.55	-12.0
Total Advanced Desktop Revenue ($M)	10,717.2	12,770.3	12,291.1	12,268.0	14,494.6	17,927.7	20,950.2	22,595.2	24,369.4	14.7
PC Workstation Units	0	10,537	115,429	301,100	722,640	1,373,016	2,086,984	2,566,991	3,157,400	60.0
PC Workstation ASP ($K)	0	11.27	6.39	6.47	6.61	6.33	5.91	5.65	5.40	-3.6
PC Workstation Revenue ($M)	0	118.8	738.1	1,948.6	4,774.0	8,688.7	12,338.0	14,497.2	17,034.3	54.3
Traditional Workstation Units	709,008	793,597	738,688	689,984	667,339	648,471	630,670	613,030	563,653	-4.0
Traditional Workstation ASP ($K)	15.12	15.94	15.64	14.96	14.57	14.25	13.66	13.21	13.01	-2.7
Traditional Workstation Revenue ($M)	10,717.2	12,651.5	11,553.0	10,319.4	9,720.6	9,239.0	8,612.2	8,098.0	7,335.1	-6.6
Changes from June 1997 Forecast										
PC Workstation Units	0	0	-2,551	40,000	135,165	344,935	544,862	716,445	NA	NA
Traditional Workstation Units	0	-47,753	-14,419	-68,812	-87,139	-102,385	-117,288	-131,308	NA	NA
Net Change in Units	0	-47,753	-16,970	-28,812	48,026	242,550	427,574	585,137	NA	NA

*The 2002 forecast and five-year CAGR shown in this table are not Dataquest's official advanced desktop forecast. The data was derived by applying the 2000-to-2001 growth rate to the 2001 forecast.
Source: Dataquest (May 1998)

Figure 2
Worldwide Workstation Unit and Revenue Forecast



Source: Dataquest (May 1998)

Dataquest Perspective

PC pricing has undergone a fundamental change. The sub-$1,000 PC is here to stay, and new, lower price points are bound to be met. This helps set the stage for convergence with digital consumer products and services, such as digital set-top boxes and interactive, digital television broadcasts.

The lack of segmentation between medium-price and low-price systems is changing. Intel's introduction of its Celeron processor family, a Pentium II in low-cost wrapping, is a major step toward significant differentiation at the semiconductor level for segment 0 PCs. Dataquest advises other semiconductor vendors to follow suit and introduce products tailored to the segment 0 PC market and the consumer/convergence market. These products must balance different trade-offs from those faced by more expensive, but still mainstream, PC designs. Savvy chip vendors will seize the market opportunities of both segments.

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Perspective

Personal Computer Semiconductors and Applications Worldwide

Market Analysis

X86 Quarterly Forecast: One Generation Passeth Away, and Another Generation Cometh, but Not at Dataquest

Abstract: *Dataquest reinvents its x86 forecast model to reflect microprocessor sales by market segment and price band instead of generation. Price erosion will limit revenue growth in traditional desktop segments, but up-market opportunities abound.*

By Nathan Brookwood

A New Forecast Model

Regular readers of Dataquest's x86 forecasts will immediately notice that the current report differs dramatically from those before. Once upon a time, suppliers differentiated their products in terms of architectural generation and clock rate. Dataquest's old model tracked this via generational transitions and average selling prices (ASPs) that served as a proxy for clock rate. Just as astronomers before Copernicus struggled to keep Ptolemy's geocentric universe intact by adding increasingly arcane constructs, Dataquest struggled with increasingly arcane generational definitions to explain and predict ASP behavior.

No more. Dataquest's new model reflects the market segmentation that increasingly pervades the computational market and drives microprocessor positioning in the market. Processors used in the personal computer market fit in three categories: deskbound (which includes desktop and deskside), mobile, and server marketed PC. These categories match precisely those used by the Dataquest Personal Computer Systems services. The deskbound and mobile categories are further broken down into six price bands, from "under $1,000" to "over $3,000" in $500 steps, as was recently detailed in the document *The Sub-$1,000 PC Opportunity* (PCIS-WW-FR-9801). The "x86-

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based Midrange" category includes processors used in servers marketed as "midrange" systems. This category differs from "PC Marketed Servers" in both price and technology. The "x86-based Workstation" category includes processors used in systems branded and marketed specifically as workstations and that use either UNIX or Windows NT as their operating system. The final category, "Upgrades and Other," includes processors sold as upgrades to existing systems, or to small, unbranded resellers, or which exist as float in the channel between the time they leave the processor vendor's dock and the time the systems in which they are included have been sold.

Each category in the model and each price band in the PC models are characterized by an ASP for the MPUs in that category and a unit volume forecast provided by the appropriate Dataquest systems group. This allows Dataquest to reconcile MPU consumption with system sales.

Table 1 and Figure 1 contain Dataquest's forecast for MPU units in each category. Overall units are forecast to grow at a 17 percent, with deskbound PC growing the slowest (at 16 percent) and x86-based workstations the fastest (at 59 percent).

Table 2 and Figure 2 contain Dataquest's forecast for MPU revenue in each category. Overall revenue growth of 15 percent (compared with 17 percent for unit growth) reflects severe erosion of desktop MPU prices, primarily as a result of the shifting mix to lower-priced personal computers. Revenue growth in the server and workstation MPU markets will exceed unit growth, as vendors target products specifically at these less price-sensitive markets.

Table 3 contains Dataquest's forecast for MPU unit shipments in each price band. Dataquest anticipates substantial erosion in the mobile band above $3,000 and in the desktop bands above $2,000. These down-market shifts result primarily from a dearth of new computationally intensive applications that have (at least in the past) driven users to purchase more powerful systems at more-or-less constant price points. The need to spend more to purchase meaningful performance advantages is absent; users will spend less in this regard. Dataquest earnestly hopes such applications will appear and will revisit its forecast whenever they begin to appear. Until that time, Dataquest will continue to project a continuing shift of personal computer sales from higher to lower-priced systems.

Table 4 contains Dataquest's forecast for microprocessor revenue in each price band. The microprocessors used in lower-priced systems cost, on average, less than those used in more expensive systems, and thus, the shifting system mix dramatically impacts microprocessor revenue, regardless of whether these processors are sold by Intel or Intel Corporation's competitors, as we will examine later in this document.

Figure 3 illustrates the shifting mix of desktop personal computer shipments within each price band, and Figure 4 shows the impact this has on the processor revenue extracted from each desktop price band. Not surprisingly, as systems priced under $1,500 increase from 36 percent of the mix to 80 percent, lower ASP processors grow from 22 percent of the revenue mix to more than 70 percent.

Table 1
Forecast of x86 Computational Microprocessor Shipments by Application, 1997 to 2002 (Thousands of Units)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Deskbound	66,611	77,709	89,677	103,212	119,459	141,815	16
Mobile	15,960	18,767	22,435	26,568	31,141	38,083	19
Server-Marketed PC	1,732	2,173	2,760	3,379	3,868	4,428	21
x86-Based Midrange	1,236	1,558	1,679	1,746	2,248	2,874	18
x86-Based Workstations	512	1,301	2,609	4,174	4,633	5,130	59
Upgrades and Others	11,324	13,211	15,245	17,546	20,308	24,109	16
x86 Total	**97,375**	**114,718**	**134,405**	**156,625**	**181,656**	**216,438**	**17**

Source: Dataquest (May 1998)

Table 2
Forecast of x86 Computational Microprocessor Revenue by Application, 1997 to 2002 (Millions of Dollars)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Deskbound	11,650	11,994	12,593	13,296	14,156	15,558	6
Mobile	4,438	5,031	5,732	6,444	7,044	8,056	13
Server-Marketed PC	650	815	1,242	1,352	1,741	1,771	22
x86-Based Midrange	927	2,025	2,346	2,624	3,630	4,989	40
x86-Based Workstations	384	1,073	2,367	4,167	5,087	6,196	74
Upgrades and Others	1,529	1,783	2,058	2,369	2,742	3,255	16
x86 Total	**19,578**	**22,722**	**26,338**	**30,251**	**34,399**	**39,825**	**15**

Source: Dataquest (May 1998)

The Shifting x86 Mix Has Profound Vendor Implications

Our discussion up to this point has focused on the overall x86 microprocessor market, an arena in which Intel plays a major role. Although Dataquest does not normally forecast individual company's market shares, we have made an exception in our past x86 forecasts, and we will continue this practice with the new model.

Table 3
Forecast of x86 Computational Microprocessor Shipments by System Price Band, 1997 to 2002 (Thousands of Units)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Mobile Less than $1,000	103	140	188	248	582	1,366	68
Mobile $1,001 to $1,500	1,326	2,040	3,134	4,460	6,399	9,180	47
Mobile $1,501 to $2,000	2,505	2,965	3,552	4,584	5,963	7,755	25
Mobile $2,001 to $2,500	3,536	4,186	5,224	6,195	7,272	8,535	19
Mobile $2,501 to $3,000	2,947	3,662	4,597	5,699	6,399	7,184	20
Mobile Greater than $3,000	4,317	4,447	4,200	3,593	2,472	1,701	-17
Ultraportable and Notepad	1,226	1,327	1,541	1,788	2,055	2,362	14
Total Mobile	**15,960**	**18,767**	**22,435**	**26,568**	**31,141**	**38,083**	**19**
Deskbound Less than $1,000	2,664	4,663	8,968	11,353	15,423	20,952	51
Deskbound $1,001 to $1,500	21,982	31,084	43,045	56,767	72,367	92,254	33
Deskbound $1,501 to $2,000	24,979	26,421	22,419	22,707	20,761	18,982	-5
Deskbound $2,001 to $2,500	10,658	10,879	10,492	8,257	7,118	6,136	-10
Deskbound $2,501 to $3,000	3,664	3,108	3,139	2,580	2,473	2,370	-8
Deskbound Greater than $3,000	2,664	1,554	1,614	1,548	1317	1,120	-16
Total Deskbound	**66,611**	**77,709**	**89,677**	**103,212**	**119,459**	**141,815**	**16**

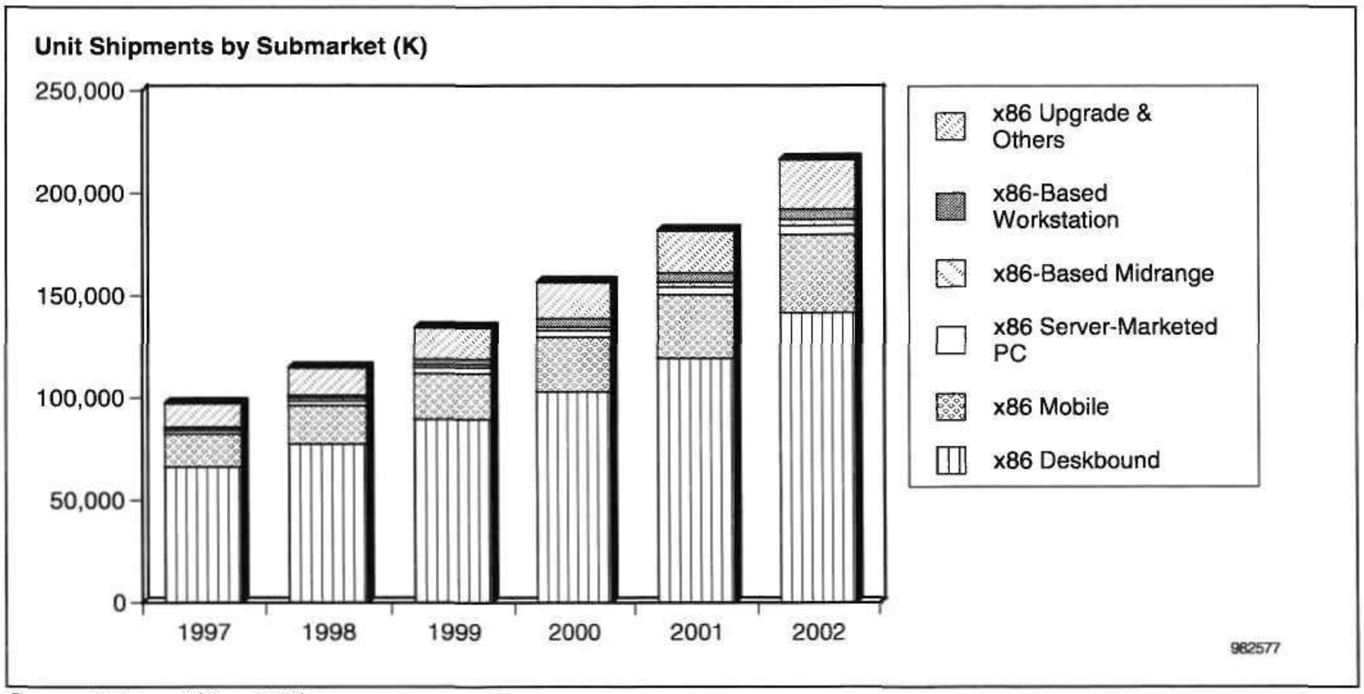
Source: Dataquest (May 1998)

Table 4
Forecast of x86 Computational Microprocessor Revenue by System Price Band, 1997 to 2002 (Millions of Dollars)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Mobile Less than $1,000	8	11	14	19	43	99	64
Mobile $1,001 to $1,500	225	340	512	714	1,003	1,411	44
Mobile $1,501 to $2,000	564	654	768	971	1,237	1,577	23
Mobile $2,001 to $2,500	972	1,128	1,380	1,603	1,844	2,122	17
Mobile $2,501 to $3,000	958	1,166	1,435	1,743	1,918	2,111	17
Mobile Greater than $3,000	1,619	1,634	1,513	1,268	855	577	-19
Ultraportable and Notepad	92	98	111	126	142	160	12
Total Mobile	**4,438**	**5,031**	**5,732**	**6,444**	**7,044**	**8,056**	**13**
Desk Less than $1,000	160	274	517	641	854	1,136	48
Desk $1,001 to $1,500	2,418	3,351	4,547	5,877	7,342	9,173	31
Desk $1,501 to $2,000	4,122	4,272	3,553	3,526	3,160	2,831	-7
Desk $2,001 to $2,500	2,345	2,346	2,217	1,710	1,444	1,220	-12
Desk $2,501 to $3,000	1,008	838	829	668	627	589	-10
Desk Greater than $3,000	1,598	914	930	874	729	608	-18
Total Deskbound	**11,650**	**11,994**	12,593	**13,296**	**14,156**	**15,558**	**6**

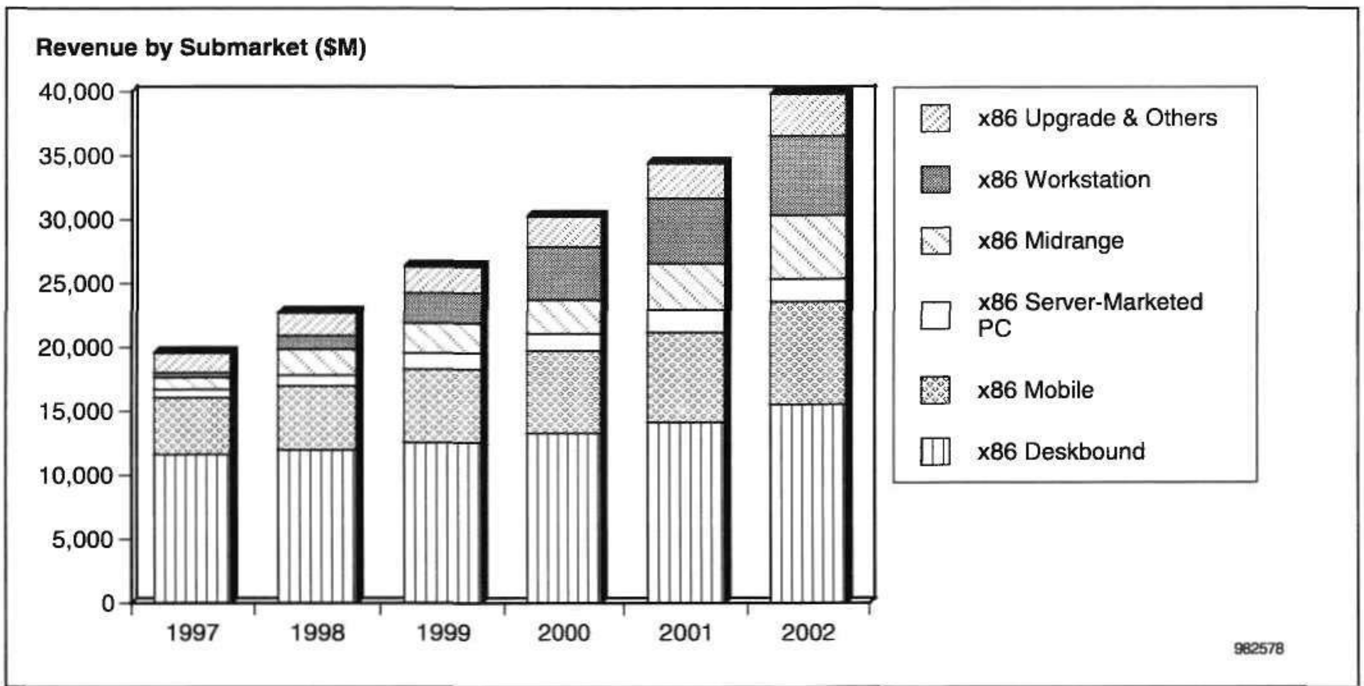
Source: Dataquest (May 1998)

Figure 1
Forecast of x86 Computational Microprocessor Shipments by Application, 1997 to 2002 (Thousands of Units)



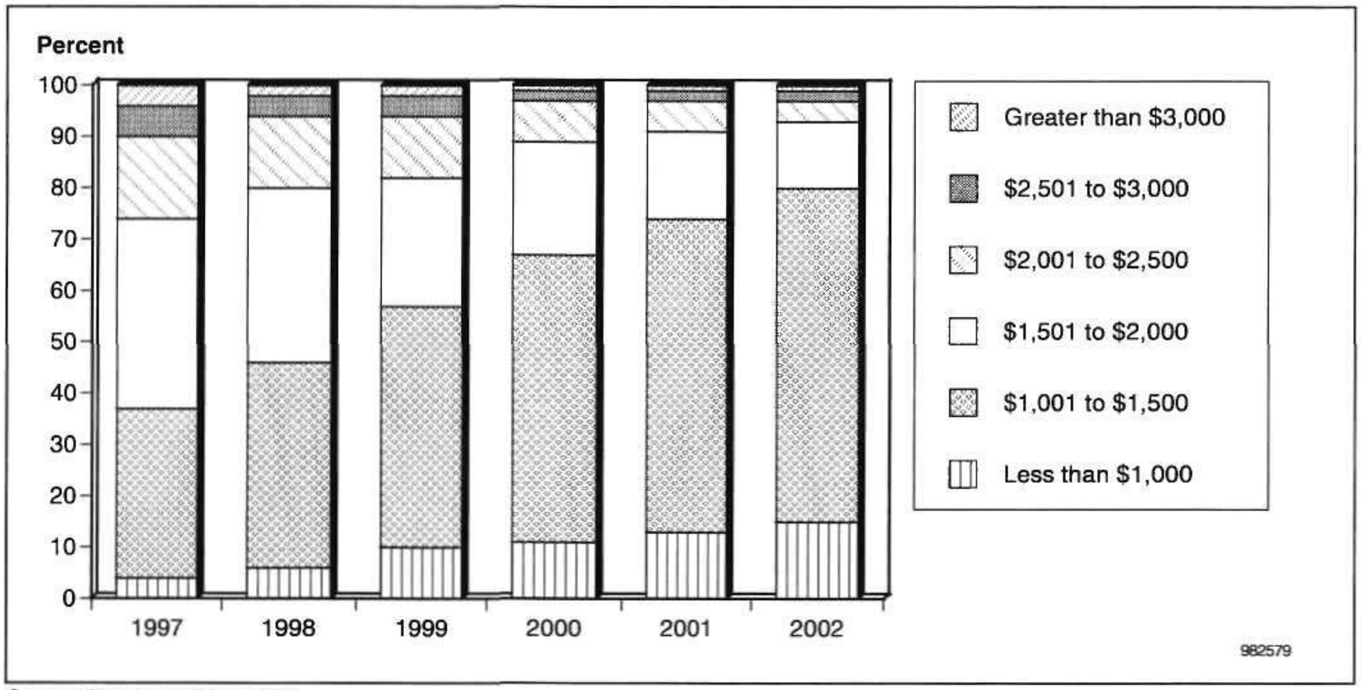
Source: Dataquest (May 1998)

Figure 2
Forecast of x86 Computational Microprocessor Revenue by Application, 1997 to 2002 (Millions of Dollars)



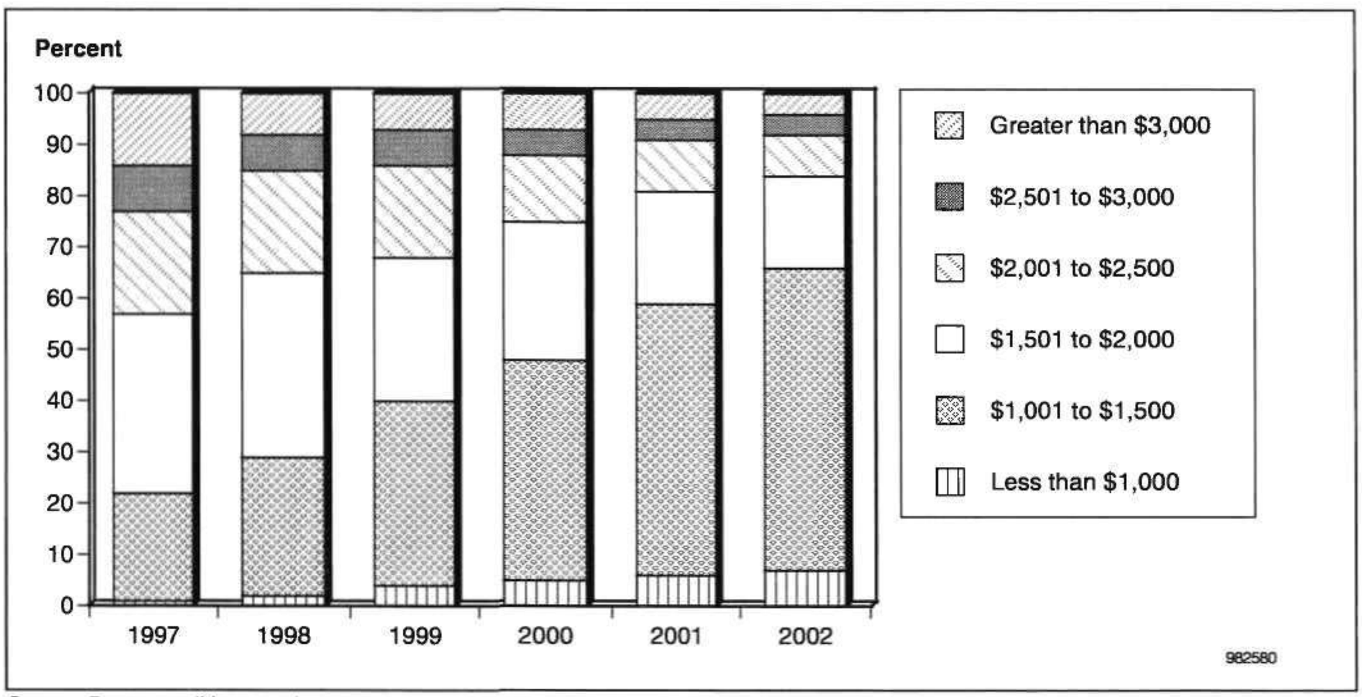
Source: Dataquest (May 1998)

Figure 3
Mix of x86 Microprocessors Used in Desktop Systems by System Price Band, 1999 to 2002



Source: Dataquest (May 1998)

Figure 4
Revenue from x86 Microprocessors Used in Desktop Systems by System Price Band, 1997 to 2002



Source: Dataquest (May 1998)

Dataquest's forecast assumes that Intel's x86-based competitors (Advanced Micro Devices (AMD), National/Cyrix, IDT/Centaur, and others to be named at a later date) will compete in lower three desktop and mobile price bands and also assumes these competitors will retain market share in these segments. As the overall mix of systems shifts downward, the overall unit share of these Intel alternatives will grow. Consequently, while overall desktop microprocessor shipments will grow at a 16 percent compounded rate, Intel's shipments into this segment will grow only 9 percent compounded. Price erosion will eat into the revenues generated by this segment, resulting in revenue growth for Intel in traditional desktop environments of only 1 percent compounded. A similar but less dramatic shift in mobile markets will limit revenue gains there to 11 percent per year. Note that these lackluster rates reflect an erosion of pricing more than of demand.

Dataquest anticipates that Intel will drive microprocessor revenue growth by increasing its emphasis on server and workstation markets. We anticipate that the "server-marketed PC" category will increasingly shift to 100-MHz "slot 1" configurations, offered only by Intel and (possibly) National/Cyrix. X86-based midrange and workstation markets will be dominated by "slot 2" (and later "slot M") configurations, offered only by Intel. As Intel and Microsoft Corporation move up-market via slot 2 and Windows NT enhancements, Intel will capture a disproportionate amount of this business, resulting in a 21 percent CAGR for revenue from processors used in server-marked PCs, 40 percent CAGR for midrange, and 74 percent for workstations. Overall, Intel's unit shipments can grow 12 percent, while its revenue grows 13 percent. Table 5 and Table 6 provide the detail behind these phenomena, while Figure 5 and Figure 6 provide a graphical representation.

The fact that revenues will grow slightly faster than unit shipments suggests a slight increase in ASP during the period. Table 7 and Figure 7 provide the details behind these assumptions. We anticipate that the pattern of increasing desktop x86 average selling prices will finally give way to system price pressures, and even Intel will experience an 8 percent erosion in the desktop personal computer segment, along with a 5 percent erosion in the mobile PC segment. Rapid ASP growth in midrange and workstation segments, driven by processors specifically enhanced for those markets and priced well above $1,000, will allow Intel to post an overall ASP growth of 1 percent for its overall processor mix. In this regard, Intel's recent focus on workstation and server markets takes on a vital strategic role in maintaining the company's overall revenue growth.

Figure 8 and Figure 9 illustrate the shifting mix of Intel processors sold into desktop systems. Processors for systems priced under $1,500 will increase from 25 percent of the mix to 70 percent, and the revenues from these low ASP devices will increase from 16 percent to 55 percent of Intel's revenue mix. Conversely, the 32 percent of high-end processors that presently constitute 48 percent of revenue will shrink to just 11 percent of units accounting for just 21 percent of revenue in 2002. Figure 10 and Figure 11 illustrate similar but less extreme shifts in Intel's revenue mix from mobile systems.

Table 5
Forecast of x86 Intel's Computational Microprocessor Shipments by Application, 1997 to 2002 (Thousands of Units)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Deskbound	55,087	62,991	67,687	72,687	78,012	86,662	9
Mobile	15,250	17,231	20,368	23,562	26,859	31,702	16
Server-Marketed PC	1,732	2,173	2,732	3,311	3,752	4,251	20
x86-Based Midrange	1,236	1,558	1,679	1,729	2,203	2,816	18
x86 Workstation	512	1,301	2,609	4,132	4,586	5,079	58
Upgrades and Others	10,191	11,229	12,958	14,037	16,246	19,287	14
Intel Unit Shipments	84,009	96,482	108,033	119,459	131,658	149,797	12

Source: Dataquest (May 1998)

Table 6
Forecast of x86 Intel's Computational Microprocessor Revenue by Application, 1997 to 2002 (Millions of Dollars)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Deskbound	10,626	10,734	10,797	10,810	10,828	11,203	1
Mobile	4,370	4,820	5,464	6,030	6,462	7,209	11
Server-Marketed PC	650	815	1,233	1,331	1,701	1,717	21
x86-Based Midrange	927	2,025	2,346	2,604	3,575	4,914	40
x86 Workstation	384	1,073	2,367	4,135	5,049	6,150	74
Upgrades and Others	1,411	1,575	1,818	1,995	2,309	2,741	14
Intel Revenue	18,367	21,042	24,025	26,905	29,924	33,934	13

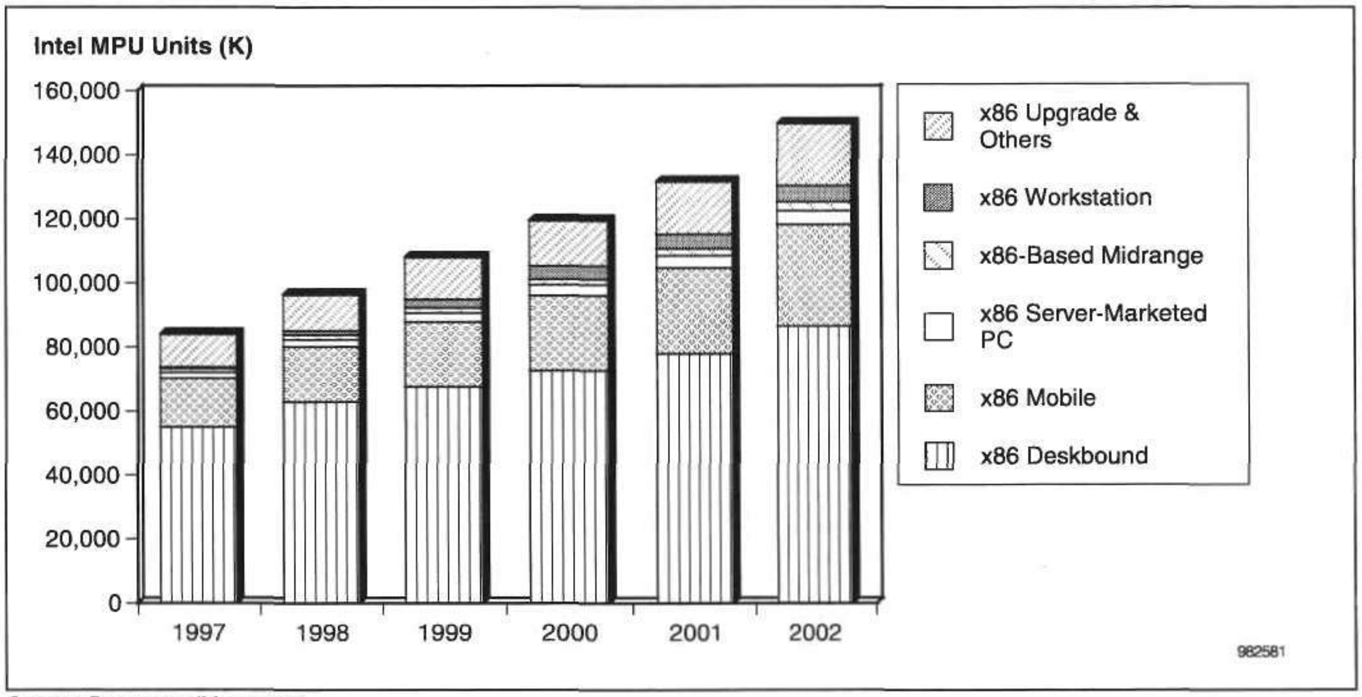
Source: Dataquest (May 1998)

Table 7
Forecast of Intel's x86 Computational Microprocessor ASP by Application, 1997 to 2002 (Dollars)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Deskbound	193	170	160	149	139	129	-8
Mobile	287	280	268	256	241	227	-5
Server-Marketed PC	375	375	451	402	453	404	2
x86-Based Midrange	750	1,300	1,398	1,506	1,623	1,745	18
x86-Based Workstations	750	825	908	1,001	1,101	1,211	10
Upgrades and Others	138	140	140	142	142	142	1
x86 Overall	219	218	222	225	227	227	1

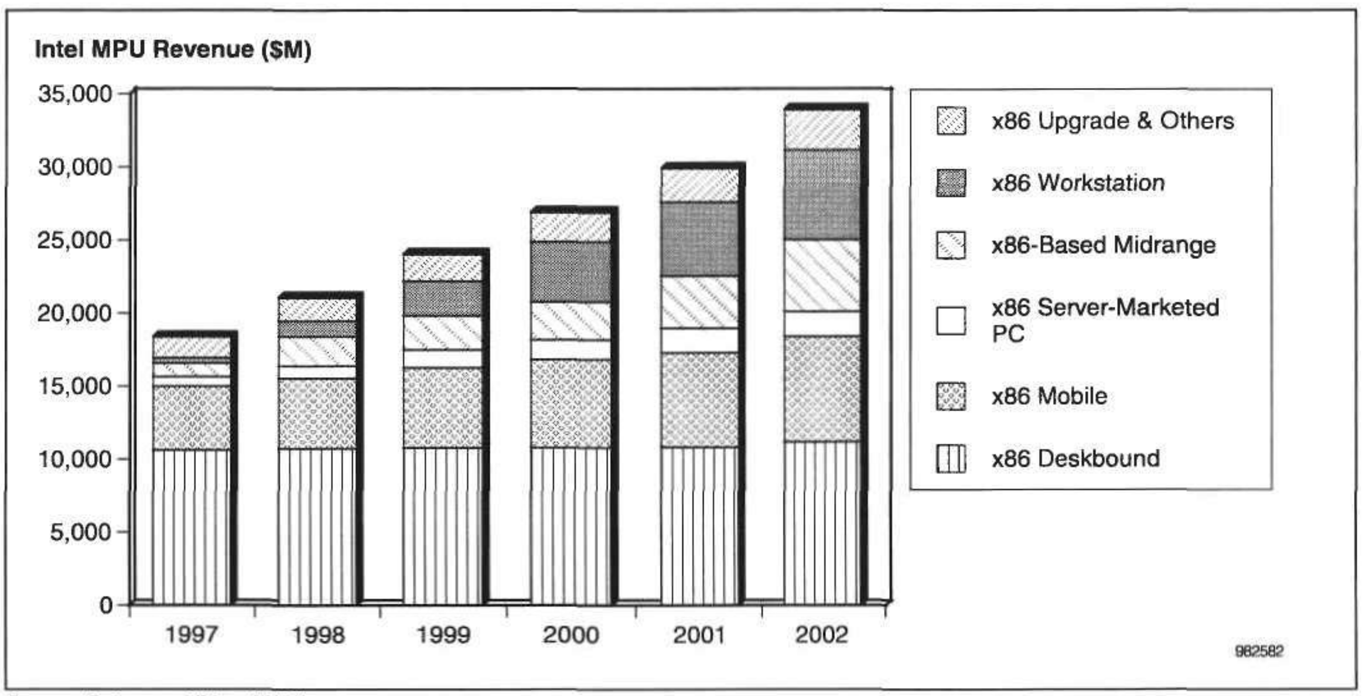
Source: Dataquest (May 1998)

Figure 5
Forecast of Intel x86 Computational Microprocessor Shipments by Application, 1997 to 2002 (Thousands of Units)



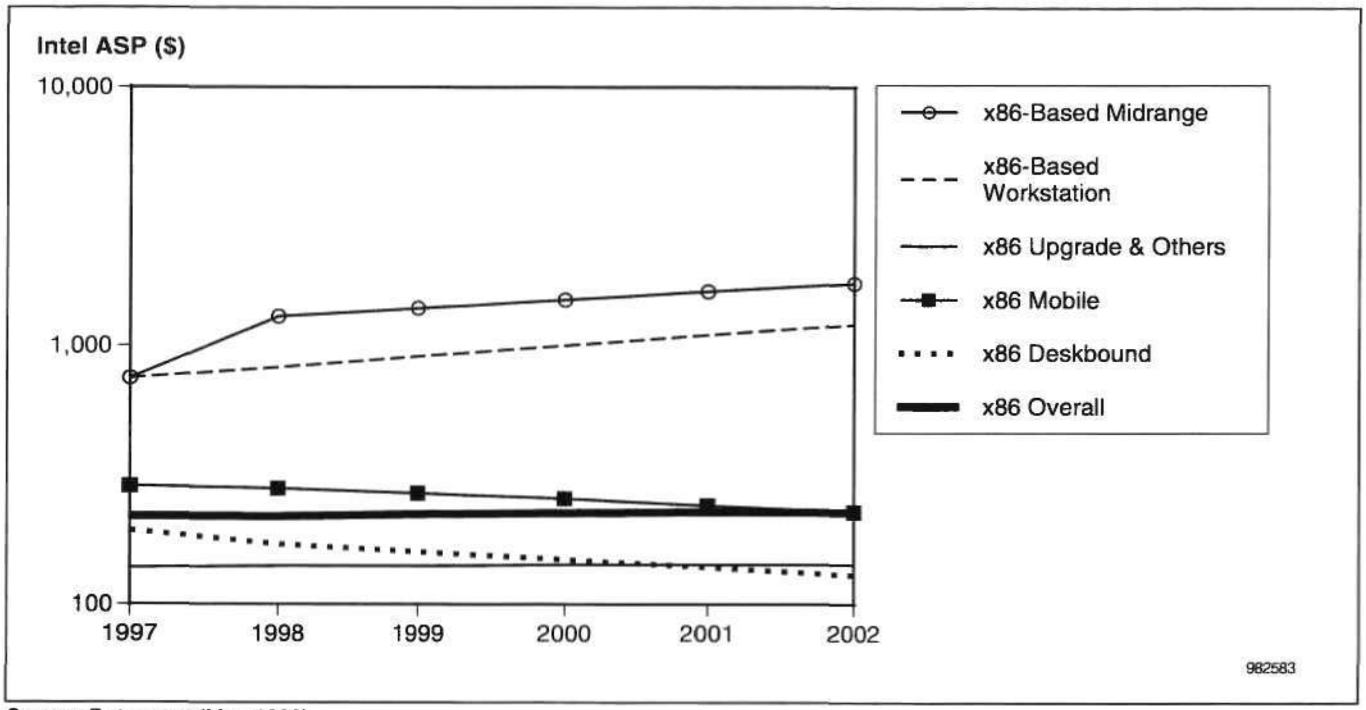
Source: Dataquest (May 1998)

Figure 6
Forecast of Intel x86 Computational Microprocessor Revenue by Application, 1997 to 2002 (Millions of Dollars)



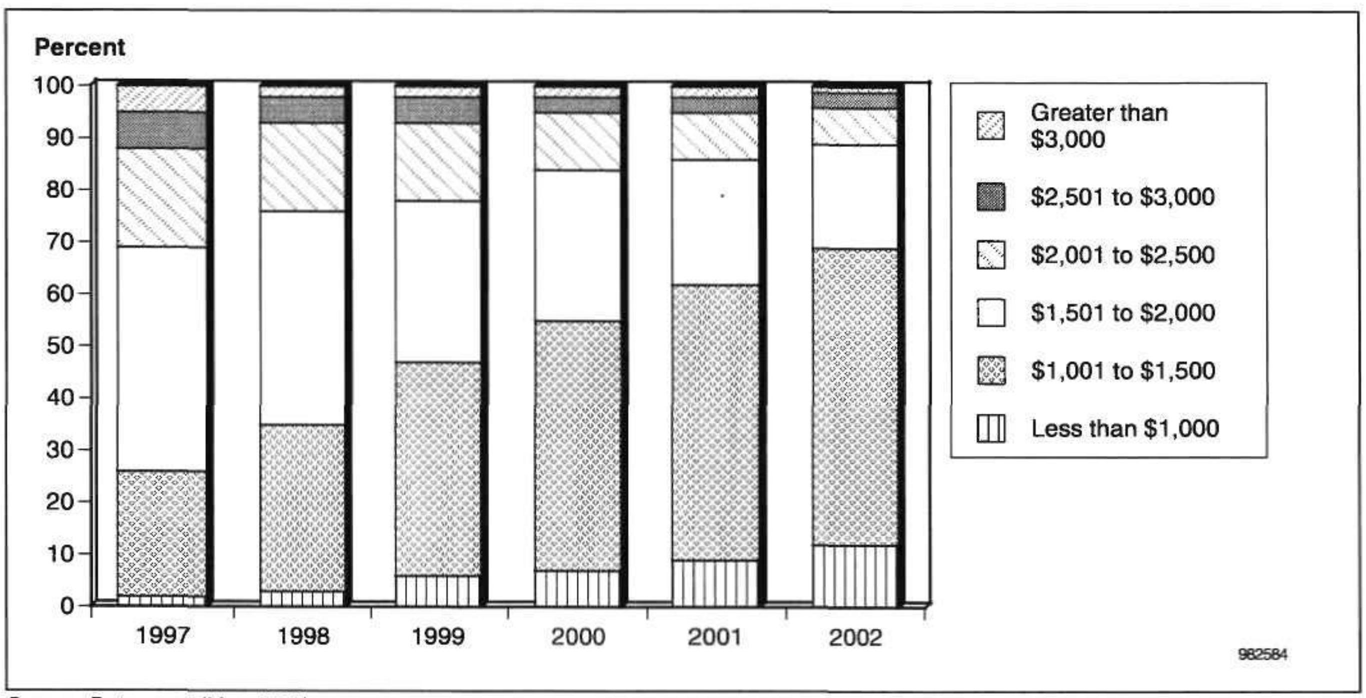
Source: Dataquest (May 1998)

Figure 7
Forecast of Intel's x86 Computational Microprocessor ASP by Application, 1997 to 2002 (Dollars)



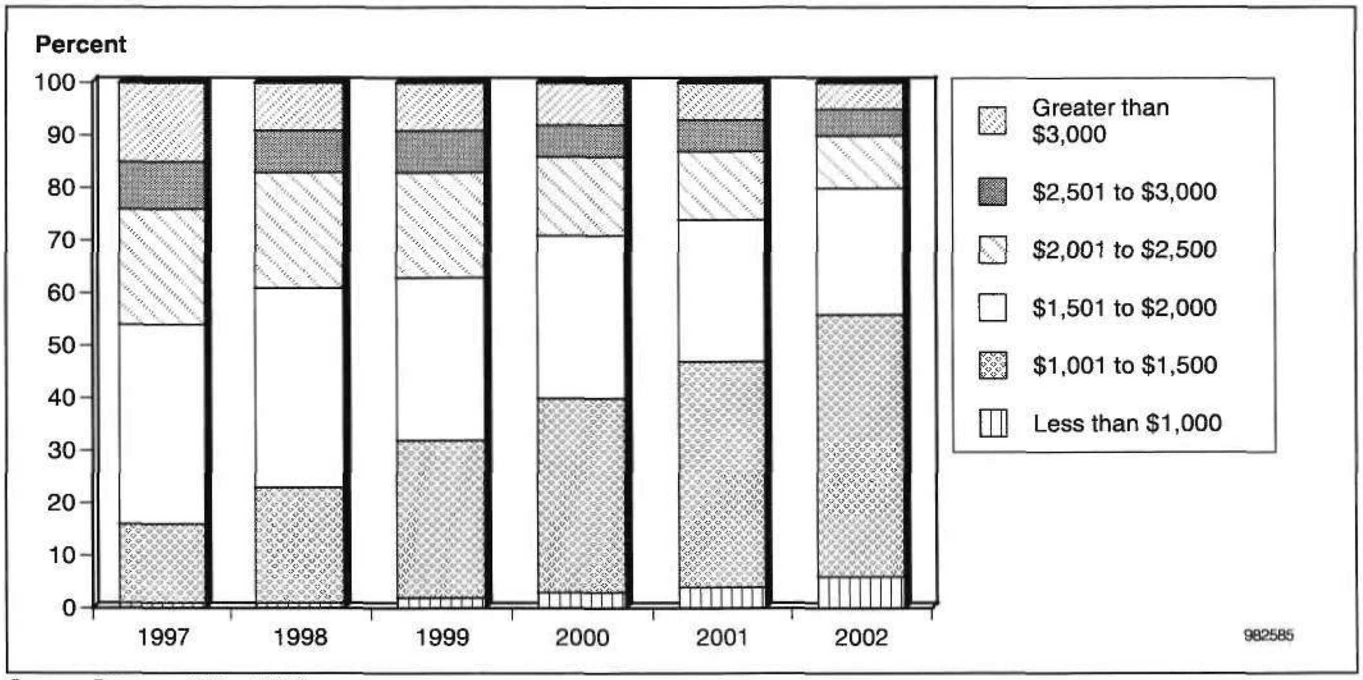
Source: Dataquest (May 1998)

Figure 8
Mix of Intel x86 Microprocessors Used in Desktop Systems by System Price Band, 1997 to 2002



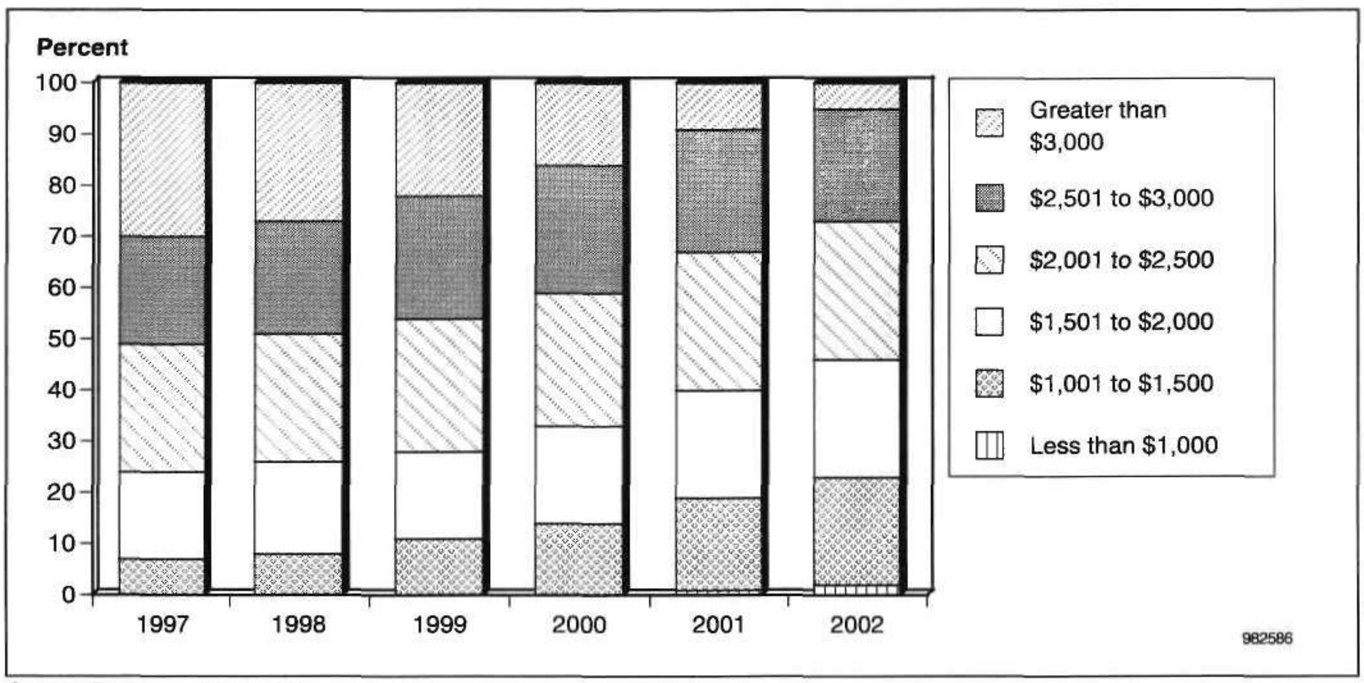
Source: Dataquest (May 1998)

Figure 9
Intel Revenue from x86 Microprocessors Used in Desktop Systems by System Price Band, 1997 to 2002



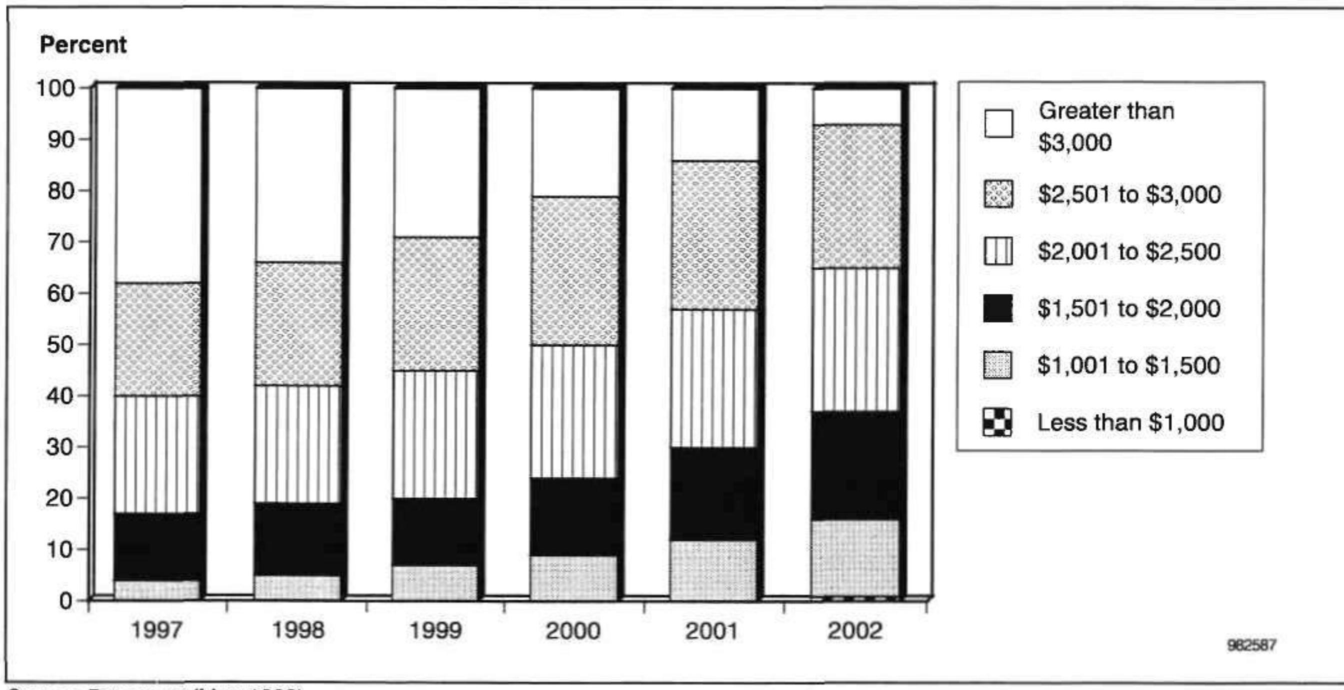
Source: Dataquest (May 1998)

Figure 10
Mix of Intel x86 Microprocessors Used in Mobile Systems by System Price Band, 1997 to 2002



Source: Dataquest (May 1998)

Figure 11
Intel Revenue from x86 Microprocessors Used in Mobile Systems by System Price Band, 1997 to 2002



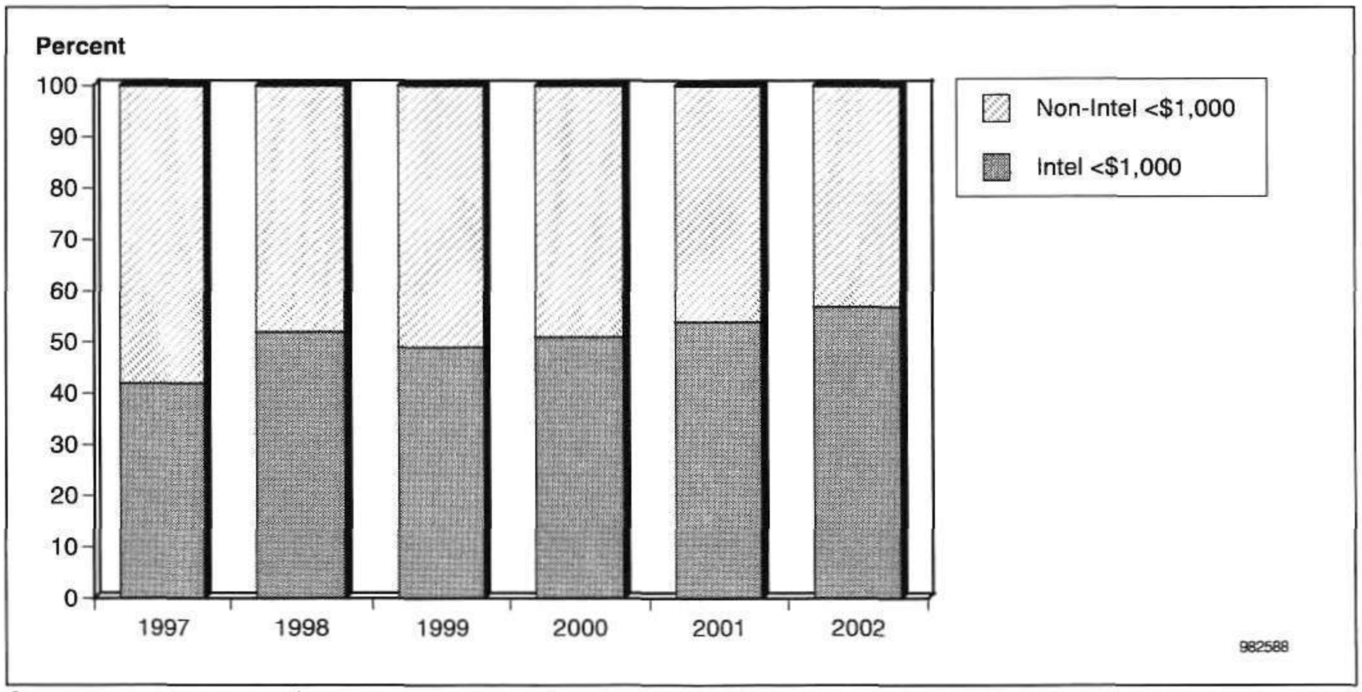
Source: Dataquest (May 1998)

Intel's Competitors Have Lots of Room for Unit and Revenue Expansion

Dataquest anticipates that Intel's competitors will be forced to compete at the low end of the traditional desktop and mobile markets, where their lack of "slot 2" features and performance will not hinder their marketing efforts. These vendors have already captured 58 percent of systems priced below $1,000 and 32 percent of systems priced from $1,001 to $1,500. We anticipate they will hold their own in the sub-$1,000 segment and gain a little share in the sub-$1,500 market, as shown in Figure 12 and Figure 13.

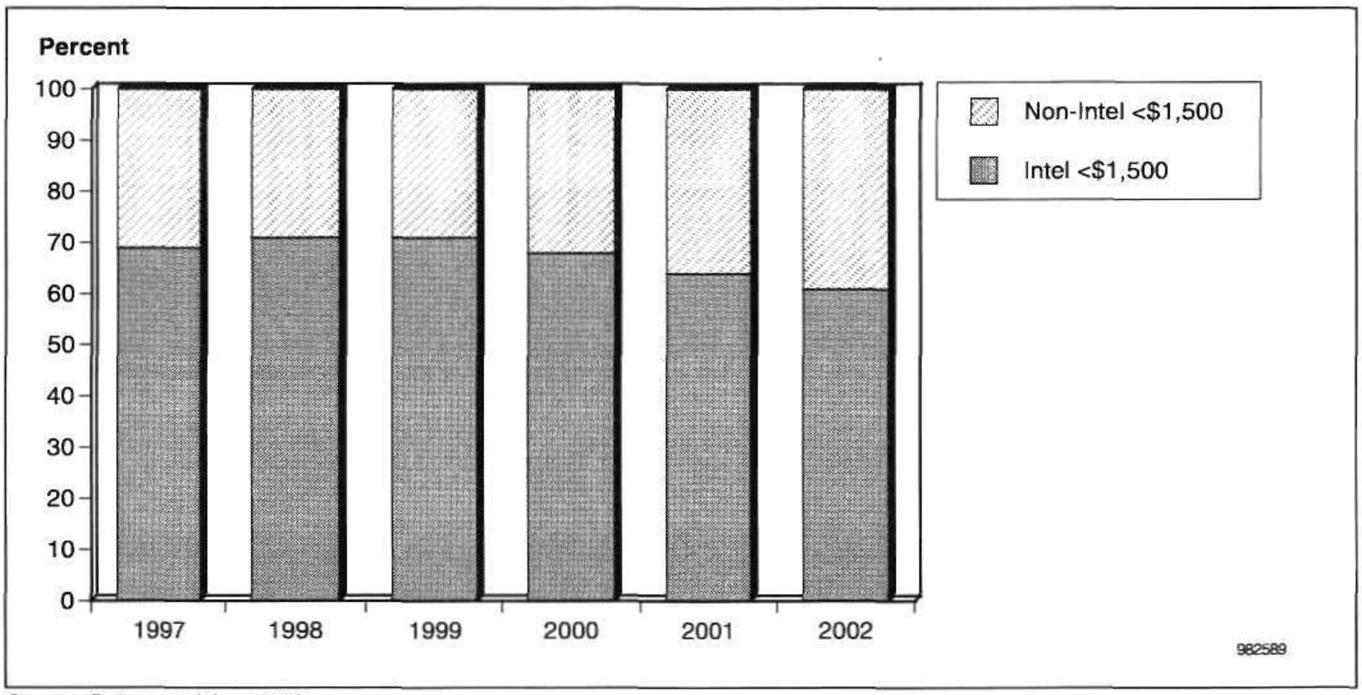
Like Intel, these vendors will face eroding ASP in these price bands, but unlike Intel, they will have very little business in other price bands and segments to drive ASP growth. Further, they must sell at a substantial discount to Intel (Dataquest estimates 25 percent) to provide incentives to system vendors and end users to deal with their slightly riskier configurations. Given these ASP assumptions and unit share projections, Dataquest anticipates that the non-Intel x86 unit shipments can grow at a CAGR of 38 percent, as shown in Table 8, while holding ASPs relatively flat, and thus growing x86 revenue at 37 percent, as shown in Table 9 and Figure 15. Table 10 and Figure 14 compare Intel and non-Intel ASP in the deskbound and mobile segments and overall for all compute x86 shipments. Most of these revenues result from sales into desktop and mobile segments below $1,500, with relatively little coming from higher-priced units, workstations, or servers, as shown in Figure 16.

Figure 12
Forecast Market Share for Revenue from Intel and Non-Intel Microprocessors in Systems Priced under $1,000, 1997 to 2002



Source: Dataquest (May 1998)

Figure 13
Forecast Market Share for Revenue from Intel and Non-Intel Microprocessors in Systems Priced from $1,001 to $1,500, 1997 to 2002



Source: Dataquest (May 1998)

Table 8
Forecast of x86 Non-Intel Computational Microprocessor Shipments by Application, 1997 to 2002 (Thousands of Units)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
x86 Deskbound	11,524	14,718	21,990	30,525	41,447	55,153	37
x86 Mobile	710	1,536	2,067	3,006	4,282	6,381	55
x86 Server-Marketed PC	-	-	28	68	116	177	-
x86-Based Midrange	-	-	-	17	45	57	-
x86 Workstation	-	-	-	42	46	51	-
x86 Upgrade and Others	1,132	1,982	2,287	3,509	4,062	4,822	34
Non-Intel Unit Shipments	13,366	18,236	26,371	37,166	49,998	66,641	38

Source: Dataquest (May 1998)

Table 9
Forecast of x86 Non-Intel Computational Microprocessor Revenue by Application, 1997 to 2002 (Millions of Dollars)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
x86 Deskbound	1,024	1,260	1,796	2,486	3,328	4,355	34
x86 Mobile	69	211	267	415	581	847	65
x86 Server-Marketed PC	-	-	9	20	39	54	-
x86-Based Midrange	-	-	-	20	55	75	-
x86 Workstation	-	-	-	31	38	47	-
x86 Upgrade and Others	118	208	241	374	433	514	34
Non-Intel Revenue	1,210	1,680	2,314	3,346	4,475	5,891	37

Source: Dataquest (May 1998)

Dataquest Perspective

From a total market perspective, Dataquest has lowered its top-line revenue growth for the x86 market from 16 percent to 15 percent over the forecast period. Although some might ascribe this reduced growth to increased competition within the segment, we believe that the lack of new, computationally intensive, mass-market applications and user paradigms has far more to do with our revised forecast than any amount of competition on the part of Intel's competitors. Advances in hardware performance and software capabilities rarely track each other precisely. In the past, popular new software applications have always emerged to tax even the fastest systems. Dataquest sees no reason why ingenious developers should not once again repeat the cycle. It just seems to be taking longer this time around. System purchasers are buying less expensive systems that seem fast enough for the applications on the immediate horizon. Dataquest remains optimistic that new applications will spark renewed high-end desktop growth, but, meanwhile, we feel we must reflect current market realities in our forecast.

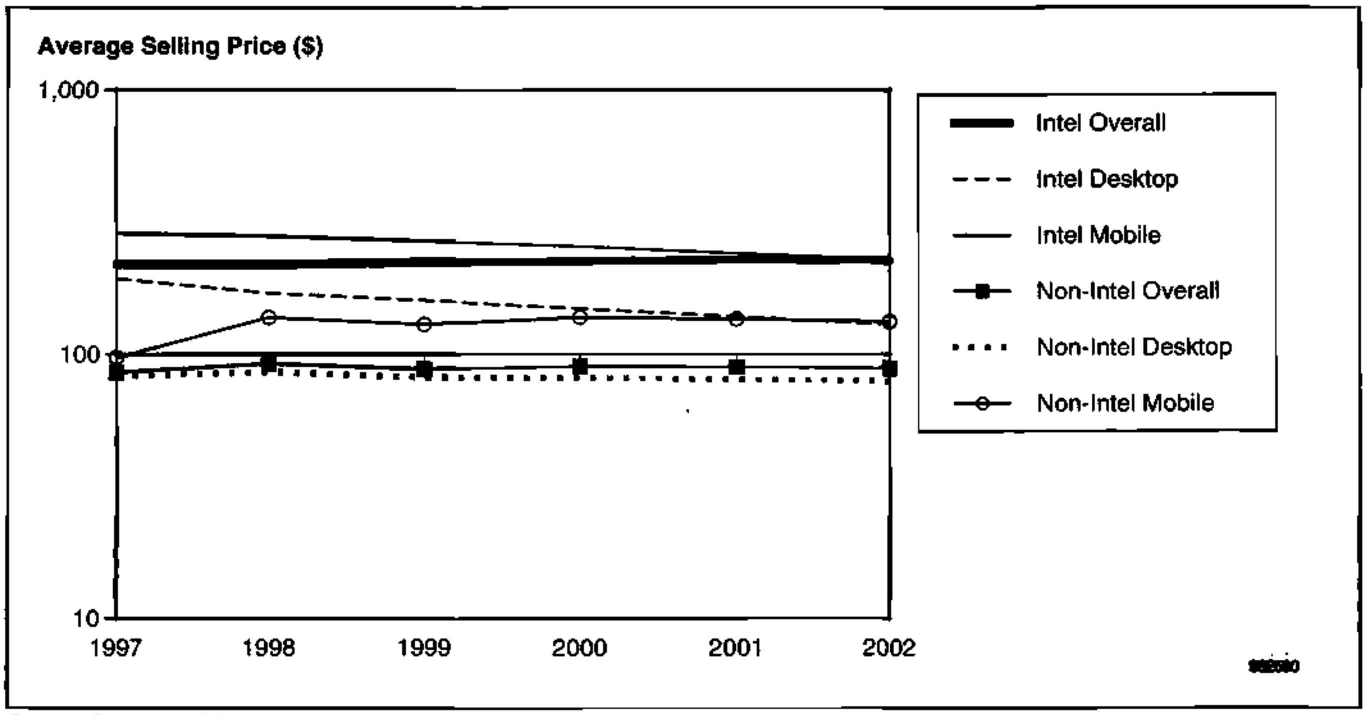
Dataquest welcomes comments from its subscribers regarding its new x86 forecasting model. The changes in the model have precluded easy comparisons with prior periods, but we look forward to amassing new data in a format that we believe provides more value.

Table 10
Comparison of Intel and Non-Intel x86 Computational Microprocessor ASP by Application, 1997 to 2002 (Dollars)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Intel Deskbound	193	170	160	149	139	129	-8
Intel Mobile	287	280	268	256	241	227	-5
Intel Overall	219	218	222	225	227	227	1
Non-Intel Deskbound	83	86	82	81	80	79	-1
Non-Intel Mobile	97	138	129	138	136	133	7
Non-Intel Overall	85	92	88	90	89	88	1

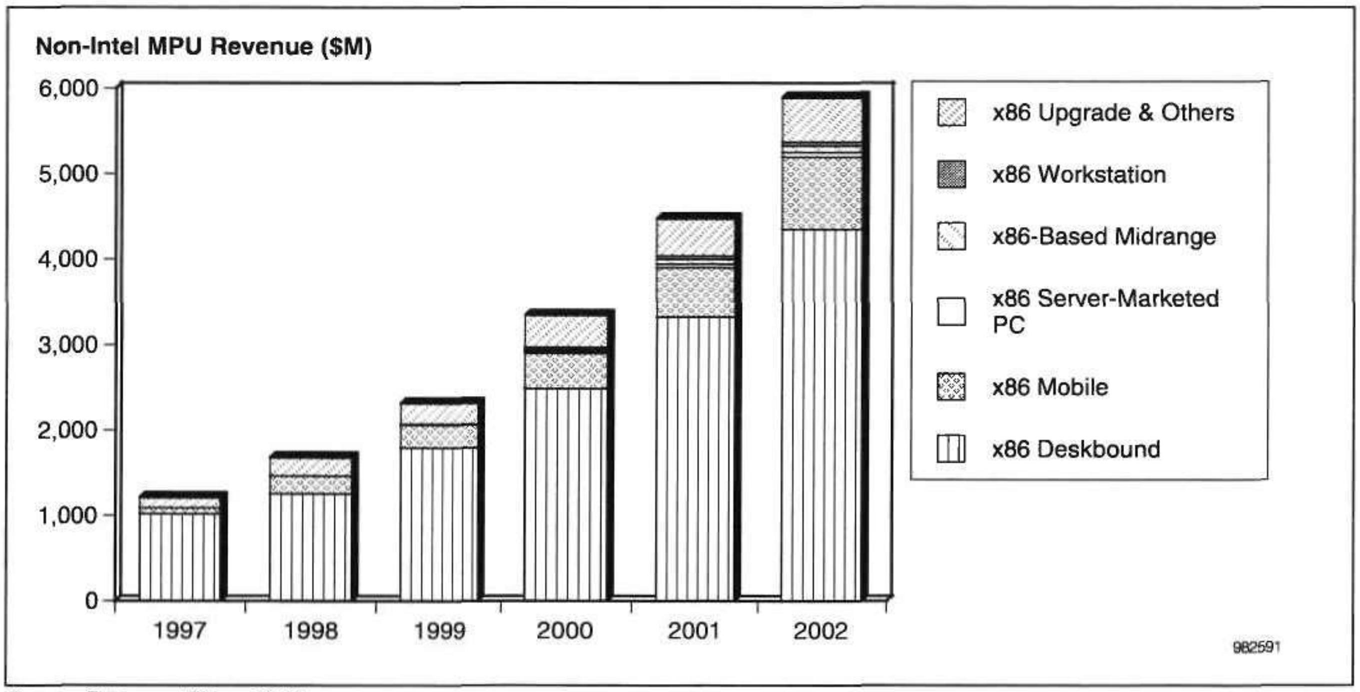
Source: Dataquest (May 1998)

Figure 14
Comparison of Intel and Non-Intel x86 Computational Microprocessor ASP by Application, 1997 to 2002 (Dollars)



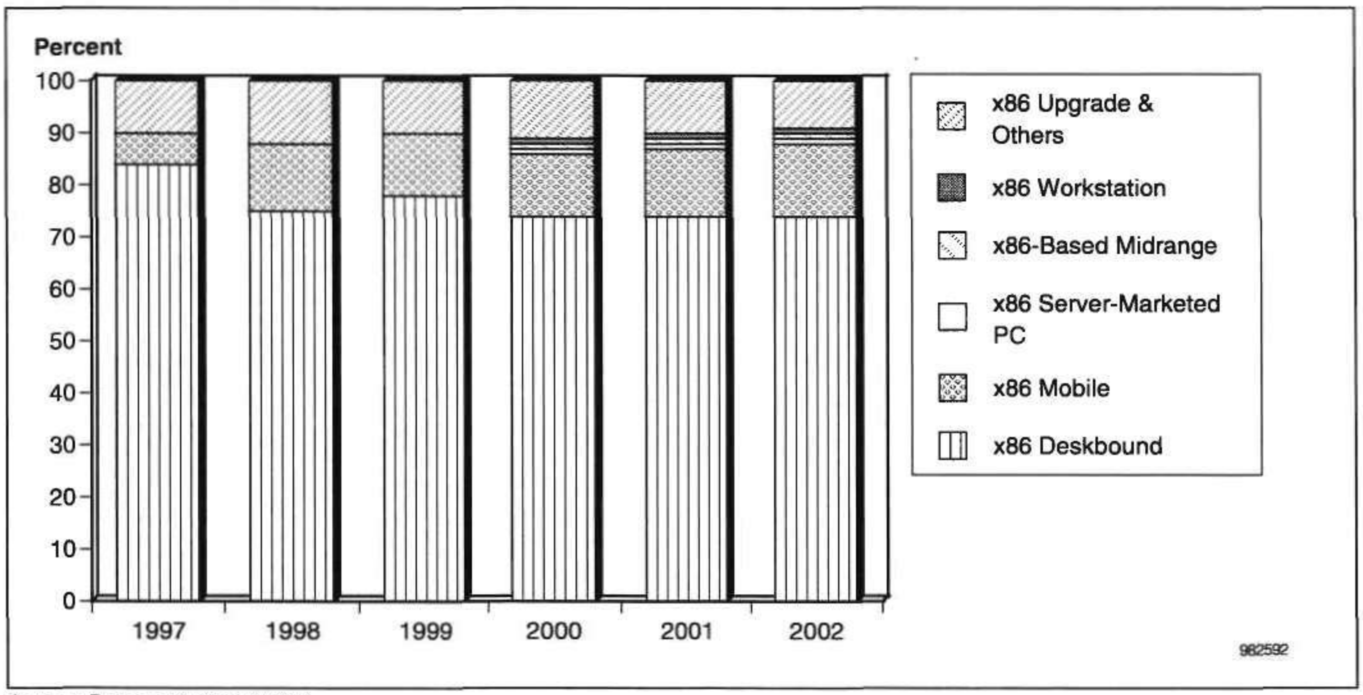
Source: Dataquest (May 1998)

Figure 15
Forecast of x86 Non-Intel Computational Microprocessor Revenue by Application, 1997 to 2002 (Millions of Dollars)



Source: Dataquest (May 1998)

Figure 16
Mix of Non-Intel x86 Microprocessors Used in Desktop Systems by System Price Band, 1997 to 2002



Source: Dataquest (May 1998)

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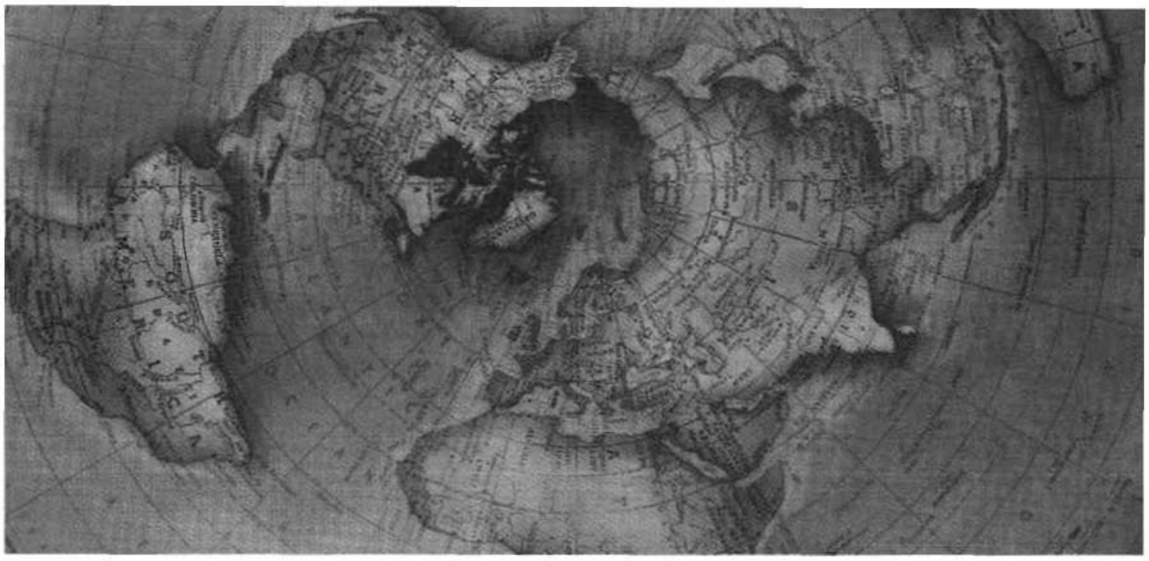

Personal Computer Semiconductors and Applications Worldwide

Market Analysis

Momentum Keeps S3 on Top of 1997 PC Graphics Market

Abstract: *The volatility of the graphics market is proven once again by market share statistics as 1997 data shows several aggressive vendors challenging the incumbent leaders—and winning. This Perspective includes market share data and a brief analysis of what those numbers mean for the industry.*
By Geoff Ballew

High-Performance Players Escape Competitive Side of 1997 Graphics Market

For most product segments in the graphics market, 1997 was a year of intense competition—except for, ironically, the high-performance segment. Dramatic changes in market share for PC graphics vendors typically stem from a fundamental shift that incumbent leaders miss by two or three design cycles. Last year brought a shift to 3-D on the desktop side and a shift to embedded memory on the notebook side. Vendors such as ATI Technologies, Nvidia, and NeoMagic capitalized on these shifts as many larger vendors stumbled. Table 1 shows the market share data for PC graphics chips in 1997.

Thoughts on Key Vendors

S3 Inc.

Though Table 1 shows S3 as the largest graphics chip vendor by a factor of two, it does not show the reversal of fortune that plagued S3 in the latter half of 1997. S3 is not winning enough new designs to sustain its past growth. The company expects to introduce two new graphics chip families this year. Watch the success of those new chips as a strong indicator of S3's ability to recover its forward momentum in 1999.

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Table 1
1997 Graphics Controller Market Share and Revenue Rank

Rank	Vendor	1996 Units (K)	1997 Units (K)	1996 Revenue ($M)	1997 Revenue ($M)
1	S3	29,038	38,185	463	436
2	ATI	10,000	15,580	190	240
3	Matrox	2,950	9,500	85	220
4	Trident	12,750	11,357	180	144
5	Cirrus	17,250	10,200	259	139
6	Chips	6,430	5,600	135	131
7	NeoMagic	900	3,100	38	120
8	Nvidia	25	901	0.5	23
9	3Dlabs	70	970	2	20
10	Rendition	150	650	4	13
-	Others	10,161	8,676	144	109
-	**Total**	**89,723**	**104,719**	**1,524**	**1,593**

Source: Dataquest (March 1998)

ATI Technologies Inc.

ATI is the heir apparent to the No. 1 position, but the company does face some challenges. ATI's RAGE PRO spurred the company's sales through the second half of 1997 and led ATI to ship more AGP chips and more AGP graphics cards than any other vendor. ATI's challenges as a chip supplier lie in two areas: limited sales in the mobile graphics segment, and a thriving board-level business.

Actually, board-level business is less of a "problem" and more of an "issue" as ATI strives to maintain its rapid growth. Other chip companies sell to multiple board vendors as well as motherboard OEMs and PC OEMs. ATI sells chips to motherboard and PC OEMs and sells boards to PC OEMs, distributors, and end users. The company does not sell chips to any other add-in board vendors. Of course, ATI makes a lot more money if it sells the board with its chip on it rather than just selling the chip. But there are accounts the company has difficulty reaching because of strategic relationships between PC OEMs and competing graphics board vendors.

The mobile graphics segment presents a growth opportunity for ATI. The company's RAGE PRO LT brings desktop-level 3-D graphics performance to mobile designs and should appear in designs from top-tier OEMs soon.

Trident Microsystems Inc.

Trident continues to be a major supplier, but it stumbled on the shift to 3-D graphics as did Cirrus Logic and, to a lesser extent, S3. After a series of top-tier OEM design-wins at the end of 1996 and early 1997, the company's business is likely to trend back to its previous position of being a volume supplier to second- and third-tier accounts. A strong product offering could reverse that, particularly if S3's new products fail to win converts.

Matrox

Matrox made its name as a graphics board vendor with award-winning 2-D graphics, large frame buffers, and robust drivers. The company's 3-D efforts to date have not been competitive, but sales have continued to surge because of 2-D performance and product quality. Matrox had always designed its own chips until last fall, when it introduced a board using a chip from NEC Electronics. This spring, Matrox's new products will set the pace for the company's graphics business growth. Matrox also sells its own video-editing products, which, though lower in unit volumes, are a profitable business.

NeoMagic

Neomagic achieved what was, at the time, the impossible: integrating a frame buffer onto a mobile graphics controller. That feat won the company many design-wins and drove its business from almost nothing in 1995 to $120 million in 1997.

NeoMagic has not rested on its laurels. The road of success has been marked with several updates to the original MagicGraph graphics chip and a very interesting technology demo at this year's WinHEC show. Folks will soon learn why the company refers to itself as a multimedia chip company and not just a graphics chip company.

Nvidia

Nvidia is back on the list of graphics chip vendors to watch as it rides the wave of success from its RIVA 128 with a midlife update known as the RIVA 128ZX and the announcement of the forthcoming RIVA TNT. Capacity constraints limited RIVA sales last year, but that should be less problematic this year. The company signed a foundry agreement with TSMC, and SGS-Thomson is rumored to have increased the wafer allocation for RIVA products in light of the high demand.

Dataquest Perspective

A look at last year's market share figures reveals smaller vendors poised for growth and established vendors that have stalled or shrunk. The cycle will continue and this time next year there is likely to be a few new names on the short list of key vendors. The graphics chip market is still too crowded, though, and Dataquest believes the market cannot profitably sustain the large number of vendors pursuing the PC graphics chip business. Last year, former No. 1 vendor Cirrus Logic announced it would cease development of traditional graphics accelerators; S-MOS killed its 3-D-only PIX chip; Tseng Labs, another former top player, was purchased by ATI; and Oak Technology, also a former graphics powerhouse, began looking for a buyer of its graphics technology and products. This year should bring several more official announcements of market exits.

Whether or not vendors exit the market, 1998 will be a competitive year with continued price pressure because of the lack of broad demand for 3-D graphics on the average office desktop. That could change as early as 1999, but like 1997, 1998 will be a tough year for pricing.

Perspective

Personal Computer Semiconductors and Applications Worldwide

Market Analysis

Fourth Quarter Financial Results Bode Tough Times Ahead for PC Semiconductor Vendors

Abstract: : *Financial results for the fourth calendar quarter of 1997 include some warning signs for PC semiconductor vendors. This Perspective explores the dynamics behind these results and highlights some of the notable PC semiconductor events of 1997. Selected financial data for key PC semiconductor and PC system vendors is provided as a center point of discussion.*
By Geoff Ballew

A Rocky Quarter

The fourth quarter of 1997 was a tumultuous time for PC semiconductor vendors. Table 1 shows the financial results of several key vendors in the PC semiconductor and PC system markets. Each group's results are discussed in this Perspective.

Microprocessor Group

Net sales revenue is up for both the microprocessor group and the systems group. But the revenue data show the effects of price pressure and average selling price (ASP) erosion in components as well as systems. The microprocessor group was up an average of 3 percent over the fourth quarter of 1996, but microprocessor shipments were up approximately 18 percent. Intel Corporation's revenue rose only 1 percent from fourth quarter 1996 to fourth quarter 1997. Even though the company dominates the microprocessor (MPU) market, it must constantly lower prices to keep unit demand growing as it has in the past. Softening demand requires more aggressive pricing to keep unit growth on track.

Dataquest

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Table 1
Q4/97 Financial Results of Key PC Semiconductor and PC Systems Vendors

Category	Company Name	Fiscal Year End	Net Sales CY Q4/96 (U.S.$K)	Net Sales CY Q3/97 (U.S.$K)	Net Sales CY Q4/97 (U.S.$K)	Q4/96-Q4/97 Growth (%)	Q3/97-Q4/97 Growth (%)	Gross Margin Q4/96 (%)	Gross Margin Q3/97 (%)	Gross Margin Q4/97 (%)	Days of Inventory Q4/96	Days of Inventory Q3/97	Days of Inventory Q4/97
MPUs	AMD	Dec. 31	496,800	596,644	613,171	23	3	29	28	30	39	34	35
MPUs	Intel	Dec. 31	6,440,004	6,155,500	6,507,000	1	6	71	58	59	62	52	57
MPUs	SGS-Thomson	Dec. 31	1,033,802	981,000	1,084,400	5	11	40	38	38	76	89	80
	Total		**7,970,606**	**7,733,144**	**8,204,571**	**3**	**6**	**64**	**53**	**54**	**62**	**56**	**58**
Peripherals	Rockwell	Sep. 30	418,000	424,000	414,000	-1	-2						
Peripherals	3Com	May 31	1,421,660	1,600,862	1,220,253	-14	-24	48	48	47	47	44	87
Peripherals	ATI Technologies	Aug. 30	121,509	109,961	186,928	54	70	29	36	36	32	38	37
Peripherals	Chips & Technologies	Jun. 30	48,231	36,000	34,757	-28	-3	47	36	48	52	13	43
Peripherals	Cirrus Logic	Mar. 30	253,309	223,960	240,843	-5	8	38	40	39	74	62	61
Peripherals	ESS Technology	Dec. 31	76,679	52,172	70,735	-8	36	51	33	-3	79	93	61
Peripherals	LSI Logic	Dec. 31	301,788	326,847	323,036	7	-1	45	50	45	49	55	52
Peripherals	Oak Technology	Jun. 30	47,611	43,293	49,353	4	14	68	52	53	68	46	47
Peripherals	S3	Dec. 31	132,063	120,349	101,911	-23	-15	41	33	38	62	64	101
Peripherals	TI	Dec. 31	2,459,002	2,500,000	2,428,000	-1	-3	15	39	39	30	45	45
Peripherals	Trident Microsystems		51,865	38,539	26,939	-48	-30	36	40	31	53	40	108
	Total		**5,331,717**	**5,475,983**	**5,096,755**	**-4**	**-7**	**36**	**47**	**46**	**39**	**47**	**58**
								53	53	52			
Systems	Compaq	Dec. 31	5,422,003	6,474,000	7,323,000	35	13	24.4	27.4	27.6	28	38	27
Systems	Dell	Jan. 31	2,412,000	3,188,000	3,737,000	55	17	21.7	22.5	22.0	12	11	7
Systems	Gateway 2000	Dec. 31	1,552,831	1,504,851	1,976,835	27	31	19.5	13.0	18.0	20	26	14
Systems	IBM	Dec. 31	23,140,004	18,605,000	23,723,000	3	28	37	38	40			
	Total		**32,526,838**	**29,771,851**	**36,759,835**	**13**	**23**	**33**	**33**	**35**	**22**	**29**	**19**

Note: Days of inventory calculations for the systems group exclude IBM.
Source: Dataquest (March 1998)

A paradox over the last few years has been Intel's ability to grow ASP while reducing prices every quarter. The trick was to introduce new parts at old prices, reduce prices on relatively new parts, but always work to encourage PC buyers to buy up. This trend reversed itself in 1997 as Intel's sales mix included too many lower-priced units, which led to a lower overall ASP.

Intel's ASP erosion has more to do with soft demand for leading edge systems and less to do with competitive pressures. The company's recent guidance about its first quarter 1998 financial results continues this story; the company reduced its public estimates of first quarter revenue down 10 percent from $6.5 billion to $5.9 billion. Soft demand and price erosion are two sides of the same coin with regard to Intel's results. The company reduced prices on many Pentium II products in January rather than waiting for the traditional February 1 price adjustment. Lower prices, of course, help to spur demand, but too much price erosion can lead to gross margin declines. Intel's gross margin fell more than 10 percent—from 71 percent to 59 percent—from fourth quarter 1996 to fourth quarter 1997. Unit shipments were strong for Intel, but the product mix included more low-end products compared to fourth quarter 1996 sales.

Advanced Micro Devices Inc.'s results were up, but that is more of a statement about AMD's lack of a competitive microprocessor product in 1996. In 1997, AMD brought the K6 to market with the promise of putting some competitive heat on Intel, forcing the MPU giant to cut prices of its Pentium with MMX family. AMD's difficulty ramping production of the K6 effectively blunted its competitive threat to Intel. Dataquest believes the K6 production problems are tied to poor yields rather than other manufacturing issues.

Peripherals Group

The results of the peripherals group tell an unwelcome story and foretell tougher times. First of all, revenue for this group is down for both the fourth quarter to fourth quarter comparison as well as the sequential quarterly comparison. Gross margin for the group as a whole actually went up, but the group's results are strongly colored by Texas Instruments Inc., whose revenue includes substantial noncomputing revenue. Without TI's results, the group's gross margin essentially would have stayed flat.

So the story so far is lower revenue and flat gross margins. Inventory levels add a sour note as days of inventory rose dramatically. Two vendors, S3 Inc. and Trident Microsystems Inc., had more than a full quarter's worth of sales in inventory at the end of December! These are two of the largest graphics chip vendors, and the fact that they have such large inventories is cause for concern. Price erosion in the graphics business was severe through 1997 and could resume again this spring.

If those two vendors had difficulty selling those chips in fourth quarter 1997, it may be even harder to sell them through first quarter 1998 without writing some of that inventory down. Dataquest believes that S3 and Trident have relatively low costs per die because of their size and foundry relationships. That allows them to compete more effectively in the lower-price ranges than newer and smaller vendors. The high inventory levels, measured in days of sales, are relative to the higher sales of the fourth quarter rather than the seasonally lower sales of the first quarter. Selling that much inventory during the first quarter will require considerable marketing savvy or some interesting write-downs resulting from product mix issues and ASP declines.

One moderating aspect with respect to the graphics chip vendors is the fact that rapidly growing vendors such as NVIDIA and NeoMagic were not included. The success of those two vendors and ATI Technologies, all of which are rapidly gaining market share, adds salt to the wounds of S3 and Trident, which are losing share.

Systems Group

The systems vendors group's results show revenue growth, slight gross margin growth, and well-managed inventories. This group's results are enhanced by the fact that the biggest PC OEMs are gaining market share to the detriment of the rest of the OEMs. Compaq Computer Corporation, Dell Computer Corporation, and Gateway 2000 Inc. are outperforming the PC industry overall. IBM's results are enhanced by strength in larger computing systems rather than just PCs. Compaq recently advised the investment community that the first quarter might be a break-even quarter even though revenue is strong. Price erosion in the PC market is impacting all PC OEMs. Part of the price erosion is the emergence of the sub-$1,000 PC as a viable product segment. Compaq is a leader in the low-cost PC segment (formally called Segment 0), and the company has reiterated its intent to continue with aggressive pricing to maintain sales volume. Lower gross margins in the PC systems market could renew price pressure on PC components such as MPUs, microperipherals, and mass storage products.

1997 in Review

1997 was a year of change in the PC system and PC semiconductor markets. Some of the highlights are noted in the earlier discussion of recent financial results, but a bulleted list of notable news is provided as follows:

- January—Intel introduces the Pentium with MMX. Pentium demand quickly shifted to demand for Pentium with MMX, leading Intel to supply shortages of the new product and abundant supply of the older Pentium products.
- February—U.S. Robotics begins shipping its x2 technology in modem products and software upgrades, making the company first to market with functional 56-Kbps modems.
- March—Intel introduces the "mobile module" for packaging mobile MPUs. The benefit for Intel is the fact that a standard module makes it easier for OEMs to use the latest mobile MPUs with less redesign, and that should benefit OEMs, as well. A potential drawback for system OEMs is less design flexibility, which may limit their ability to differentiate products through unique designs.
- April—NVIDIA and SGS-Thomson introduce the RIVA 128 graphics chip, demand for which will outstrip supply, putting NVIDIA back on the list of graphics chip vendors to watch. Also, U.S. taxpayers scramble to complete their tax filings by April 15.

- May—Intel introduces the Pentium II processor in the single-edge connector (SEC) cartridge. This processor is meant to target the market for $2,500 and higher-priced PCs. By year-end, Pentium II systems become available for $1,500 from leading OEMs. Also, Rockwell begins volume shipments of modem chipsets with K56Flex technology for 56-Kbps operation, competing with US Robotics' x2 technology. K56Flex is a combination of technologies from Rockwell, Lucent, and Motorola.
- June—Graphics chip vendors, board vendors, and independent software vendors descend on Atlanta, Georgia, for the E3 trade show (Electronic Entertainment Exposition). The show started three years ago with more of a focus on console and arcade gaming (hardware and software), but PC-specific content has grown.
- July—Intel announces a tender offer to buy graphics chip vendor Chips & Technologies Inc.. Intel was already working with Chips & Technologies and the Real3D subsidiary of Lockheed Martin on the Intel i740 graphics chip. Chips & Technologies is the world's largest mobile graphics chip vendor. Also, Dell unveils its new line of PC workstation products.
- August—Crowds gather at SIGGRAPH in Los Angeles to see the latest in graphics hardware, graphics software, and bleeding-edge technologies for imaging and visualization amid TV screens displaying cutting-edge animation and visual effects for movies.
- September—The United States Federal Trade Commission (FTC) announces that it is investigating Intel's intended acquisition of Chips & Technologies for potential trade violations. The investigation is to continue into January 1998, when the FTC announces it would not block the acquisition.
- October—Financial news from Asia takes another turn for the worse as stock markets in Hong Kong and Singapore tumble.
- November—COMDEX in Las Vegas draws record crowds but suffers from a lack of ground-breaking announcements. Also, Asian financial problems spread to Korea and Japan as the Won and Korean stock market fall. Yamaichi Securities Co., Japan's fourth-largest securities firm, closes only one week after the close of Japan's 10th-largest commercial bank, Hokkaido Tokushoku Bank.
- December—Christmas sales of PCs and consumer electronics are respectable in North America and Europe but are affected by the financial crisis in many parts of Asia. Sales of PC-based DVD drives, whether factory-installed or in upgrade kits, are sluggish, failing to reach a million units for the year.

Dataquest Perspective

Problems stemming from the Asian financial crisis and PC system price erosion in the United States will continue to affect PC semiconductor vendors through 1998. Inventory management becomes even more critical as PC OEMs move toward more build-to-order (BTO) business; whether it is strictly BTO or a variation such as channel configuration, the reality is less forward visibility for vendors of PC components. Forewarned is forearmed.

Chip vendors that find creative ways to help PC OEMs hit new and lower price points will have new opportunities. A $499 PC was unthinkable at this time last year, but it gets much discussion these days. Now, a $999 PC seems mainstream, and a $2,999 PC seems outrageous. Dataquest advises chip vendors to hunt for ways to compete profitably at lower ASPs. Integrate two subsystems onto a chip instead of just one. Offer scalable hardware/ software solutions. Graphics with soft DVD and PC audio with soft modem are two examples of growth opportunities for 1999. Graphics without soft DVD and audio without modem will be obsolete in two years. Remember what happened to the dinosaurs. Act now to have products in the pipeline a year from now—if those products aren't there already.

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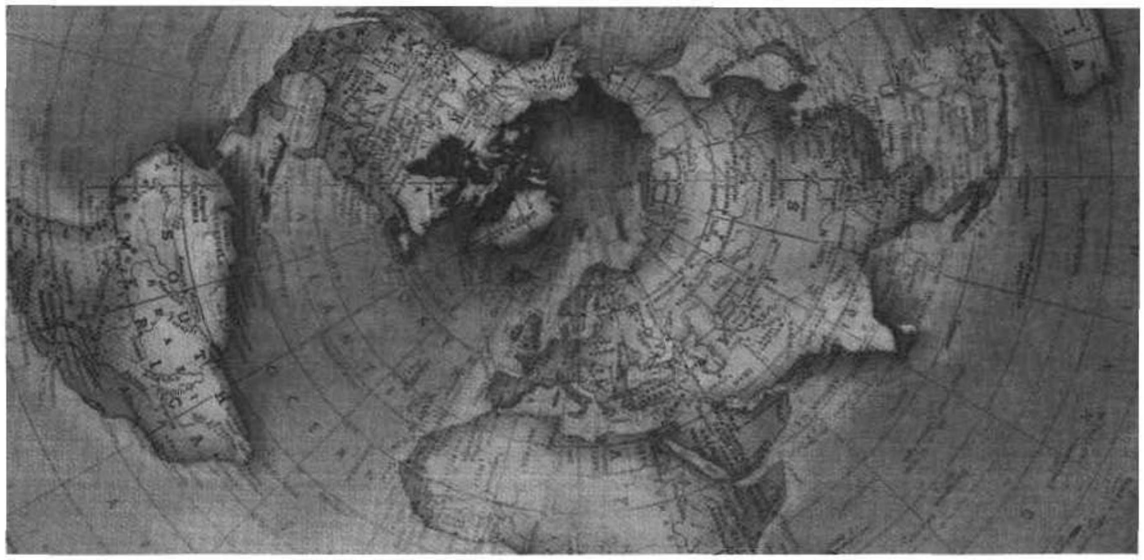
Perspective



Personal Computer Semiconductors and Applications Worldwide

Product Analysis

Palm PC Crashes the PalmPilot Party

Abstract: *At the recent Consumer Electronics Show (CES) 1998, Microsoft unveiled its new Windows CE 2.0 standard along with specifications for applications in what it has labeled the "Palm PC" and "AutoPC" product categories. This Perspective presents an analysis of the Palm PC and compares it with other similar products, such as the PalmPilot.*
By Tom Starnes

Handheld Personal Information Managers (a.k.a. PDAs)

Microsoft has crashed another party—this time it's the PalmPilot party. Perhaps having Microsoft show up is a sure sign of a good bash, but the company's arrival means most revelers are going to feel bad in the morning.

PalmPilot Soars

The PalmPilot is a handheld organizer with a simple touch screen input and easy synchronization to files on the Macintosh or PC. One of the most remarkable features of the PalmPilot is its simplicity, exemplified by its use of a slow MC68328 integrated microprocessor, a small operating system and compact applications, and most-usable handwriting recognition scheme. Third parties filled in with additional applications, and tiny 25KB to 100KB application sizes are typical.

The PalmPilot drew a significant following, becoming the PDA-type device that was talked about with the most favor. A million PalmPilots have been sold. The PalmPilot has become the white collar equivalent of the cigarette pack rolled up in a tee-shirt sleeve, showing just a little rebellion. Palm Computing first designed the PalmPilot, U.S. Robotics bought it, and 3Com got the PalmPilot when it bought U.S. Robotics. It has sold well, with prices starting at less than $300. Recently, IBM started shipping WorkPad, a

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remarketed version of the PalmPilot that should broaden the sales base of the original machine and bring IBM software and accessories to improve its appeal.

Palm PC

Typical of the software giant, Microsoft recognized the popularity of the PalmPilot, envied its success, and decided it needed a piece of the action. Not that the PalmPilot couldn't be improved, but when Microsoft designed its look-alike product, Microsoft took its task literally. No photograph of the Palm PC will be included in this document, because if you've seen one, you've seen the other. A witness describing a PalmPilot to a police sketch artist could just as easily result in a sketch of the Palm PC. The minute differences in appearance indeed are notable, but the base description is so identical as to almost tempt legal action. Operation of the Palm PC is also a knockoff of the PalmPilot. Differences here are described in literature using terms like "Windows" and "one hand." The point obviously overlooked was that PalmPilot became popular without any similarity to Windows. PalmPilot was simple.

Some of the striking similarities include shape, stylus/pen, docking cradle, buttons, and optional modem. In case somebody still didn't connect the new platform to PalmPilot, the system is officially dubbed Palm PC—not Hand PC, not Glove PC, not Pen PC, not Shirt PC. Lee Iacocca did not make the 1964 Ford Mustang look and operate just like the Chevrolet Corvette. He created an entirely new market by making an entirely different car. Nobody would ever mistake a Corvette for a Mustang, even though both would be described as a small, sporty, fast, two-seater, fun automobile for the young at heart. And Mr. Iacocca didn't call it the Ford Covet. Features of PalmPilot and Palm PC are tabulated in Table 1. Coincidence? Unlikely.

Despite their similarities, the Palm PC has many features not found on the PalmPilot. Not only can Palm PC recognize a graffiti-style simplified hand-written input, it also has a proper handwriting recognition front end that can read normal handwriting and proposes to adapt to the user (though Dataquest has not yet seen the recognition speed). This has some advantages, but considering the ease with which the single-stroke characters can be formed, it is almost superfluous. Capturing the pen strokes and sketches like a Magic Slate is indeed useful. Microsoft calls this "rich ink" because it can later be altered beyond what could be done on a real piece of paper. A straightforward version can be added to the PalmPilot with a 9KB piece of software from a third party.

Voice capture is another useful addition to the Palm PC. By simply pressing a button (with one hand) the user can dictate directly into RAM, probably with some compression; later, this oral message can be transcribed to text manually by the user. This is very handy, as people often have simple thoughts that are most readily spoken rather than recorded with a pen on a note. The Palm PC does not have the horsepower to convert the speech to text, though one would think that this could be done in the background during otherwise quiet time if it didn't eat up valuable battery power.

Table 1
Features of 3Com's PalmPilot and Microsoft's Palm PC

Feature	PalmPilot	Palm PC
Size (Inches)	4.7 x 3.2 x 0.7	4.7 x 3.2 x 0.7
Display	3.2 x 2.3-inch backlit black/white FSTN LCD, 160 x 160 pixel	3.2 x 2.3-inch, backlit black/white FSTN LCD, 240 x 320 pixel
Processor	MC68328	V_R4102, V_R4111
Weight (Oz.)	5.7	5.3
Operating System	Palm OS 2.0/Pro*	Windows CE 2.0
ROM Memory (MB)	1	4 (minimum)
Batteries (Life)	Two AAA (12 to 18 weeks)	Two AAA (12 to 15 hours)
RAM Memory	512KB/1MB*	2MB
Input	Stylus, soft keyboard	Stylus, soft keyboard, microphone
Output	Simple sound	Speaker and jack, LED, vibration
Computer Synchronization	Windows 95, Windows NT, Mac OS	Windows 95, Windows NT
Palm-Based Applications	Calendar, contacts, activities, memo, expenses, calculator, games, TCP/IP*, e-mail*, synchronization, security	Calendar, contacts, activities, memo, expenses (verify), calculator, games, TCP/IP, e-mail, synchronization, voice recording, information reader
Host-Based PIM Synchronization	Microsoft Schedule+, Excel, Lotus Organizer, Symantec ACT!, Sidekick, ECCO, Day-Timer Organizer, Maximizer, Now Up-To-Date, Franklin Ascend 97	Microsoft Schedule+, Outlook, Lotus Organizer, Symantec ACT!, Sidekick, ECCO, Day-Timer Organizer, Maximizer, GoldMine
Buttons	On, two scroll, four launch	On, two scroll, four launch, enter, escape, voice
Serial Output	Serial	Serial, IrDA
Vendors (Announced Only for Palm PC)	3Com, IBM	Casio, Everex, Philips Electronics, LG Electronics, Samsung, Uniden, Palmax
Pricing ($)	$299/$399*	$599 and up
Fax Modem	Optional	Optional

*On professional model
Source: 3Com, Microsoft, Everex, Dataquest (March 1998)

Palm PC has an interesting new application called "Mobile Channels." In conjunction with Internet Explorer on the PC, it will accept blocks of information from the Web and save them on the Palm PC. When convenient, the user can review this information offline. This information reader allows users to keep up on news, weather, stock quotes, and e-mail. This is not a live channel, but information that is collected over time, transferred in bulk to the Palm PC, and reviewed at leisure.

A few other pluses on the Palm PC aren't brain surgery, but they are nice additions. An expansion slot takes the form of CompactFlash cards. These ports can be used for additional memory capacity, serial ports, or additional I/O functions. An IrDA infrared transmitter allows the Palm PC to communicate with properly equipped PCs (laptops), Auto PCs (see "Putting Information on the Superhighway: Automotive Information Systems," MCRO-WW-DP-9804), Handheld PCs (H/PCs) (see "Opening the Window on Handheld PCs," MCRO-WW-DP-9702, February 3, 1997), printers, and peripherals. Though IrDA has had only limited real use so far, there are signs that it may start being used more commonly. Everex Systems Inc.'s incarnation of the Palm PC uses a thumb-controlled rocker switch, and a flashing LED or vibration serves as an alert.

How Will Palm PC Stack Up Against Alternatives?

The PalmPilot will continue in the space it originally carved out in the market. The cost model for the PalmPilot is certain to stay far below that of a Palm PC. There can surely be price reductions made in the PalmPilot to spur considerable interest—almost any product will rocket to success when it approaches the $100 mark after having provided the value that has been demonstrated at the $300 to $400 level. The convenience of having one's daily schedule in one's pocket is a real plus when it has been synchronized with coworkers' schedules through PCs on the network.

PalmPilot is nearly as open a system as Palm PC. Expansion is limited by hardware ports and software drivers, but this has not severely hindered application development. Independents have written fax applications and even a Web browser. The operating system is controlled by the Palm Computing division of 3Com, but anybody can write code for the machine. 3Com counts 3,000 vendors working on products supporting the PalmPilot. These may well be totaled by counting the number of Metrowerks CodeWarrior development systems that were sold for the device.

This all plays into the original strategy of the PalmPilot: make it simple and inexpensive. Metrowerks set the industry on its ear with its low-cost, fully functional products. Third parties from shareware programmers to the largest corporations have endorsed and supported PalmPilot. Applications can be downloaded from the Web for nothing or up to $100. The hobbyists that were the underground microcomputer freaks before 1980 now tinker on PalmPilot software because it is such a clean machine. There is already a lot of momentum rolling on PalmPilot.

The positioning of H/PC against Palm PC deserves a look. Is there room for both? The market, as always, will eventually answer this, but until then one must consider the major distinctions of each. H/PCs definitely retain the look and feel of the familiar Windows environment and the popular Word and Excel applications. But just how much people really want to carry a tiny computer in their pocket so they can do word processing or alter medium-size spreadsheets from a token keyboard is up in the air. The Palm PC has the look and feel of the PalmPilot, hoping to draw more money out of a personal information manager (PIM) super organizer. Where does one leave off and the other take up?

Now if a person's pocket (or pocketbook) leaves room for either a PalmPilot or an H/PC (but not both), which way will one go? Will one buy a $1,000 PC, a $3,000 laptop, an $800 H/PC, a $500 Palm PC, or a $200 PalmPilot? Pricing, features, and the perceived value of each product will determine its ultimate success.

When talking software, one can pretend that all it takes is ROM and RAM (no disks here) to add new programs and update and extend old ones. But with the Palm PC, vastly expanding features that result in hardware changes or extensions creates a dilemma. The attraction of the handheld devices is their small size and convenience. But every bit of hardware that one adds on chips away at those benefits. Cords and cards and antennae and accessories and drives and user manuals all add up to a grocery bag full of widgets and gadgets that make the package complex, expensive, and not so mobile. Soon the complete laptop looks attractive.

Microsoft

Microsoft is going to do to PDAs what Microsoft does to many things: focus on how much one can do, not how economically. A remarkably trimmed-down Windows in the form of Windows CE is still burdened with its heritage, exotic application programming interfaces (APIs), and expansion as though it were a mainframe. But because Microsoft commands so many developers (already numbering 1,000 for the H/PC), there will be many programmers trimming their applications down from the heavy desktop versions to the Palm PC (and H/PC and Auto PC?) platforms.

Could someone other than Microsoft attract such attention to the struggling PDA industry? Not in the short run. Will Microsoft's magnet to the palm-size product turn production figures up to the tens of millions? Not likely. The device prices will have to be very low, and Microsoft is rarely in a price-reduction sort of business. On the desktop, Microsoft dishes out more functionality while holding the cost of software fairly constant over time, similar to what Intel does with the central processor.

For functionality, sons of Newton, Omnis, Wizards, and other PDAs have tried to cover the spectrum with software and products. It is not clear if having 40 of these functions available on one palm-size device is the optimum combination. Prior attempts have not failed because of an inadequate operating system. PalmPilot succeeded by providing just the right combination of simple things for a little money.

Microsoft and Windows CE—An Update

A year ago, Microsoft was mostly left out of embedded applications of microprocessors and microcontrollers. Windows CE had just been introduced and demonstrated on H/PCs. Windows CE was Microsoft's latest effort at making an impact in a PC-like market. Windows CE strayed away from the Intel and x86 base of Microsoft's fortunes. It allowed other architectures from other vendors to have a common software platform on which to build applications.

H/PCs in Microsoft's definition still sit in the "developing" category, and the jury is still out as to their acceptance in spite of Microsoft's reporting half a million total units built. It is not known how many of these are in the channels (there are many channels because many vendors have products) or how many are going to early adopters who may more enthusiastically embrace a Microsoft-sponsored architecture.

As discussed, there is some possibility of cannibalism of the H/PC by the new Palm PC products, although much of the effort put into developing applications for H/PC should be quickly port-able to the Palm PC, if indeed that is the surviving configuration. Thus, Windows CE offers additional insurance to the software developers that may not be available on other operating systems.

Key to all of these products is mobility. People will have to use their dollars to show which applications are ideal for which platform. Windows CE provides a single operating system for applications appropriate for the mobile market so they can readily be made available on the best platform. Only a company of Microsoft's magnitude could draw the necessary application developers, hardware developers, and product designers to assure a critical mass for long-term survival.

Unlike the PC, where Intel was the initial winner for the processor slot and became sufficiently focused to totally dominate the platforms, the mobile information market will have numerous microprocessor vendors serving it, spreading some of the hardware wealth. This may cause lesser players to fall by the wayside or consolidate, and the market may end up with only two or three processor winners. Ten years from now, antitrust factions may have two real-world models to determine which approach has best served its market: a single operating system with a single key component manufacturer (Windows/DOS and Intel), or a single operating system with multiple key component manufacturers (Windows CE and NEC, Hitachi, Philips, and so on). Of course, central to both of these strategies will be that one operating system and the company that harvests great wealth from it.

Perspective

Personal Computer Semiconductors and Applications Worldwide

Market Analysis

Collateral Damage from the Sub-$1,000 PC Bomb

Abstract: *This Perspective shows the latest Dataquest PC forecast and discusses the implications of this new forecast on the market for PC semiconductors. At issue are continued price competition across the major product segments of the PC semiconductor market and the recent success of low-cost PCs, specifically sub-$1,000 PCs, which has a dampening effect on PC system ASPs.*
By Geoff Ballew

Unit Growth Likely to Outpace Revenue Growth

Dataquest's latest PC forecast predicts continued strength in unit shipments, but at the expense of factory average selling prices (ASPs). The revised five-year growth rate for unit shipments is 16.5 percent compound annual growth rate (CAGR) for 1996-2001 compared to the 16.4 percent forecast from spring 1997. The steadiness of that long-term rate indicates Dataquest's confidence in the continued growth of the PC market but does belie the specter of lower revenue growth.

Dataquest revised its revenue forecast down significantly for the fall PC forecast, with the new CAGR of 13.1 percent rather than the previous 17.2 percent. Price reductions were necessary last year to sustain the unit shipment growth rate and will continue to play a role in keeping percentage unit growth in the mid to upper teens.

Table 1 and Figure 1 show the fall 1997 PC forecast and the changes from the previous forecast.

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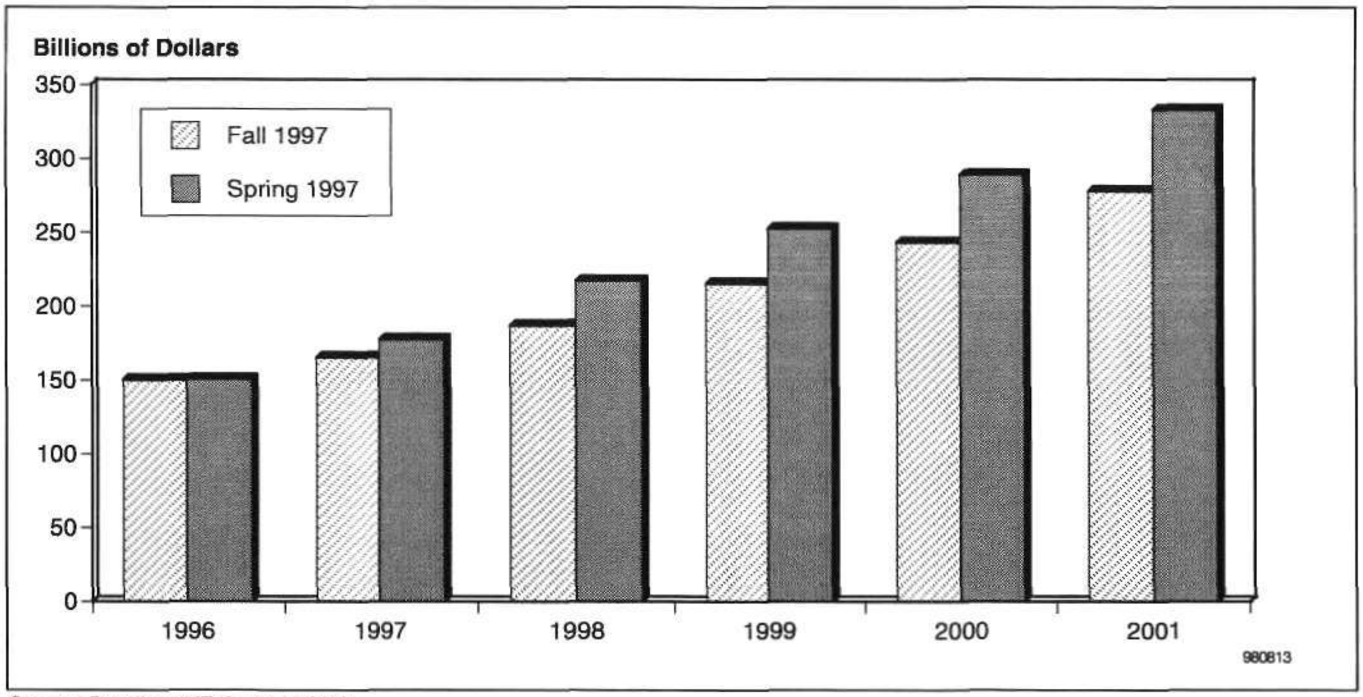
(For Cross-Technology, file in the Semiconductor Application Markets binder)

Table 1
Fall 1997 PC Forecast and Differences from Spring 1997 Forecast

	1995	1996	1997	1998	1999	2000	2001	CAGR (%) 1996-2001
Fall 1997 Forecast								
Units (K)	60,170	70,870	83,081	97,322	113,329	131,371	151,795	16.5
Unit Growth (%)	-	17.8	17.2	17.1	16.4	15.9	15.5	-
ASP ($K)	2.05	2.12	1.99	1.92	1.90	1.85	1.83	-
Factory Revenue ($M)	123,644	150,150	165,325	186,853	215,612	243,210	277,819	13.1
Revenue Growth (%)	-	21.4	10.1	13.0	15.4	12.8	14.2	-
Change from Spring 1997 Forecast *								
Units (K)	-	20.0	-1,201.3	-1,055.6	-266.1	154.4	194.0	-
Factory Revenue ($M)	-	-562.2	-12,146.9	-30,505.8	-37,039.0	-45,891.2	-55,156.6	-

* Negative numbers indicate revision downward for fall 1997
Source: Dataquest (February 1998)

Figure 1
Fall 1997 PC Forecast and Differences from Spring 1997 Forecast



Source: Dataquest (February 1998)

Slower PC Revenue Growth Will Impact PC Semiconductor Spending

Dataquest's forecast for PC semiconductor spending is tied to unit sales and pricing assumptions from the PC forecast and therefore must be revised downward to remain rationalized against the PC forecast. Comprehensive analysis of PC semiconductor spending is published annually following the spring PC forecast from Dataquest, but dramatic changes to the outlook for PC system revenue warrant revised PC semiconductor numbers now.

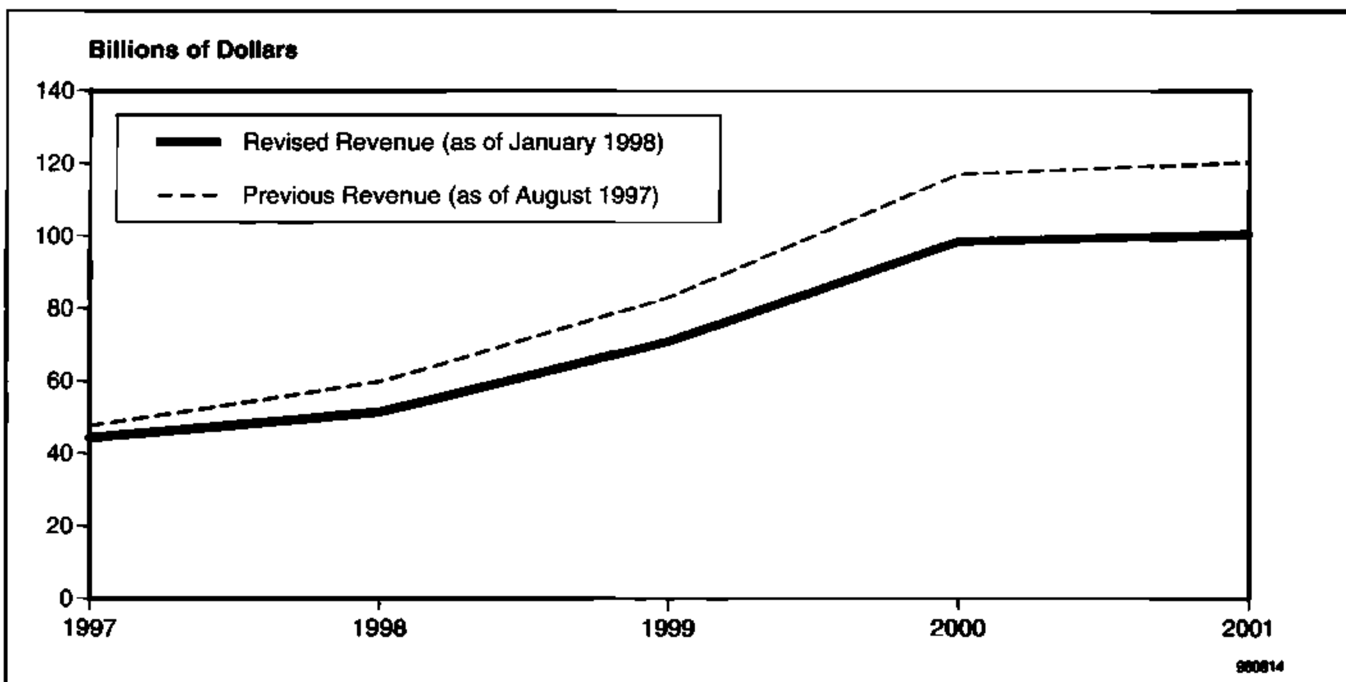
Table 2 and Figure 2 show the results from a simple ratio analysis of PC semiconductor spending, which holds the input/output (I/O) ratio of semiconductor spending to factory ASP constant. In other words, the PC semiconductor revenue was reduced by the same percentage that PC system revenue was reduced.

Table 2
Revised PC Semiconductor Revenue Forecast (Millions of Dollars)

	1997	1998	1999	2000	2001	CAGR (%) 1996-2001
Previous Revenue Forecast (as of August 1997)	47.7	59.8	83.1	117.0	120.4	26.0
Revised Revenue Forecast (as of February 1998)	44.5	51.4	70.9	98.5	100.5	22.6

Source: Dataquest (February 1998)

Figure 2
Revised PC Semiconductor Revenue Forecast



Source: Dataquest (February 1998)

The unit demand for PC semiconductor devices is likely to remain on par with previous expectations because the PC unit shipment expectations have not changed appreciably as noted in Table 1. What this means for the broad categories of PC semiconductors is discussed briefly in the following sections.

Microprocessors

Microprocessors are the most expensive single component in an average PC. Computer microprocessor vendors must acknowledge the new pricing trends for PC systems to be successful in this market. There is simply not budget for a $250 microprocessor in a sub-$1,000 PC; the budget hovers much closer to $100. Although Intel Corporation is loath to sell MPUs for less than $100, the company has voiced the intention to service all major segments of the PC market to avoid leaving too green a pasture for either Adavanced Micro Devices Inc. or Cyrix Corporation. AMD and Cyrix, however, do not have the market power that Intel wields and have identified the lower end of the market as a segment they can service competitively with their existing products. The combined forces of alternative (that is non-Intel) x86 microprocessor vendors wanting to build market share and declining PC system ASPs will most likely keep microprocessor revenue growth below PC unit growth as microprocessor ASPs stagnate and decline, reversing the ASP growth trend of the past several years.

Multimedia Chips

Widespread competition and price pressure continue to define the PC multimedia chip markets as vendors prepare for the spring design cycle. Mainstream application software still does not require 3-D acceleration, and graphics chip vendors are having difficulty charging a premium for 3-D in the corporate desktop space. 3-D accelerators have obvious benefit for entertainment and professional applications, but not for productivity applications such as Microsoft Office. 3-D graphics is rapidly becoming a standard feature for all types of PCs, but corporate desktop models are more likely to have low-end 3-D products where essentially no premium is paid for those 3-D capabilities.

Audio chips for PCs are in a similar position. Prices for basic audio chips plummeted during 1997, and the more advanced audio products have limited appeal for business PC users. Revenue growth for audio products is aided by the fact that penetration rates for audio continue to increase as basic audio becomes a standard feature for deskbound and mobile products alike.

Communications chips for wireline connections, namely modem chips and network controllers, have seen price erosion, too. Single-chip 10/100 Ethernet solutions meet the performance needs of most buyers and are competitively priced. Full 100-Mbps solutions present an opportunity to raise ASPs during the next year or two, but low-cost 10/100 products are very compelling and rather inexpensive. The modem side of communications should firm up with respect to pricing as the International Telecommunications Union (ITU) moves closer to finalizing a 56-Kbps standard. Fear, uncertainty, and doubt over the interoperability issues between competing 56-Kbps technologies dampened retail sales of finished modems in 1997 and limited PC OEM buying of 56-Kbps products, too. As a result, prices for 56-Kbps modem chipsets have fallen closer to V.34 prices than one would expect given the performance difference.

Memory

The story for memory in PCs is either good or bad, depending on whether one is buying or selling memory. Dataquest is confident in its megabytes (MB)-per-system numbers, but revenue growth will be lower than expected because of continuing softness for memory prices. Memory manufacturers are shipping more bits than ever; they just aren't getting paid much for them. This is a boon for PC OEMs and PC buyers, and it has greatly increased the number of PCs configured with 32MB or more at the factory. Of course, bargain prices on memory come at the expense of the memory manufacturers and overall semiconductor industry growth.

Success and Challenges for the Sub-$1,000 PC Market Segment

Several factors drive the lower expectations for PC revenue growth during the next five years. First and foremost is the industry focus on lower-cost PCs. 1997 marked the first time that major PC OEMs introduced innovative new products for the sub-$1,000 segment of the PC market. The new low-cost PCs are not just close-out deals on aging products; they are new products aimed to address new consumer markets. They are also here to stay, according to Dataquest, and the impact of this market segment is much greater than unit sales alone show. Table 3 and Figure 3 show the PC unit forecast with Segment 0 PC units (sub-$1,000) and Segment 1 PC units ($1,000 to $1,500) highlighted. Note that Segment 0 and Segment 1 show tremendous unit growth rates at the expense of the other segments.

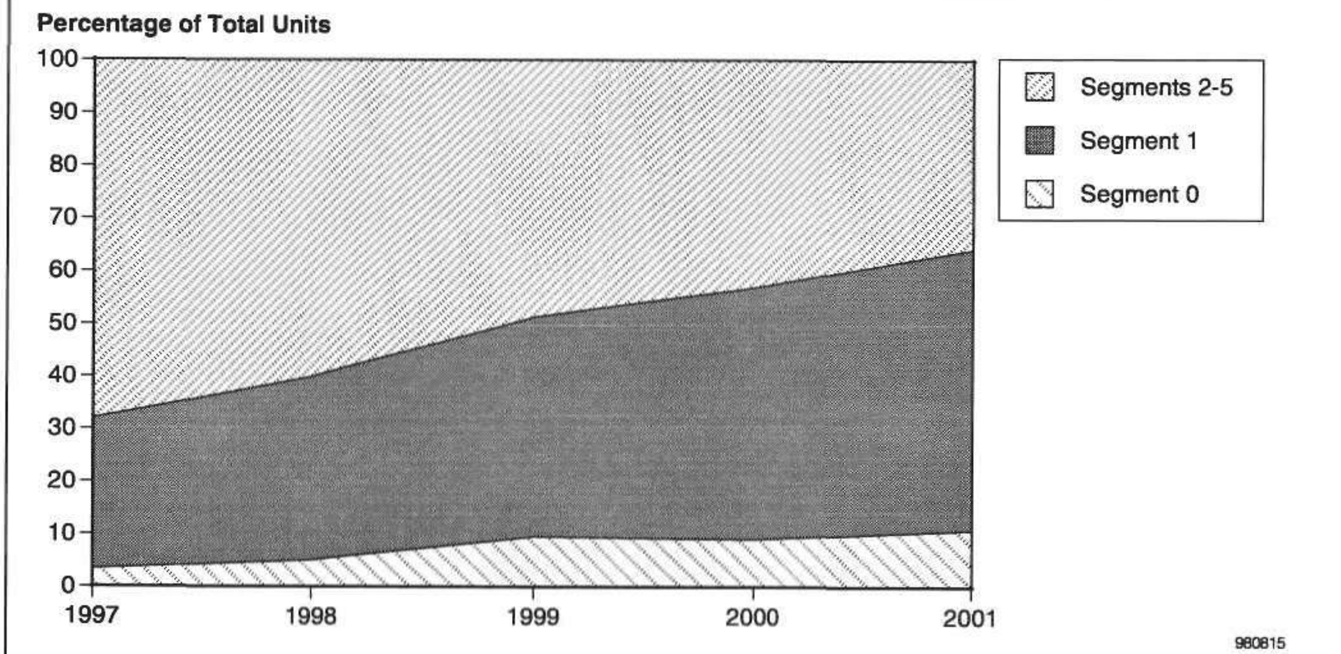
The penetration rate of PCs into new homes slowed considerably in 1996 compared to the multimedia PC boom of the previous years. Dataquest's surveys of U.S. households and their buying intentions have identified purchase cost as a barrier to higher market penetration. Many consumers in non-PC households feel that PCs were important but simply too expensive. The new sub-$1,000 PC models appeal to those potential buyers.

Table 3
PC Unit Forecast with Segment 0 and Segment 1 Breakouts (Thousands of Units)

	1997	1998	1999	2000	2001	CAGR (%) 1997-2001
Segment 0	2,768	4,837	10,535	11,601	16,004	55.1
Segment 1	23,308	33,124	46,179	61,227	78,766	35.6
Segments 2-5	57,005	59,361	56,615	58,543	57,025	13.8
Total	**83,081**	**97,322**	**113,329**	**131,371**	**151,795**	-

Source: Dataquest (February 1998)

Figure 3
PC Unit Forecast with Segment 0 and Segment 1 Breakouts



Source: Dataquest (February 1998)

Sub-$1,000 PCs also make owning a second or third PC more feasible for households that already have a PC. Lower prices make purchasing a PC for a college student or younger child easier to justify.

Problems do arise, however, as PC OEMs struggle to define compelling products in the traditional pricing bands as the new sub-$1,000 segment grows in popularity. What features justify spending $500, $1,000, or $2,000 more? Even if sub-$1,000 PCs do not parasitically drain sales of $1,500 PCs, the impact of this segment is one of lower ASPs.

Robust sales in the sub-$1,000 PC segment do not spell certain death for the $1,500 PC; in fact, Dataquest believes the reverse is true. However, PC OEMs must convince buyers that the product difference is worth the price. Dataquest believes the focus on lower-cost PCs will intensify vendors' efforts to market and sell Segment 1 products.

As Table 3 and Figure 3 show, the volume of units in Segment 1 is high, and the CAGR from 1997 to 2001 is still greater than 35 percent. That rate of growth is eclipsed by Segment 0, but Segment 0 is starting from a much smaller base in 1997, so Segment 1 products dominate the PC unit volume from 1998 through 2001.

What Is a Semiconductor Vendor to Do?

Recognize Market Bifurcation

The impact of lower-cost PCs and slower revenue growth for the PC market is fewer dollars for PC semiconductor spending. PC semiconductor vendors must demonstrate value to get the design wins. The popular press in the United States has recently fixated on consumer spending patterns that have changed from the extravagant, label-conscious 1980s to the value-conscious late 1990s. That transition is important because it characterizes an opportunity for success during the next few years. Consumers are looking for value. Why should they buy a $2,000 computer if a $1,000 model will fit their needs? Buyers focused on the more demanding applications will most likely continue to buy at traditional price points, but others can opt for lower-cost systems without the stigma of buying a PC on the edge of obsolescence.

This leads Dataquest to note the existence of a bifurcation of the market for PCs. Semiconductor vendors should recognize that bifurcation and market their products accordingly.

One lobe of this market is the continuation of the $1,500-or-more PC and the megahertz-marketing model. Users who want or need the latest and greatest features will continue to "buy up." Semiconductor vendors must continue adding new features in the traditional way to service this market. The message here is selling to the traditional $2,000 price point. This lobe is still the majority of the PC market and will continue to be so for the next few years. Additionally, the semiconductor content of PCs is skewed toward the higher end, so the concentration of semiconductor revenue is highest for this part of the PC market. The problem with this segment is sluggish growth. Most of the PC unit growth today stems from low-cost PCs.

The second lobe is the rapidly growing sub-$1,500 segment of the PC market. Buyers of this category are price-conscious but want a modern PC that will run new software adequately. Buyers are still buying to a price point to some degree, but that price point is much lower than $2,000. Dataquest believes that these buyers will buy for identifiable features and may adjust their spending plan downward if they discover they can get what they want for less money. (Example: "A Pentium-200 with MMX fits my needs, how much does it cost?") The buyer might be prepared to spend up to $1,000 but may walk out of the electronics store with a $799 PC instead of a $999 PC.

A key factor is that the fear of obsolescence does not inspire this buyer to spend more because the $799 PC is good enough. The phrase "good enough" is a scary one for the PC industry, but is a reality until a new class of mainstream applications emerge that renders Pentium-class performance inadequate.

Tailor Products to Target PC Segments

Semiconductor vendors need to tailor their products for different segments of the deskbound PC market. In this way, the deskbound PC market is being divided between categories of deskbound PC in the same way that the entire PC market was divided by the deskbound versus mobile PC splits. Mobile PCs require more sophisticated power management features as well as parts that fit into the power dissipation capabilities of mobile PC cases.

The bifurcation of the deskbound PC market requires semiconductor products that provide more bang for the buck for specific segments of the deskbound PC market. Semiconductor vendors who plan to introduce high-end products and let them ride down the price curve until they reach the sub-$1,000 PC segment will find they do not have an opportunity in the sub-$1,000 space. Some other vendor will have defined a new product that provides better value to the OEM and already will have won that business. Witness the success of the MediaGX family from Cyrix.

Can parts be forced into the market? Only by marginless pricing tactics that damage the profitability of all vendors. One need only to look at the revenue growth and profitability of the DRAM market to see the effects of forcing parts into the market through price reductions. Exceptions exist, but Dataquest expects more semiconductor vendors to create and market products specifically for the sub-$1,000 segment. Does the traditional market go away? No. Does unit growth in the market come from this new segment? Yes. Savvy vendors will participate in both markets unless they want to remain (or become) niche players.

How to Target the Sub-$1,000 PC

The sub-$1,000 PC market is not limited to the $999 price point and semiconductor vendors must be prepared to enable PC OEMs to reach $799 and even $599. Indeed, Compaq Computer Corporation and Hewlett-Packard Company have each announced sub-$800 PCs. Consumers expect these systems to have multimedia features such as CD-ROM drives, audio capabilities, and modems, so the OEM is caught between a rock and a hard place as to how to keep all the necessary features while cutting costs. Semiconductor vendors that provide system solutions with this in mind should find success. System solutions involve more than one critical function into a single chip plus software. Examples are graphics-plus-DVD solutions and telephony-plus-audio solutions. Media processors and similar products fit right up this alley. Programmability is not required but does offer many advantages as long as the total cost is comparable to fixed-logic solutions. Cost is critical because the absolute dollar margins are so thin on these low-cost PC products.

Hardware and software scalability is an important issue for the sub-$1,000 PC. The host microprocessor is capable of many diverse functions because of its general-purpose design. It is not the most effective choice in terms of dollars per function for many multimedia tasks, but its presence is a given and does not need to be justified—only its performance level needs to be justified. In contrast, adding a $25 MPEG-2 decoder chip to a PC design is a major issue and must be justified by rigorous cost/benefit analysis.

Peripheral chip vendors should critically assess their software expertise. Successful chip vendors will need to offer a range of solutions that span the range from mostly-software solutions to complete hardware solutions. Dataquest applies the term "hybrid" to solutions that partition functions between dedicated hardware and software running on the host CPU.

Hybrid solutions are already popular in PC audio as software wavetable synthesizers ship with single-chip audio subsystems that do not feature hardware wavetable synthesizers. DVD creates additional opportunity for hybrid solutions as graphics vendors add some acceleration functions to mainstream graphics products but leave decompression and decode functions to the host.

Modem functions are a third opportunity for hybrid solutions. Controllerless modem chipsets and software modems are both gaining acceptance and growing rapidly. "Software modem" is a bit of a misnomer because it is a hybrid solution. Today, a software modem requires hardware for the modem coder/decoder (CODEC) functions and analog interface.

The future will bring Universal Serial Bus (USB)-enabled telephones and could eliminate the need for any dedicated telephony hardware inside the PC. The idea is to leverage the host CPU and standard I/O capabilities as much as possible and therefore minimize the incremental cost off adding modem functions to a PC.

Dataquest Perspective

The PC market has fundamentally changed with the emergence of the sub-$1,000 PC segment. This change impacts the PC semiconductor market and creates new opportunity for semiconductor vendors who adapt to the new model. Not only must PC semiconductor vendors face slower revenue growth, they must also adapt to increasing segmentation in the market. Those that do not adapt will face a smaller market opportunity almost immediately because the viability of the sub-$1,000 segment was established in 1997, and PC design activity in 1998 will further endorse the new age of PC sales and marketing.

Chip vendors should tailor their products for narrower segments of the market. Previously, many vendors maintained desktop versus mobile PC product lines for their semiconductor devices. Now those vendors must segment their desktop products into traditional product lines and new product lines targeted at the sub-$1,000 PC segment. Dataquest facetiously suggests a new acronym to define this trend of SSSP instead of ASSP. SSSP could stand for "segment-specific standard product" instead of the "application-specific standard product" (ASSP) we all know and love.

The new products need to address system costs and integration issues to enable PC OEMs to meet the aggressive sub-$1,000 price targets with compelling designs. This focus on systems solutions rather than subsystems solutions could be infectious and travel up market into the mainstream PC segment. Semiconductor vendors that ignore this new opportunity run the risk of missing a fundamental transition of the market. This transition will most likely separate the long-term winners from the long-term losers.

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Perspective

Personal Computer Semiconductors and Applications Worldwide

Market Analysis

A Look Back at 1997

Abstract: *Dataquest reviews key events microprocessor market in 1997, the year that Time Magazine named Intel CEO Andy Grove "Man of the Year."*
By Nathan Brookwood and Joe D'Elia

Intel's Year: Challenging but Productive

Time Magazine rarely names a business person Man of the Year, so when it hands this honor to a company's CEO, one can conclude that company had an extraordinary year. Intel Corporation certainly qualifies in this regard. In addition to being named Man of the Year, Intel CEO Andy Grove earned about $94 million last year, or about $1 million for each point of share Intel held in the market for computational microprocessors. Not surprisingly, most of the year's key stories in the microprocessor market involve Intel. These are the stories Dataquest believes have most impacted the industry.

The MMX Transition

Intel kicked off the year with the launch of its "Pentium Processor with MMX Technology," and MMX continued as a theme throughout the industry for the remainder of the year. In the second quarter, Intel extended MMX to the high end with its Pentium II launch, Advanced Micro Devices Inc. introduced it in the K6, and Cyrix Corporation wove it into the 6x86MX.

Oddly, little software actually exploited the MMX instructions in 1997, and buyers did not know why they wanted MMX technology. The rapid acceptance of this technology created a minor product mix problem for all vendors, especially Intel. The vendors responded with heavy discounts on its non-MMX processors, now believed to be technologically obsolete. By year's end, it was hard to give away processors that lacked MMX technology.

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Pentium II

In May, Intel launched Pentium II (formerly known as Klamath). The initial pricing of the new design in its distinctive black cartridge limited it to desktop configurations selling for $2,500 or more. Price reductions applied at regular quarterly intervals brought this chip down into systems priced at $1,600 by year's end. Dataquest anticipates that in 1998, Intel will continue to drop Pentium II prices until even the lowest-cost systems priced at less than $1,000 incorporate this latest Intel design. At that point, toward the end of 1998, the Pentium line will fade into history (and into embedded systems), and system vendors will be able to use Pentium II processors for their highest-performance and least-expensive product offerings.

Closing the Mobile Performance Gap

During the year, Intel narrowed the performance gap that had emerged between mainstream desktop and mainstream mobile environments. In the past, mobile processor launches usually lagged the equivalent desktop versions by six to 12 months. In 1997, Intel radically changed this pattern. First it introduced desktop and mobile versions of its Pentium with MMX in January. Next, it launched its "mobile module" in March with the introduction of its Mobile Triton chipset. Then, in September, Intel used its newest 0.25-micron manufacturing process to launch yet another version of a mobile Pentium processor, bringing the mobile line up to the same 233-MHz operating frequency of the fastest desktop Pentium systems.

Lifting the Veil on Merced

Late in the year, Intel began to tell the story of its forthcoming 64-bit architecture called "Explicitly Parallel Instruction Computing" (EPIC). EPIC will first be available in Intel's Merced product, targeted for release late in 1999. Intel worked with engineers from the Hewlett-Packard Company to develop this new architecture and hopes that when EPIC systems appear they will be faster than the fastest available RISC-based computers. The RISC suppliers, including Digital Equipment Corporation with its Alpha and Sun Microsystems with its SPARC, hope to dodge Intel's bullet by speeding up their own designs.

Digital Sues Intel

In May, Digital filed suit against Intel, charging the company had used Digital's patented technology to advance the performance of its own Pentium and Pentium II processors. Digital's lawyers wrestled with Intel's lawyers for six months and finally agreed on a cross-licensing deal that also had Intel buying Digital's semiconductor operations in Massachusetts, Texas, and Israel. If the U.S. Federal Trade Commission approves the deal, Digital will become the latest semiconductor vendor to go fabless, but probably not the last, given the ever-escalating cost of semiconductor manufacturing facilities.

The C&T Acquisition

In July, Intel announced its intention to buy graphics chip vendor Chips & Technologies Inc. in a deal valued at just more than $384 million. Intel had been working with Real3D, a subsidiary of Lockheed Martin, and Chips on a single-chip graphics product due this quarter. Chips is the largest supplier of mobile PC graphics chips, with more than 46 percent market share and revenue of $134 million. When the deal closes, Intel will have the tools to compete aggressively in the graphics market. The near-term impact of this deal is minimal, but the longer-term impact could be much greater.

The FTC Inquiry

In September, the Federal Trade Commission (FTC) notified Intel that it was opening a new investigation into its business practices, including monopolistic activities, price competition, and noncompetitive pricing. A similar FTC investigation in 1993 ended with a finding that the company had engaged in no wrongdoing. Railroad boxcars were directed toward Santa Clara, California, to transport the vast quantities of documents the FTC requested Intel to produce. As the year drew to a close, the FTC had three separate ongoing investigations of Intel, including this one, a review of the Chips deal, and a review of the Digital deal. Shortly after the start of 1998, Intel received a provisional green light on its Chips acquisition, leaving only two of the investigations still active.

Swatting Errata

Twice during 1997, technical issues arose regarding the stability or accuracy of Intel's processors. Just prior to the May Pentium II announcement, an Intel gadfly announced the discovery of a bug that affected the way the new chips handled certain esoteric math functions. In November, reports surfaced on the Internet of another Pentium bug that allowed potential miscreants to maliciously halt multiuser systems such as UNIX, thus impacting other users of the system. Both times, Intel demonstrated that it had taken to heart the $475 million lesson it got following its maladroit handling of a floating-point bug discovered in 1994. It dealt with the problems in such a smooth fashion that they soon were relegated to the ranks of the erratum list, where they had belonged all along.

Competitors Wonder How Intel Makes It Look So Easy When It's So Hard

K6: The Agony and the Ecstasy

For AMD, 1997 proved to be a frustrating year. The company began 1997 awash in optimism, buoyed by tests that showed its new K6 microprocessor could deliver highly competitive performance. It announced the product in April and aggressively pursued OEM deals with major system vendors. Unfortunately, AMD's ability to manufacture the part in high volume lagged its ability to design and sell the chip, and the company continued to struggle financially. As 1998 begins, the world still waits for AMD to perfect its manufacturing processes and pose a serious challenge to Intel's microprocessor dominance.

Compaq Endorses Sub-$1,000 PC with Cyrix-Based Entry

Cyrix struggled throughout 1996 to win a major OEM customer; its efforts finally bore fruit early in 1997 when Compaq Computer Corporation introduced its $999 Presario 2100 that included a Cyrix 133-MHz MediaGX processor. Compaq's use of the MediaGX processor represented a new degree of acceptance for Cyrix within the OEM community. The lasting impact of the Presario 2100 may be that it legitimized the sub-$1,000 PC category. Compaq followed this with the launch of the $799 Presario 2200, also based on the MediaGX. These aggressively priced systems let the genie out of the bottle, forcing all PC vendors to adapt their business models to cope with lower-priced systems.

National Re-Enters CPU Business with Cyrix Acquisition

In July, National Semiconductor Corporation announced plans to acquire chipmaker Cyrix for about $550 million, a transaction it completed in November. The companies have attempted to spin this acquisition as a high-integration, consumer PC/compute appliance story and have focused their announcements on the sub-$1.000 and sub-$500 highly integrated PC segments. The fusion of NSC's Super I/O, networking, communications and analog skills, and Cyrix's CPU cores makes for a very powerful combination. Dataquest expects that NSC's new 0.25-micron fab in Portland, Maine can provide Cyrix with much-needed manufacturing capacity at a lower cost than it could achieve through its IBM foundry agreements. Dataquest anticipates that as a National subsidiary, Cyrix will continue its relationship with IBM both to augment National's resources and to provide access to advanced manufacturing processes such as IBM's recently introduced copper metalization technology. For its part, IBM also expects to continue its Cyrix relationship.

IDT Enters x86 Business via Centaur Subsidiary

In October, Integrated Device Technology Inc. entered the x86 market when it announced its WinChip C6 processor, designed by Centaur Technology Inc., a wholly owned IDT subsidiary. At 5.4-million transistors, this processor measures only 88 mm^2 when manufactured on IDT's 0.35-micron, 4-layer-metal CMOS technology. IDT intends to price this product aggressively and targets price-sensitive third-world markets. Given the price erosion the SRAM market has experienced over the past two years, the x86 market must look very attractive to IDT. If the company can overcome the challenges of competing with Intel, it may very well succeed in carving a niche for itself in this lucrative market.

TI Exits the x86 Business

After years of trying to crack the x86 market by licensing designs from Cyrix, and trying to design its own chip in-house, Texas Instruments Inc. finally concluded the grass was greener in the DSP field and wound down its x86-related efforts. Wall Street appears to like this move and has doubled the value of the company's stock since it made its decision to focus on a few key areas of strength.

Perspective

Personal Computer Semiconductors and Applications Worldwide

Dataquest Predicts

Will Modems Get "Soft" or Keep a Stiff Upper Lip?

Abstract: OEMs face new decisions regarding how they add modem functions to their products. New software programs and faster microprocessors now make soft modems more feasible than before. This document examines the market issues of soft modems versus hardware modems and provides a forecast of software modem opportunities.
by Geoff Ballew

Modem Chip Vendors Face Software Competition

Modem chip vendors are facing new competition—not from other chip vendors but rather from software vendors. As microprocessors get faster, new vendors want to grab a share of the lucrative modem chip market by selling software that leverages the host microprocessor of a PC or other electronic equipment. Traditional vendors do not want to lose business and will fight to keep their bread and butter. At issue are the cost and performance issues that surround many hardware versus software debates.

Software Modems as a Product

Definition of a Software Modem

Dataquest defines a software modem as a modem that uses software running on the CPU or host microprocessor to perform the controller and data pump functions of a traditional modem. To clarify this, it is appropriate to explain briefly the major components of a modem. Four major functions are necessary in a modem: a coder/decoder (codec), a data pump, a controller, and a host interface. The codec converts information between digital signals required on the PC side of the modem and the analog signals required by standard telephone services. The data pump performs a variety

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of digital signal processing tasks including error correction, data compression, and modulation. The controller communicates with the host to schedule bus traffic and interpret the standard modem commands. The host interface is the connection to the PC system.

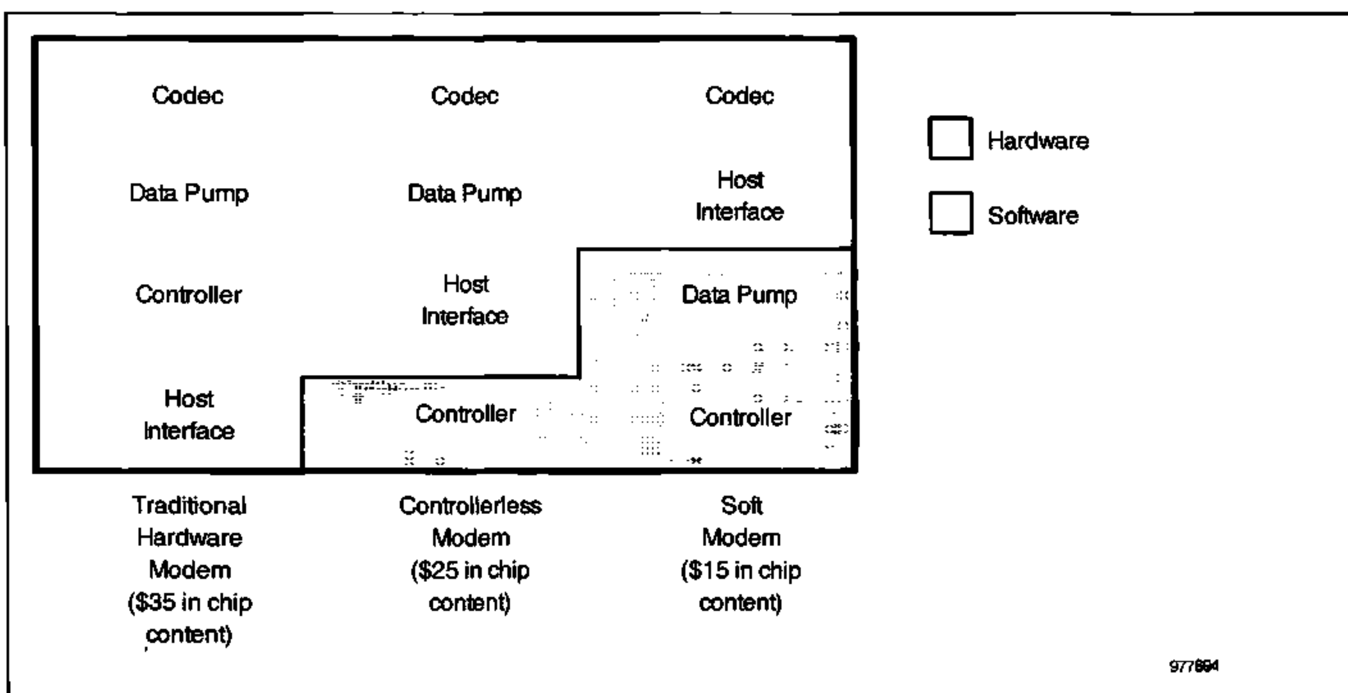
Traditional hardware modems comprise one or more chips that provide all four of those functions with the controller and host interface typically integrated onto the same chip. Software modems have one chip containing the codec and host interface, providing all other functions via software that runs on the host MPU. Software modems are also called "soft modems" for short. Controllerless modems are another class of products that use the host MPU for some processing, specifically that of the controller, but provide all other functions in hardware. Figure 1 shows the differences between these types of modems.

The Promise of Software Modems

The first question to be answered is what benefits could soft modems bring to an OEM versus a traditional hardware modem? First and foremost is lower prices, but other benefits stem from smaller form factors and upgradability.

Software modem vendors cite cost savings as the biggest benefit. Indeed, this is the primary motivation for OEMs to buy soft modems. Gross margins are thin for PCs and other consumer electronics goods, so OEMs are always looking for ways to cut their costs without compromising value. Manufacturing economics naturally favor software products over hardware

Figure 1
Hardware versus Software Functions for Modem Categories



Source: Dataquest (October 1997)

products. Fewer parts and less physical material translates to lower per-modem costs in high volume in addition to making fab capacity issues less relevant.

Another benefit of software modems is space savings. Internal modems are common for mobile PCs where size and weight are critical issues. This issue becomes more extreme for handheld PCs such as Windows CE machines or products such as the Palm Pilot, which fits in a typical shirt pocket. Space savings is not a significant issue for deskbound equipment other than the lower cost from using less physical board space.

Software modems also offer greater upgradability than traditional modems. Most modems sold in the past were not upgradable at all. Users had to purchase new modems if they wanted new features or higher performance. This condition has changed to some degree as more hardware modems use flash memory instead of ROM to store information such as modem protocols, but this is driven more by the lack of an International Telecommunications Union (ITU) standard for 56-Kbps (56K) operation than general upgradability. Modem chipsets that support 56K operation need to be upgradable to the future ITU standard in order to have market appeal. So, despite the fact that many of today's new hardware modems are upgradable, this circumstance could change once an ITU standard for 56K operation is ratified. Software modems are inherently upgradable because the software can be replaced with new versions.

The Problems with Software Modems

The benefits of software modems do come with some caveats, otherwise we would all be using them today. Both technical and market issues exist. The technical issues include compatibility with mainstream operating systems, the robustness of software modems compared to hardware modems, and compatibility with other software applications. Market issues include the perceived value by consumers and OEMs of hardware modems versus software modems and the fear, uncertainty, and doubt (FUD) of OEMs when moving from an incumbent solution to a new solution.

Compatibility with mainstream operating systems is critical to the success of software modems. Windows 95 is the volume leader for installation on new PCs, but Windows 3.1 (and DOS) are still in widespread use. These operating systems do not have true support for real-time processes such as modem communications. Windows 95 is superior to Windows 3.1 for real-time tasks, and Windows 98 will be better still, but "better" does not necessarily mean robust.

The robustness of software modems is a difficult issue because vendors on both sides of the issue claim to have data from extensive testing that proves their points. Latency, whether related to the bus or the CPU, is the most likely cause of any degradation in robustness for software modems. Software modem vendors claim their testing shows no difference in connect rates, dropped calls, and connect speeds. Hardware modem chip vendors claim their test results show that software modems are less robust in all categories.

Dataquest leaves this as an open question and advises OEMs or other buyers of modem chips to examine this issue thoroughly.

Compatibility with other software applications is a bottomless pit in some respects because it is logistically impossible to test every application. Compatibility in this case is not whether an application can use the modem, but rather it can coexist with the modem without causing noticeable problems. Games and the plethora of shareware/freeware are the greatest potential sources of problems. Mainstream business applications are more likely to behave according to the rules, particularly those applications written by Microsoft and other major software application vendors. This is an issue for software modems because of the greater dependence on the CPU and tighter integration with the operating system.

Market Impact and Potential

Competitive Dynamics

The modem chip market has only a few major vendors. Three vendors—Rockwell Semiconductor Systems, Texas Instruments Inc., and Lucent Technologies—control almost 90 percent of the market in terms of revenue. None of these vendors sell software modem products, but they have the most to lose if software modems become popular. They are now battling each other over standards for 56K operation, and each is working to build market share and mind share for its version of 56K technology. Rockwell and Lucent have partially teamed up for the 56K battle and mutually promote a joint standard called K56flex. TI is aligned with modem (not modem chipset) powerhouse 3Com Corporation. (3Com purchased U.S. Robotics Inc. to gain a dominant position in the modem market.)

These modem chip giants are strong companies with captive fabs. Dataquest believes they will defend their turf (that is, the lucrative modem chip market) aggressively if they believe they are threatened by software modem vendors. They could do this by becoming more aggressive on pricing because their chip fabrication is handled internally. Rockwell and Lucent also have the advantage of owning their modem intellectual property (IP). TI licenses a substantial amount of IP from 3Com, continuing its U.S. Robotics relationship. Similarly, all of the software modem vendors must license modem IP from other companies because they do not own it. License fees amount to a couple of dollars for a V.34 modem and a few dollars more for a 56K modem.

Dataquest also believes that each of the three big vendors has internal software modem projects. This is not to say that actual software modem products will be forthcoming, but simply that these vendors are aware of the potential threat.

The only modem chip vendor with a foothold on each side of the hardware/software line is Motorola Incorporated. Table 1 lists the key vendors for software modems and traditional hardware chipsets, with both lists in alphabetical order.

Table 1
Key Modem Chipset and Software Vendors

Software Modems	Hardware Modem Chips
AltoCom	Lucent Technologies
HostModem	Rockwell Semiconductor
Motorola	Texas Instruments
PCtel	
Smartlink	

Source: Dataquest (October 1997)

Market Forecast

The market for hardware modems is well established, and modem functions are growing not only in PCs but other applications as well. The Dataquest forecast for modem chipsets provides a "most likely" demand scenario for modem functions. Figure 2 shows the unit forecast for modem chipsets with three scenarios for software modem shipments. The top-line modem chipset forecast includes the "conservative" forecast for software modem shipments. However, software modems could create upside unit demand because of the lower price points for a given feature set. Dataquest believes the most likely scenario involves moderate success for software modems and somewhat greater overall demand for modem units. A third scenario, termed "optimistic," involves much greater unit volumes for software modems stemming from widespread acceptance. Both the most likely and optimistic scenarios involve modem functions being bundled with audio functions as standard features. Table 2 presents the data in Figure 2 as text.

The key assumptions for the three demand scenarios are as follows.

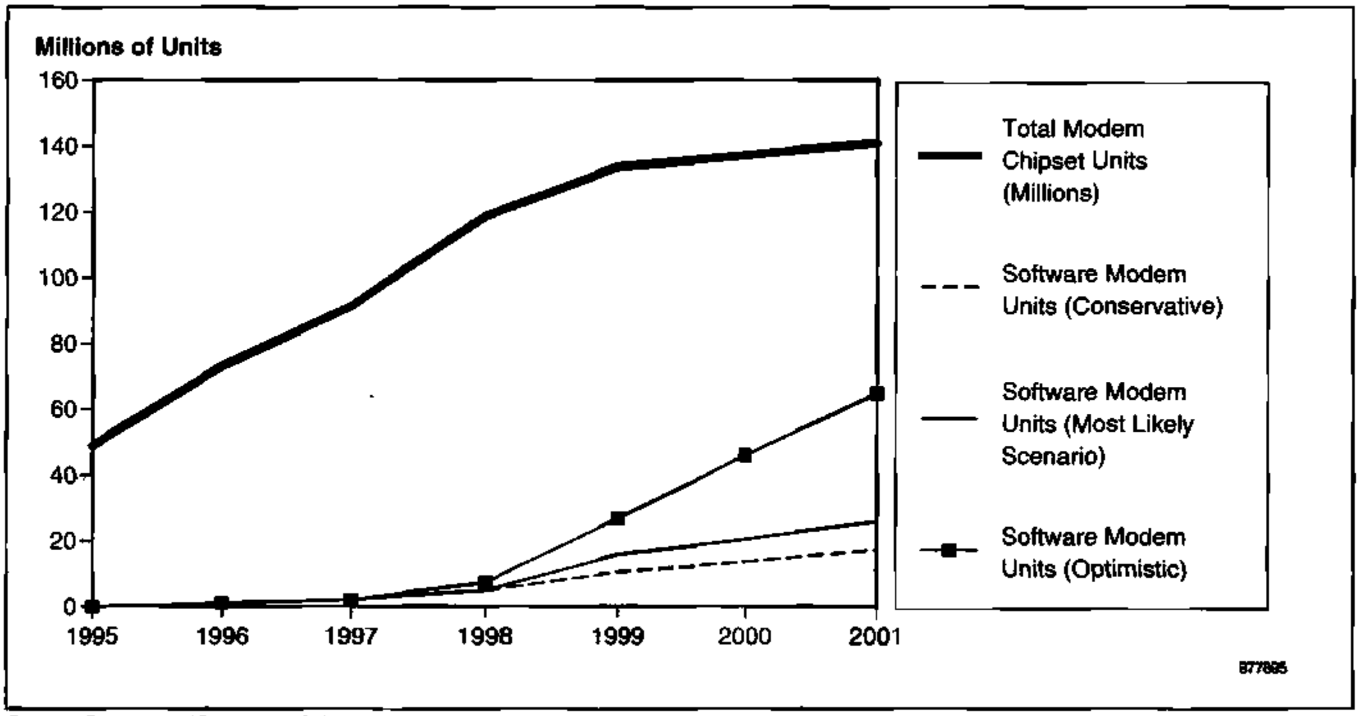
Conservative Scenario

There will be steady progress for software modem vendors selling into standard PC or handheld PC markets. PCtel Inc. shipped 1 million units last year, and AltoCom Inc. is designed into the Philips Velo, a Windows CE-based handheld PC. Shipments for the software modem market could easily double each year without significant impact on the overall modem market. Growth is limited because of a lack of acceptance of software modems by top-tier OEMs for any high-volume deskbound PC product lines. The retail market will not develop over the forecast period. Mainstream operating systems will continue to lack real-time support for software modems.

Most Likely Scenario

Software modems will begin to win more designs in the PC market, but design-wins will be limited to the lower end of the deskbound market and bottom half of the mobile PC market. The initial success of PCtel and AltoCom will allay the FUD factor, but hardware modem vendors will keep prices for hardware modems low enough to limit software modem penetration. Some PC audio subsystems will be designed with software modem features and either a dual-purpose audio/telephony codec or a

Figure 2
Modem Chipset Forecast



Source: Dataquest (October 1997)

Table 2
Modem Chipset Forecast, 1995-2001

	1995	1996	1997	1998	1999	2000	2001	1996-2001 CAGR (%)
Total Modem Chipset Units (M)	**48.83**	**73.23**	**91.46**	**118.85**	**133.71**	**137.19**	**141.03**	**14.0**
Total Modem Chipset Revenue ($M)	**1,246.3**	**2,131.9**	**2,225.6**	**2,713.5**	**2,637.4**	**2,487.6**	**2,267.9**	**1.2**
Conservative Scenario								
Software Modem Units (M)	0	1.10	2.06	4.95	10.50	13.63	17.28	73.5
Software Modem Revenue ($M)	0	18.0	23.0	51.0	97.0	113.0	125.0	47.2
Total Market by Units (%)	0	1.5	2.2	4.2	7.9	9.9	12.2	-
Total Market by Revenue (%)	0	0.9	1.0	1.9	3.7	4.5	5.5	-
Most Likely Scenario								
Software Modem Units (M)	0	1.10	2.06	4.95	15.75	20.45	25.91	88.1
Software Modem Revenue ($M)	0	18.0	23.0	50.7	144.8	168.8	187.8	59.6
Total Market by Units (%)	0	1.5	2.2	4.2	11.8	14.9	18.4	-
Total Market by Revenue (%)	0	0.9	1.0	1.9	5.5	6.8	8.3	-
Optimistic Scenario								
Software Modem Units (M)	0	1.10	2.06	7.42	26.78	46.01	64.79	126.0
Software Modem Revenue ($M)	0	18.0	23.0	76.0	246.2	337.6	413.0	86.8
Total Market by Units (%)	0	1.5	2.2	6.2	20.0	33.5	45.9	-
Total Market by Revenue (%)	0	0.9	1.0	2.8	9.3	13.6	18.2	-

Source: Dataquest (October 1997)

separate telephony codec. The retail market for software modems will not develop over the forecast period.

Optimistic Scenario

Software modems will gain acceptance and grow quickly in PC applications and some embedded, consumer-electronics applications. The issues of robustness and compatibility will be viewed as insignificant by OEMs and PC buyers. Top-tier PC OEMs will endorse software modems and use the low unit cost to add modems as a standard feature to many deskbound PCs targeting corporate buyers in addition to mobile PCs. (Deskbound PCs targeted at consumers already have modems as standard features.) The retail market for software modems will develop, but it will be mostly associated with multifunction audio cards and some media processor-based cards. Hardware modem vendors will react by lowering prices but will be limited by profitability issues. Hardware modem vendors will lose unit market share but maintain a smaller, profitable business.

Dataquest will watch the adoption rates of software modems by top-tier OEMs as the single-most-important indicator for the long-term success of software modems.

Dataquest Perspective

The software modem market is beginning to develop and should not be ignored by anyone. OEMs are advised to investigate software modems as an opportunity to make modem features more ubiquitous, particularly for corporate desktop PCs. Part of that investigation should be asking the hard questions about robustness and compatibility. Hardware modem chip vendors should not be overly concerned about losing sales today, but they are advised to plan software modem products as part of their product road map for 1999. Let the customers choose the software/hardware combinations that fit their needs because they may change vendors to do so, if their preferred vendor fails to deliver scalable solutions. Chip vendors will need to walk a delicate line to balance the threat of losing sales to software modem vendors against the danger of prematurely obsoleting hardware chipsets by introducing lower-cost software modem products.

Scalability between hardware and software solutions is an important trend for digital video disc (DVD) video and audio features in PCs. Although modems entail different issues regarding hardware and software scalability, do not assume that they are exempt from this trend—or do so at your own risk!

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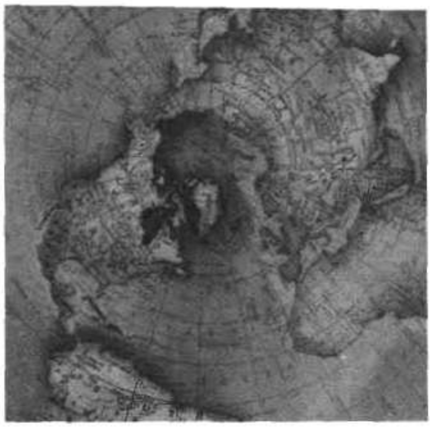
Market Trends



Dataquest

Multimedia Market Trends, 1998

Market Trends

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Filing: Market Trends

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Chapter 1
Executive Summary

1997 Snapshot

The multimedia market continues to grow, with a healthy 47 percent growth in overall unit shipments from 1996 to 1997 and a 52 percent growth in revenue in the same period. The top categories experiencing growth included 3-D graphics/playback boards, voice recognition, video servers, video editing software/capture peripherals, computer-based training (CBT) authoring tools, and modeling/animation software. Although the shipments of multimedia PCs (MMPCs) with CD-ROM drives grew 74 percent from 1996 to 1997, Dataquest believes that this was the peak year, with the transition to DVD-ROM drives already happening.

The categories that did not fare so well included authoring tools (with Macromedia Inc.'s Director dominating this category), multimedia kits with CD-ROM, sound boards, and videoconferencing. Although some of these are in an obvious stage of decline, being replaced by competing technologies, the decline in some categories is more a result of the transition to cheaper products, which is making it more difficult to be profitable. Videoconferencing is a perfect example of the latter. While the percentage of organizations in the United States using videoconferencing increased 74 percent from 1996 to 1997, many of these vendors are finding it extremely difficult to be profitable and are redefining their business models.

Home versus Business

The home market has so far been the focal point of multimedia activities. Consumers took to MMPCs more readily than businesses did. In 1998, multimedia has become mainstream in the consumer segment, with corporations just beginning to consider the potential applications. There are a number of factors indicative of this trend. The percentage of businesses using videoconferencing systems has gone up from 1996 to 1997, with the potential for it to go up even further in the next two years. The percentage of MMPCs in corporations continues to increase. The percentage of U.S. organizations that intend to use streaming video in the next two years is also impressive, given the age of this technology. The Web is also providing the impetus for the use of multimedia in the commercial sector.

PC/TV versus TV/PC

With the introduction of Web TV-like devices and the debut of digital television (DTV) later this year, the trend toward TVs acquiring PC capabilities and PCs acquiring TV capabilities is clear. DTV will also make it necessary for broadcasters to switch to digital broadcasting. Although these stations can technically meet legal requirements by simply changing their tower and transmitter, Dataquest believes that most of them will begin the transition to digital equipment, albeit slowly. Thus, the market for video production-related hardware and software will continue to grow in these segments during the next seven years.

Chapter 2
Report Objectives

Dataquest's Multimedia Worldwide program provides in-depth analysis of markets, products, technologies, and issues that affect various markets impacted by multimedia technology. It is a comprehensive program that covers a wide range of multimedia technologies and products and provides qualitative and/or quantitative analysis of the worldwide market for the following areas:

- Capture devices, such as digital cameras, camcorders, PC cameras/kits, and video capture devices
- Creation software/hardware, such as 2-D and 3-D animation, video editing, and video production equipment
- Playback devices/peripherals, such as sound and video boards, speakers, and MMPCs
- Multimedia communication technologies, such as videoconferencing, voice recognition, and streaming video

The specific objectives of this report are as follows:

- To identify the demand- and supply-side issues, technological developments, and environmental trends shaping the industry
- To estimate the size and growth (decline) of various market segments based on key market forces
- To examine major opportunities and challenges facing vendors competing in various multimedia markets
- To provide specific, actionable recommendations based on the above factors

(For more details on market share and forecast, please refer to Dataquest reports MULT-WW-MS-9801, MULT-WW-MS-9802, and MULT-WW-MS-9803.)

Definitions and Methodology

Multimedia Definitions

Multimedia

Dataquest defines multimedia as the creation or playback of a combination of more than two media, at least one of which is time-sequenced, such as audio or video. An example of more than two media generally would include text, audio, and video, but it could also be text, audio, and animation.

Computer-Based Multimedia

Computer-based multimedia is multimedia content recorded or played back using microprocessor or digital technology on PCs and workstations in conjunction with software and add-in boards and peripherals.

Computer-Based Multimedia Hardware

Computer multimedia hardware is any computer-based hardware that can record or play back multimedia content. This is in contrast to analog multimedia hardware, such as TVs, which have no digital components. More specific definitions are as follows:

- Multimedia-capable computers—Computers that can record or play multimedia content, given sufficient processor speed, RAM, and storage. Multimedia-capable computers do not necessarily include a CD- or DVD-ROM drive. A multimedia-capable computer is based on an Intel Pentium, Motorola PowerPC, or better, series of processors.
  - Multimedia-capable PCs—PCs that fulfill the requirements for multimedia-capable computers
    - Complete MMPC systems—Multimedia-capable PCs equipped with sound capability and a CD- or DVD-ROM drive
      - Deskbound PCs—These systems have all the physical characteristics and functionality outlined in the PC definition and come in deskside and desktop versions.
      - Mobile PCs—These systems meet all other criteria for PCs but are designed to be easily transportable; they come in notebook, laptop, and ultraportable versions.
  - Multimedia-capable workstations—Workstations that fulfill the requirements for multimedia-capable computers
    - Complete multimedia workstation systems—Workstations equipped with sound capability and a CD- or DVD-ROM drive
  - Video production hardware
    - Video production systems, turnkey—Production systems that are turnkey nonlinear digital systems based on a PC, Macintosh, or workstation (for example, from Silicon Graphics Inc.) and include a capture board and editing software application
    - Video editing/capture boards and peripherals—Add-in boards or external devices that digitize analog video signals and/or support the editing of digital video files
  - Motion Picture Experts Group (MPEG) capture and encode boards—Expansion boards that digitize analog video signals and convert the digital data into MPEG formats
- Discrete sound boards—Sound boards are PC expansion boards that provide analog audio outputs for amplification. Discrete sound boards are sold alone rather than in a multimedia kit.
- Multimedia kits, CD-ROM—An upgrade kit for a PC, Macintosh, or workstation. It includes, at a minimum, a sound board and a CD-ROM drive.
- Multimedia kits, DVD-ROM—An upgrade kit for a PC, Macintosh, or workstation. It includes, at a minimum, a sound board and a DVD-ROM drive.

- Discrete multimedia CD-ROM drives—CD-ROM drives for a PC, Macintosh, or workstation that are sold alone. These can be in internal or external form factors.
- Standalone speakers—Speakers for PCs that are not integrated into a computer/monitor or bundled with a kit or system. This is the after-market or "add-on" market for speakers.
- Video, graphics, and 3-D boards—PC add-in boards that provide enhanced video/graphics capability.
  - Integrated 3-D graphics/playback boards—Expansion boards that provide integrated 2-D, 3-D, and/or video display, acceleration, and playback features to enhance performance.
  - TV tuner boards—Expansion boards or daughtercards that receive television signals and display the images on the PC monitor. These boards are exclusively TV tuners, but they often operate in conjunction with other PC video boards.
- Videoconferencing—Computer hardware and telecommunications equipment used to compress and play video of meetings of groups or individuals
  - Group videoconferencing—Videoconferencing equipment that is designed for group use. These digital systems can be permanently installed and configured in a conference room or can be moved from room to room on a rolling cart; they use dedicated communications equipment apart from the computer, which in most cases is a workstation but could be a PC or set-top box.
  - Desktop videoconferencing—Videoconferencing systems designed for individual use. These digital systems are integrated into a PC or workstation, generally on one board that sits in a bus slot.
  - PC videoconferencing kits/cameras—Kits with video cameras that can be attached to the PC and provide video compression and conferencing capability in conjunction with bundled software.

Computer-Based Multimedia Software

Computer multimedia software includes multimedia applications and tools. More specific definitions are as follows:

- Voice recognition software—This software recognizes human speech and translates it into computer text.
- Video server software—Software that allows the user to access digitally stored data, such as videos, from a video server. One example is StarWorks, the flagship product from Starlight Networks Inc.
- Multimedia production software—Software used to create multimedia content or applications software. It includes authoring tools, animation and rendering tools, video editing, and other multimedia development tools, all of which are used in the creation of multimedia products.
  - Video editing software—Software-only editing applications used to edit video. Examples include Adobe Premiere and in:sync corporation's Razor.

- Low-end video editing software—Software-only editing applications used to edit video that have partial or "lite" feature sets. Typically, these products are bundled with video hardware.
- 3-D modeling and animation software—Software that combines 3-D modeling, rendering, and animation features to create 3-D characters and environments for applications such as games and education. These tools are used in conjunction with other tools, such as authoring tools, for the production of the completed product.
- 2-D modeling and animation software—This software is used for creating 2-D animation.
- Compositing software—This software combines multiple images, video, and animation with effects and transitions into a single playback file.
- Authoring tools—Authoring tools allow the author of an interactive multimedia application to incorporate finished products from other tools (such as photos from Photoshop or edited video from Premiere) into a general-purpose playback environment. Examples include Macromedia's Director and Quark Inc.'s mTropolis software.
- CBT authoring tools—CBT tools are similar to authoring tools but have feature sets that are optimized for the creation of multimedia content for interactive training. Examples include Macromedia's Authorware and Asymetrix Learning Systems Inc.'s IconAuthor.

- Videoconferencing and data conferencing software—This software runs on a PC or other type of videoconferencing system for the purpose of enabling real-time audio and video of the participants or real-time sharing of documents and speech or whiteboarding.

Methodology

Dataquest's Market Trends report provides qualitative analysis of trends in the multimedia industry; it is based on a variety of information sources, which include the following:

- Historical and projected vendor and supply-side data
- User and demand data from Dataquest's User Wants & Needs studies
- Qualitative and quantitative input from vendors
- Overall trends in other technology areas tracked within Dataquest

Chapter 3
Home versus Business Market

Multimedia in the Home

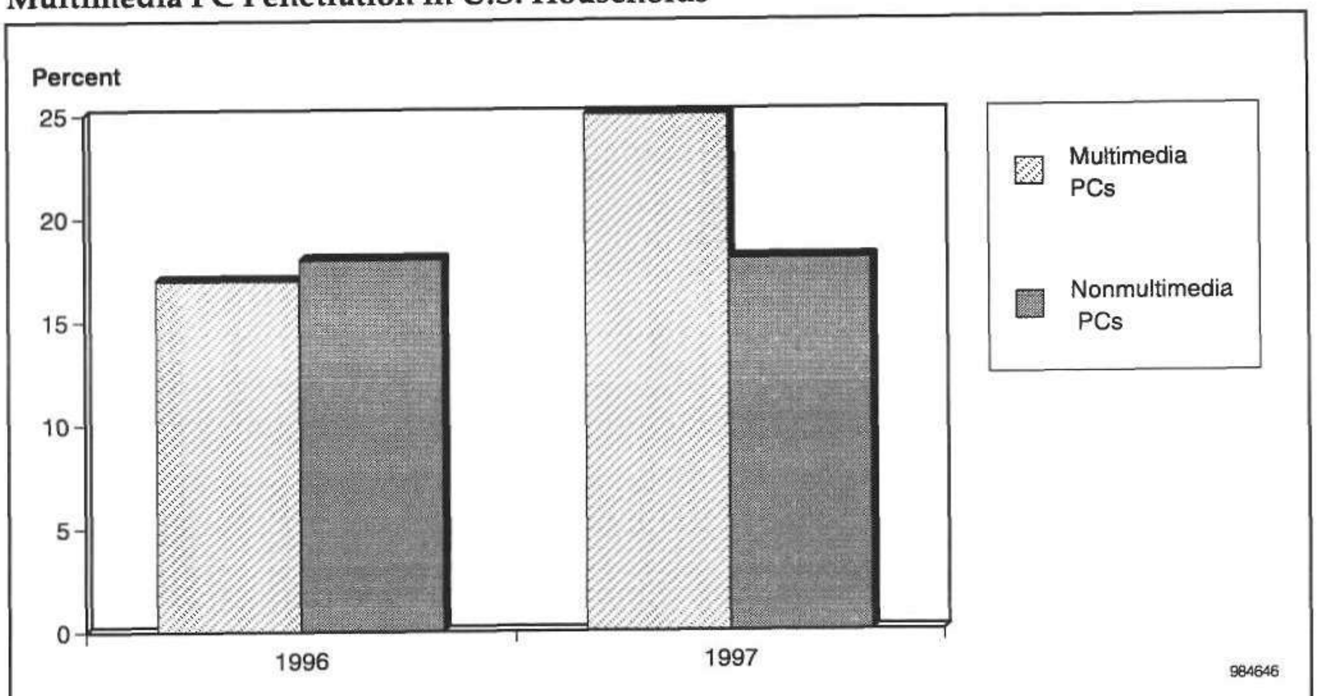
Dataquest defined an MMPC as a computer system with sound capability that includes a CD-ROM drive. This definition was created in 1993 when MMPCs and the term "multimedia" were a novelty. In 1998, multimedia has come a long way—from an emerging industry to a growing market.

Multimedia PC in the Home

In 1997, 43 percent of U.S. households reported owning a PC, compared to 35 percent in 1996. Twenty-five percent of U.S. households in 1997 had an MMPC (defined as a computer system with a sound card, speakers, and a CD-ROM or DVD-ROM drive), compared to 17 percent in 1996. This reflects a minimum installed base of 25 million MMPCs in U.S. homes, as more than one PC in any home could be an MMPC (see Figure 3-1).

In 1997, 76 percent of PCs shipping into U.S. homes were MMPCs (as defined previously).

Figure 3-1
Multimedia PC Penetration in U.S. Households



Source: Dataquest (June 1998)

New Multimedia Technologies in the Home

In 1998, multimedia has become mainstream. The question now is one of the penetration of new multimedia technologies such as DVD-ROM drive into PCs and 3-D/video in homes and enterprises.

Although DVD as a technology has certain advantages over CD, its adoption has been slower than expected because of competing standards, a lack of software titles, and cost differences between a CD-ROM and a DVD-ROM drive. With the popularity of sub-$1,000 PCs, there is less of an incentive for PC manufacturers to replace CD-ROM drives in PCs.

That manufacturers of DVD-related products need to launch more educational promotion is evident from the fact that 19 percent of U.S. households surveyed in 1997 mentioned purchasing a DVD-ROM drive, and the vast majority of these respondents also mentioned purchasing a CD-ROM drive. DVD represents true convergence between electronics and computers, and this by itself is enough to warrant greater education of consumers, who are bombarded by advertisements regarding PCs with DVD-ROM drives, DVD players, and Digital Video Express (DIVX), to add to the confusion.

CD-ROM drives in PCs no doubt will slowly be replaced by DVD-ROM drives. Dataquest anticipates that about 2.3 million PCs in 1998 will ship with DVD-ROMs installed, compared to 590,234 PCs in 1997. Dataquest expects the number of PCs shipping with DVD-ROM drives to overtake those shipping with CD-ROM drives in 2002. As has been the case with MMPCs traditionally, the penetration of PCs with DVD-ROM drives initially will be greater in the home market.

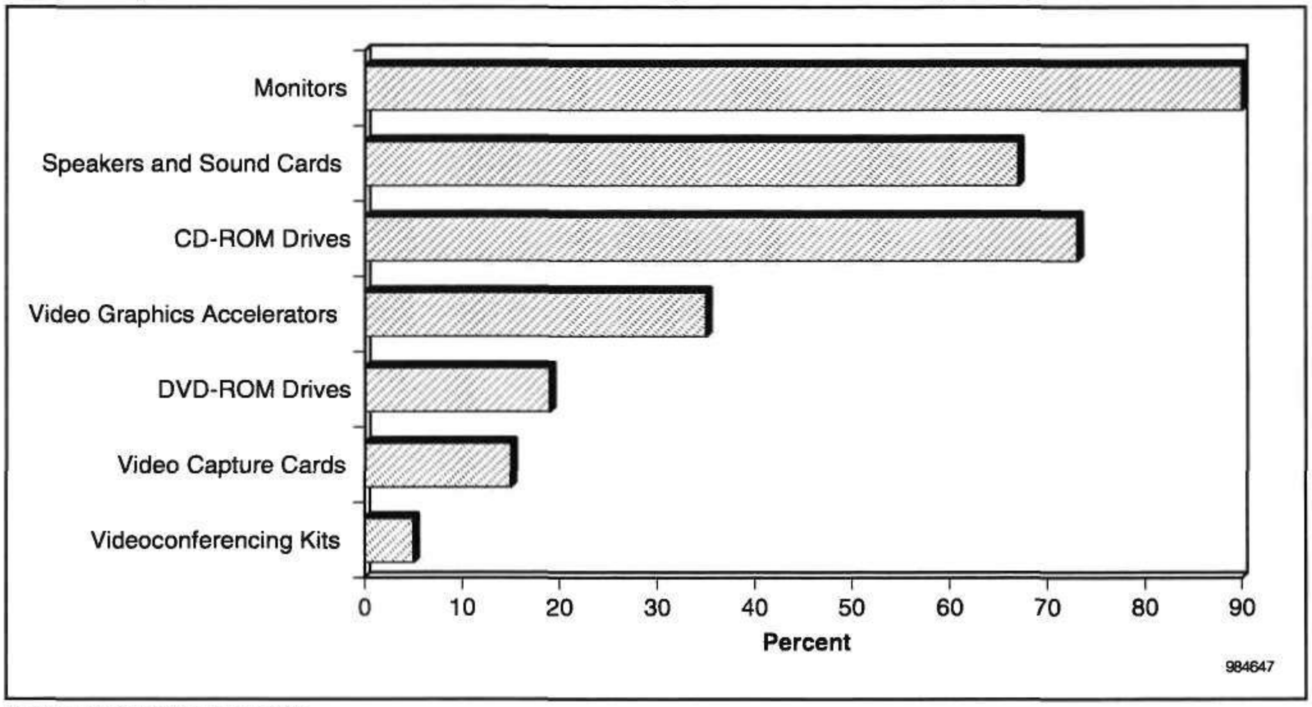
Figure 3-2 shows the percentage of PC households in the United States purchasing different multimedia peripherals. Monitors (90 percent), sound cards and speakers (67 percent), and CD-ROM drives (73 percent) are the top-mentioned peripherals most recently purchased with PCs by U.S. home consumers. Other peripherals that showed relatively good penetration levels included video graphics accelerators and video capture cards.

Demographic Profile of Home PC Owners

Multimedia or otherwise, in the United States, PC ownership is strongly related to education, income, and the presence of children in the household. It is possible that the income factor may become less of an influence as the penetration of low-priced PCs increases.

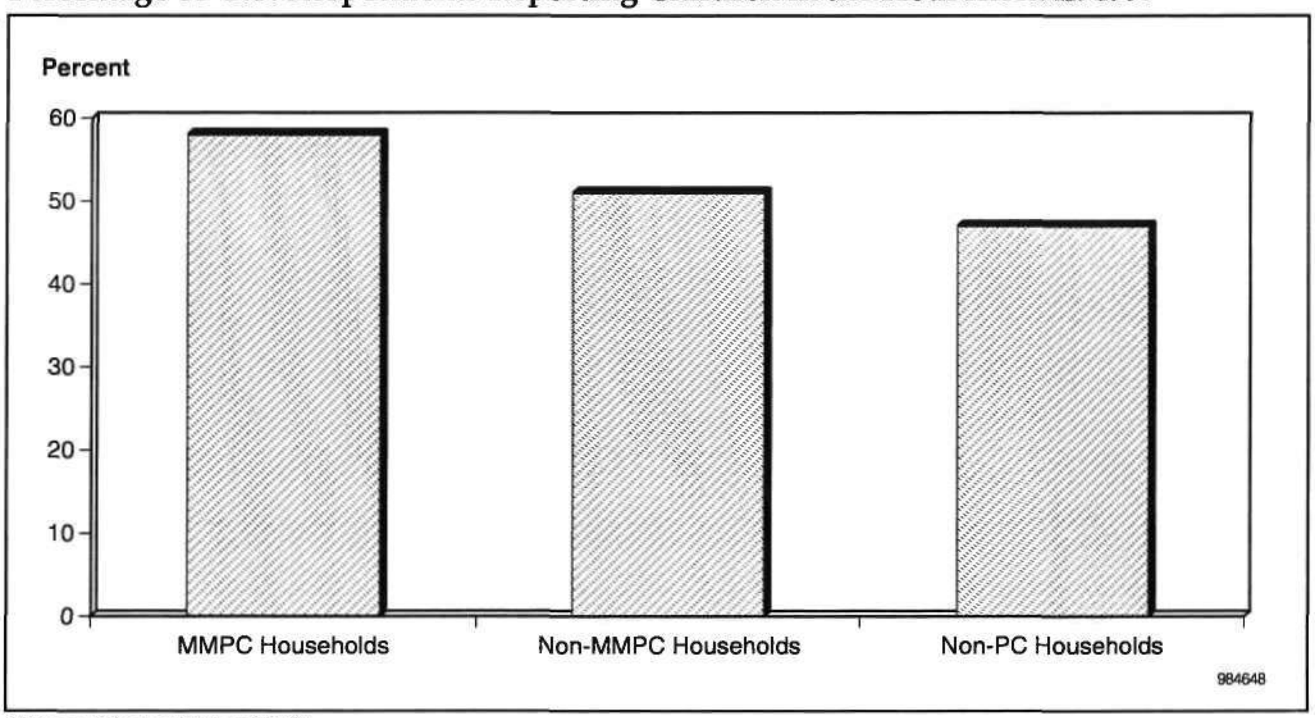
Children appear to be another factor that is positively related to PC ownership, and especially to MMPC ownership. Only 47 percent of U.S. non-PC households reported having children living in the household, compared with 58 percent among MMPC households and 51 percent among non-MMPC households (see Figure 3-3).

Figure 3-2
Percentage of U.S. PC Households Purchasing Multimedia Peripherals in 1997



Source: Dataquest (June 1998)

Figure 3-3
Percentage of U.S. Respondents Reporting Children in the Household in 1997



Source: Dataquest (June 1998)

Future Growth Expectations

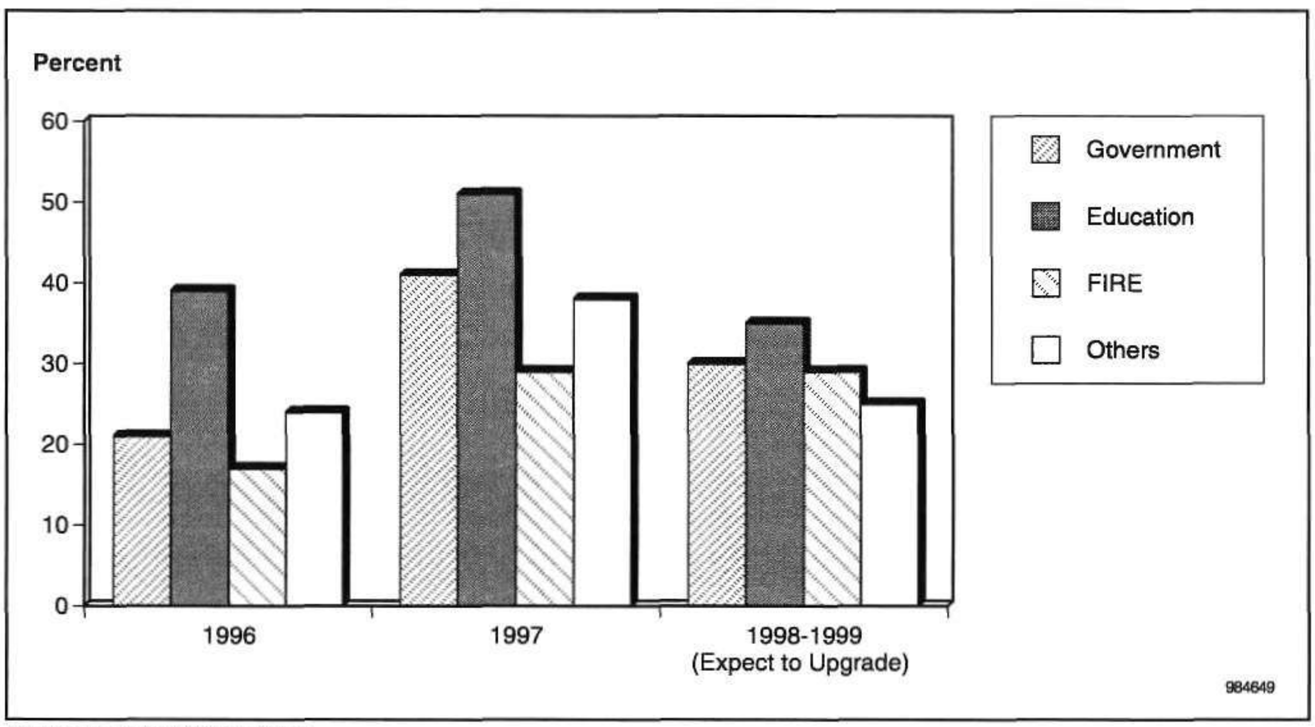
Twenty-three percent of MMPC households in the United States expected to purchase a PC in the future, with 25 percent of them expecting to add or replace in two or fewer years, another 35 percent expecting to replace or add in three to five years, and another 25 percent expecting to replace or add in six or more years. About two-thirds of the MMPC households said that the PC they planned to purchase would be an additional PC. (For more details on the use of multimedia in the home, please refer to Dataquest report MULT-WW-UW-9701.)

Multimedia in Business

Multimedia PCs in the Commercial Sector

The average percentage of PCs/workstations in the U.S. commercial sector that could play audio/video went up from 1996 to 1997, with a reported average of 24 percent in the overall sample in 1996, compared to 37 percent in 1997. The greatest increase was in the government segment, and the lowest increase was in education. On average, businesses expect to upgrade about 28 percent of their PCs/workstations to play audio/video by 1999. This effectively means that by 1999, we can expect at least 50 percent of PCs/workstations to be audio/video-capable in any average business (see Figure 3-4).

Figure 3-4
Average Percentage of PCs and Workstations That Play Audio and Video in the U.S. Commercial Sector



Source: Dataquest (June 1998)

Multimedia Peripheral Penetration in the Commercial Sector

The installed base of 3-D hardware appears to have grown about 200 percent from 1996 to 1997 in the U.S. commercial sector. In 1996, respondents reported that 8.5 percent of their multimedia systems had 3-D hardware. In 1997, respondents reported that, on average, 19 percent of their multimedia systems had 3-D hardware. The government sector is far ahead in the percentage of multimedia systems with 3-D hardware, compared to the education, finance/insurance/real estate (FIRE), and other business segments.

The top planned areas of spending in 1998 in the U.S. commercial sector are multimedia systems, single CD-ROM drives, and multimedia kits, reflecting the current top areas of spending. Of the four segments considered in the commercial sector, government and education expected to spend more on infrastructure to handle video traffic.

Multimedia Communication in the Commercial Sector

Streaming audio, video, animation, and other Internet media formats showed a reasonable level of penetration in the commercial sector despite the age of these technologies. About 25 percent of the organizations are expected to use streaming video format on their Web sites in the next two years.

Videoconferencing also made inroads in the commercial sector and, in fact, even grew comparatively in segments outside of the traditional vertical markets of education and government. For more information, please refer to the section on videoconferencing in this report. (For more details on the use of multimedia in the commercial sector, please refer to Dataquest report MULT-WW-UW-9801.)

Chapter 4
Multimedia Capture Devices

Digital Cameras

With more and more consumers and corporations getting onto the Internet and the clutter of information in cyberspace, pictures have become a way to differentiate Web sites and/or share special moments. Compared to video, they also take up less bandwidth, or storage, as the case may be. According to the Consumer Electronics Manufacturers Association (CEMA), about 700,000 digital still cameras were sold to dealers in the United States in 1997, up from 300,000 in 1996. For 1998, CEMA estimates that digital camera sales will increase to 1.1 million. According to a CEMA survey, 68 percent of respondents owning a PC and a color printer indicated that regular film cameras meet their needs, and 61 percent said that a digital still camera is too expensive to buy. The prices for digital still cameras continue to fall, while the performance level increases.

Another way to gauge the adoption of "PC photography" is to take a look at the shipments of photo editing software. Dataquest research shows that worldwide shipments of consumer photo editing software increased from 6.4 million in 1996 to 18.7 million in 1997.

Digital Camcorders

Along with everything else entering the digital race are digital camcorders. The average price of digital camcorders is currently $1,600, compared to $200 to $300 for analog camcorders. Dataquest estimates that in 1996, in the United States, about 4 million analog camcorders were sold to dealers, and the figure should look very similar in 1997.

Currently, digital camcorders are using the DV format for acquisition, which still requires transcoding to MPEG for delivery. Dataquest expects that the industry will slowly move to MPEG2 format as the cost of the compression semiconductor falls.

Video Capture Devices

The year 1997 saw the beginning of the appearance of external parallel port devices for video capture, such as Snazzi from Dazzle Multimedia, Buz from Iomega Corporation, Python from Videonics Inc., and Video Sphinx Pro from FutureTel Inc. This was one of the fastest-growing areas in 1997, with the worldwide shipments of video editing/capture devices growing from 471,162 units in 1996 to 1,046,248 units in 1997. Parallel port devices are still a small fraction of the total market for video capture devices, but anything that makes it easy for consumers to capture video gets them closer to using it, and parallel port devices do exactly that.

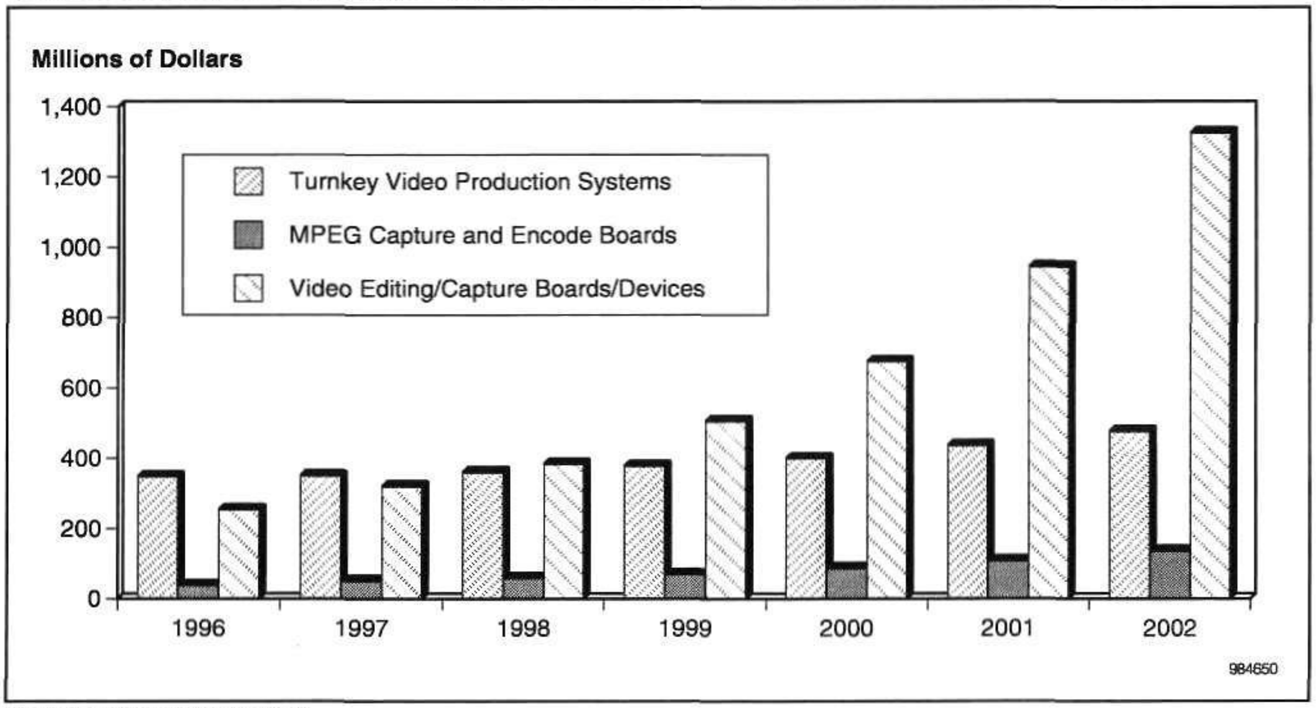
Some of these capture boards also were bundled with videoconferencing kits, and some were actually built into PC cameras. As digital camcorders come down in price sufficiently, the need for these capture devices will only be among the installed base of consumers using analog camcorders, scanners, and PCs. However, Dataquest expects that the manufacturers of these capture boards will extend the life of the product by bundling it with analog camcorders, which are high-margin products compared to their digital counterparts.

Chapter 5
Multimedia Creation

Video Production

Figure 5-1 shows the video production hardware market size. The total market size in 1997 was $721 million, with turnkey video production systems accounting for the major share of 48.5 percent. Dataquest expects this market to grow to $1.9 billion by 2002. The biggest driver is the transition to DTV and digital broadcasting by 2006, mandated by the Federal Communications Commission (FCC). Although there are still some issues of opposition from cable companies and consumer adoption of DTV, there is no doubt that all stations will have to switch to digital broadcasting by 2006. Some of the major networks are already moving to embrace this change. More importantly, a lot of these media (print/TV station/radio/Internet company) are often owned by a single company, and it makes more sense to leverage than to reshoot, rerecord, or send multiple teams to cover the same story.

Figure 5-1
Video Production Hardware Market Forecast in Terms of Worldwide Revenue



Source: Dataquest (June 1998)

Video editing software has shown similar growth, from $144 million in revenue in 1996 to $172 million in 1997. In 1997, MGI Software Corp. introduced the first low-end video editing software for consumers. Since then, many other companies have also introduced low-end video editing solutions. Although this market is still small, Dataquest sees great potential for it and expects it to grow to $41 million by 2002. With the Web becoming the window to the outside world, Dataquest expects that consumers will take to video editing and putting videos on Web sites as they have done with pictures. Moreover, a camcorder is an item that most people purchase and use to capture videos of their children growing up. Video editing software can certainly help to make these videos more interesting. However, the price of digital camcorders and bandwidth limitations are still inhibitors to its adoption.

2-D/3-D Animation

The 2-D/3-D animation market is a growing market driven by the Web, the entertainment and broadcasting industry's transition to digital, and the growth of electronic commerce. Many 3-D creation tools are also incorporating 2-D generation features, somewhat akin to the introduction of multifunctional graphics add-in boards in the hardware space.

The 2-D animation tools market grew from $20 million in 1996 to $26 million in 1997. The 3-D animation tools market grew from $222 million in 1996 to $242 million in 1997. Dataquest forecasts that this market overall will grow to $708 million by 2002. (For more details on trends in this industry, please refer to Dataquest's Perspective on Siggraph 1998 [MULT-WW-DP-9808].)

Microsoft Corporation recently announced Chromeffects, an add-on feature to the DirectX application program interface (API) in Windows 98. Chromeffects is designed to let developers get around bandwidth limitations by sending lightweight HyperText Markup Language (HTML)-based instructions to the end user's desktop, where they are finally rendered. This, Dataquest believes, will encourage greater development of 3-D animation on the Web.

Among the emerging areas in the animation industry are 3-D object digitization scanners and software and 3-D motion capture hardware and software. Companies in these areas include Cyberware Inc., Paraform Inc., PuppetWorks, Ascension Technology Corporation, Kaydara Inc., Minolta Corporation, and Immersion Corporation.

Media Asset Management

The latest development in the area of creation is a growing awareness of the need for digital media asset management. There are many companies offering different components necessary for media asset management, with no single company offering complete solutions by itself. According to Dataquest's survey of U.S. organizations on IT spending, 18 percent of the organizations are or will be working on asset management projects in 1998.

The many components to media asset management include: the indexing/archiving of videos provided by companies such as ISLIP Media and Virage Inc.; the file management of multimedia assets provided by products from Cinebase Software Inc. and The Bulldog Group Inc.; and other services provided by traditional database vendors and systems integrators, such as Oracle Corporation, Informix Software Inc., and IBM.

Chapter 6
Multimedia Playback

Multimedia PCs

Most PCs shipping into U.S. homes in 1997 were MMPCs with CD-ROM drives. Total deskbound MMPC shipments in 1997 were 56.4 million, a 74 percent increase over 1996. Of these, 99 percent shipped with CD-ROM drives and the remaining 1 percent with DVD-ROM drives. Dataquest expects this (that is, MMPCs with CD-ROM drives) to come down to 97 percent of total deskbound MMPC shipments in 1998.

Of the 10.4 million mobile MMPCs shipping in 1997, Dataquest estimates that only 3,800 shipped with DVD-ROM drives (see Table 6-1).

Table 6-1
Shipments of Worldwide Multimedia Hardware

Category	1996 Unit Shipments (K)	1997 Unit Shipments (K)	Growth Rate (%)
Shipped with CD-ROM			
Mobile MMPCs	5,732.7	10,419.1	81.7
Deskbound MMPCs	31,946.0	55,777.5	74.6
MM Workstations	811.6	971.4	19.7
Shipped with DVD-ROM			
Mobile MMPCs	0	3.8	-
Deskbound MMPCs	0	586.4	-
Total	**38,490.3**	**67,758.3**	**76.0**

Note: Numbers may not add to totals because of rounding.
Source: Dataquest (July 1998)

PC/TV versus TV/PC

With the introduction of Web TV-like devices and the debut of DTV later this year, the trend toward TVs acquiring PC capabilities and PCs acquiring TV capabilities is clear. The two will continue to be different devices for different purposes, with the TV/PC's emphasis more on entertainment-centric use by a group and the PC/TV's emphasis on information-centric use by individuals.

Microsoft has been doing everything in its power to bring TV capabilities to the PC. Windows 98 provides support for TV tuner capabilities. Dataquest research shows that the worldwide shipments of TV-tuner boards increased 122 percent from 132,757 units in 1996 to 295,455 units in 1997. Microsoft is working with A.C. Nielsen to develop a rating system for TV-watching on the PC, similar to what Nielsen currently has with analog TVs. Microsoft is also opposed to the interlaced format on DTV, which reflects its desire to make the operating system (Windows or CE) an essential part of TV.

Sound Boards

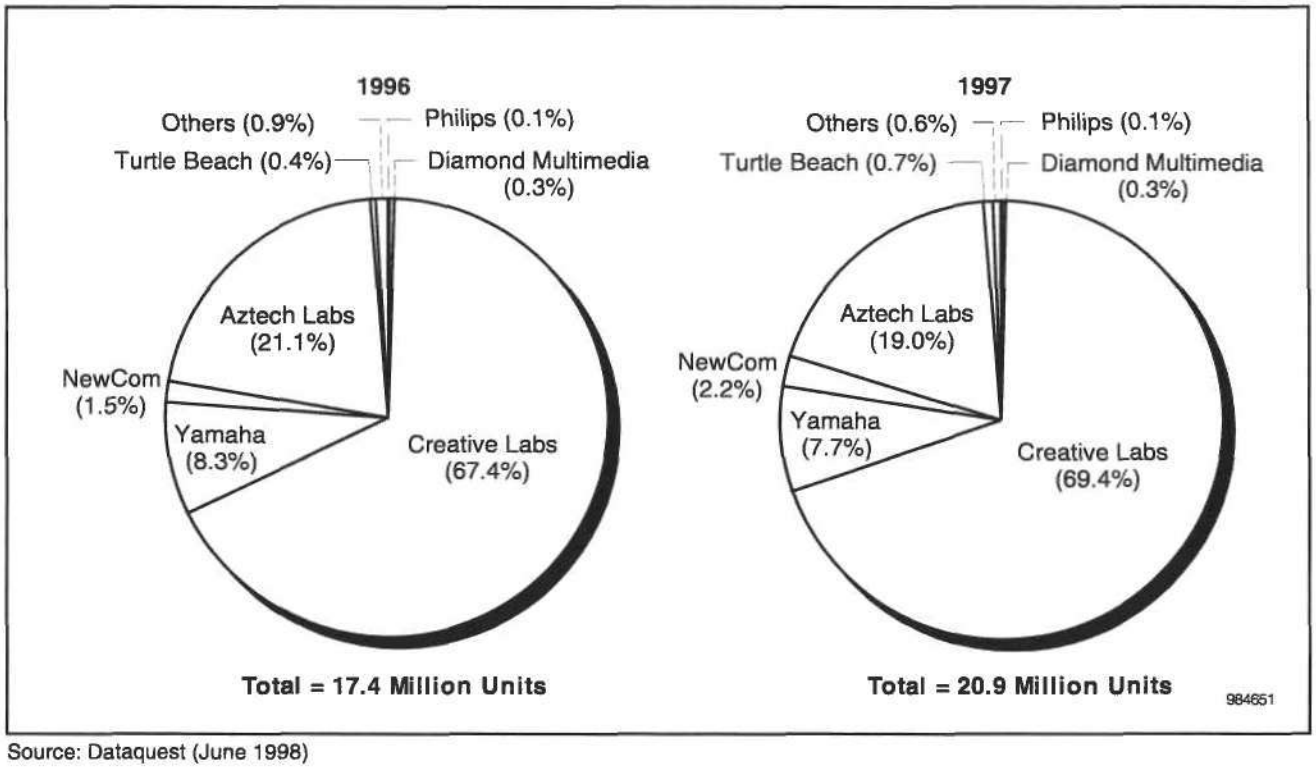
The majority of PCs these days ship with the sound chip on the motherboard. However, there continues to be a market for discrete sound boards as consumers/businesses upgrade to achieve better sound, with more consumers doing so than businesses. In 1997, 85 percent of MMPCs/workstations shipped with the sound chip subsystem on the motherboard.

Sound boards are sold already integrated into PCs and multimedia kits and as standalone units at retail. Dataquest research shows that worldwide discrete sound board shipments increased from 17.4 million units in 1996 to 20.9 million units in 1997. Creative Labs Inc. continues to lead the market with a 69 percent market share, followed by Aztech Systems Ltd. with a 19 percent market share (see Figure 6-1).

Sound Chip in Motherboard

Of the 81.8 million sound chip subsystems shipped in 1997, 58.2 million shipped sound on the motherboard. Table 6-2 shows PC sound shipments by category. Although more and more sound chips are shipping on the motherboard (about 71 percent), there is an aftermarket for add-in boards for better sound or for the latest in games.

Figure 6-1
Sound Board Market Share in Terms of Units



Source: Dataquest (June 1998)

Table 6-2
1997 Worldwide PC Sound Shipments by Category

Category	Shipments (M)	Market Share (%)
PC Motherboard Audio	58.2	71.2
PC Sound Boards	23.6	28.8
Discrete Boards: OEM	5.2	6.4
Discrete Boards: Retail	15.7	19.1
Boards in Kits	2.7	3.3
Total	**81.8**	**100.0**

Source: Dataquest (July 1998)

The major shift happening in the sound board space is the shift to Peripheral Component Interconnect (PCI)-based cards from Industry Standard Architecture (ISA)-based cards. The PCI bus is a 66100-MHzB bus, leaving greater microprocessor resources free. Both Creative Labs and Diamond Multimedia Systems Inc. have announced the next-generation sound boards based on 3-D positional technology, which means that the intensity of sound you hear will reflect the distance of the sound source from you. While these technologies will continue to find a place in the gaming community, the board vendors face some challenges because of the upcoming introduction of digital speakers. Digital speakers will have the capability to process sound and retain quality because the conversion from digital to analog will occur outside the PC. This also explains Creative Labs' acquisition of Cambridge SoundWorks. It is possible that the board companies will start incorporating their sound technology into these speakers while they continue to introduce the latest technology as boards or external Universal Serial Bus (USB) devices.

Integrated 3-D Graphics/Playback Boards

Shipments of integrated 3-D graphics/playback boards grew 56 percent, from a worldwide total of 26.6 million in 1996 to 41.4 million in 1997. However, this market only grew about 12 percent in revenue. In the last two years, it has been characterized by many new entrants, with quite a few in Southeast Asia.

Intel Corporation's acquisition of Chips & Technologies Inc. and its decision to incorporate 3-D on the motherboard will put additional pressure on these vendors to keep ahead of the race by introducing faster and newer technologies. Diamond Multimedia has already decided to hedge its bets by acquiring Micronics Computers Inc., a motherboard manufacturer. Diamond Multimedia's plans are to incorporate 3-D, audio, and modem onto the motherboard with microprocessors from different vendors, including Intel. 3Dlabs Inc. has decided to vertically integrate by acquiring an add-in board company.

The target market for new 3-D technologies continues to be either professional or gaming segments. As Dataquest observed in the last Market Trends report, compelling 3-D applications for businesses and consumers other than games are still nonexistent. However, with Microsoft's introduction of Chromeffects, Dataquest expects that the introduction of such applications is not too far in the future.

Speakers

The upgrade market for speakers continues to be strong and should be doubly so with more PCs shipping with USB ports in the coming years. Although there will be very few of them being bought in 1998—because they require a USB-enabled computer and Windows 98—Dataquest expects that most USB speakers will be sold at retail (as opposed to being bundled with PCs) in 1999 because of the additional cost over analog speakers. There are also other technological changes, such as the shift to wireless speakers, that will continue to keep the aftermarket for speakers alive and healthy.

As of 1997, at least 25 million households in the United States had speakers. Speakers continue to be a product category predominantly for the consumer space.

Chapter 7
Multimedia Communication

Streaming Video

Streaming has made admirable inroads as a brand-new technology and is here to stay. What is notable is that it has had an almost equal amount of success with both businesses and consumers, although businesses are the primary revenue-generating source for streaming technology. However, consumers using it are one of the primary drivers for its adoption by businesses. In certain cases, the consumers are also a direct revenue-generating source, as in the case of players from RealNetworks Inc. that are better than the ones offered free of charge.

The industry has gone through innumerable changes in a very short period of time. The technology was pioneered initially by vendors such as VDOnet Corp. and Xing Technology Corp. The competitive landscape has changed considerably, with the number of vendors in the space rapidly multiplying in 1997, followed by consolidation in the same year. Now, the market is segmented, with Microsoft and RealNetworks as the lead players in the low- to mid-bandwidth space, and others, such as SGI, Oracle, and Starlight Networks (which is now being acquired by PictureTel Corporation), in the high-bandwidth segment.

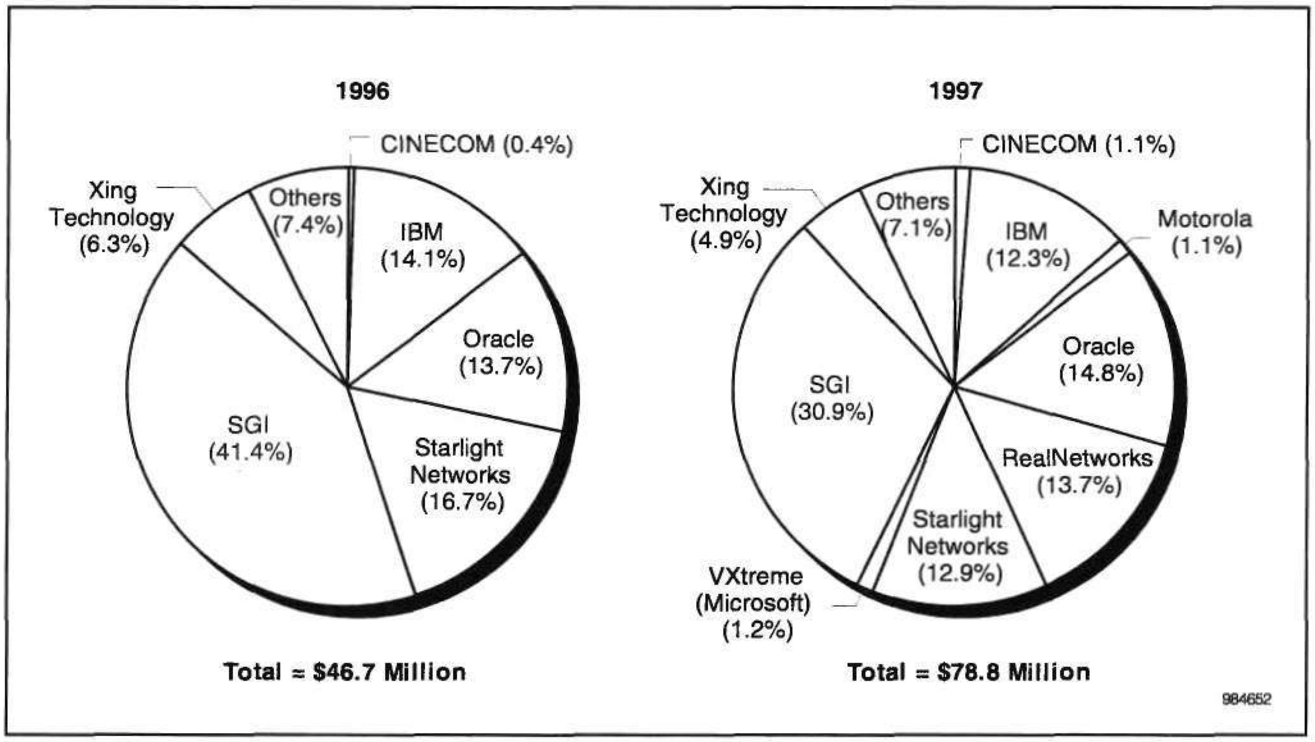
The video server market increased from $46.7 million in 1996 to $78.8 million in 1997. Dataquest expects this market to grow to $1.47 billion by 2002. In Dataquest's multimedia survey of businesses conducted in 1997, 25 percent of businesses expected to use streaming video on their Web sites in the next two years. Figure 7-1 shows the market shares of companies in the video server market.

Videoconferencing (Hardware and Software)

In 1997, there was a lot of interest in videoconferencing. It was supposed to be "the year" that videoconferencing would explode. In anticipation, there were many new entrants offering varied versions and form factors to conduct videoconferencing. Apart from the traditional vendors in this space, such as PictureTel, Intel, and VTEL Corporation, new entrants included VCON Ltd., Zydacron Inc., and Tandberg Data Inc. (not so new but making more headway into this market). Innovative in this space were Polycom Inc., 8x8 Inc., and Connectix Corporation, each with a product that appealed to a very different segment.

Of the three innovative entrants mentioned, Polycom is one vendor that competes in the market targeted by the traditional "big three" in videoconferencing: PictureTel, VTEL, and Intel. PictureTel earlier in the year introduced its compact SwiftSite videoconferencing system that was set-top-based at $8,999. Polycom's solution was similar, except it was integrated with a Web server. At a similar price, it has made more inroads into the market in a very short period of time. The leader of the pack, PictureTel, has gone through management changes but is still struggling and not yet past the danger mark.

Figure 7-1
Video Server Market Share in Terms of Revenue

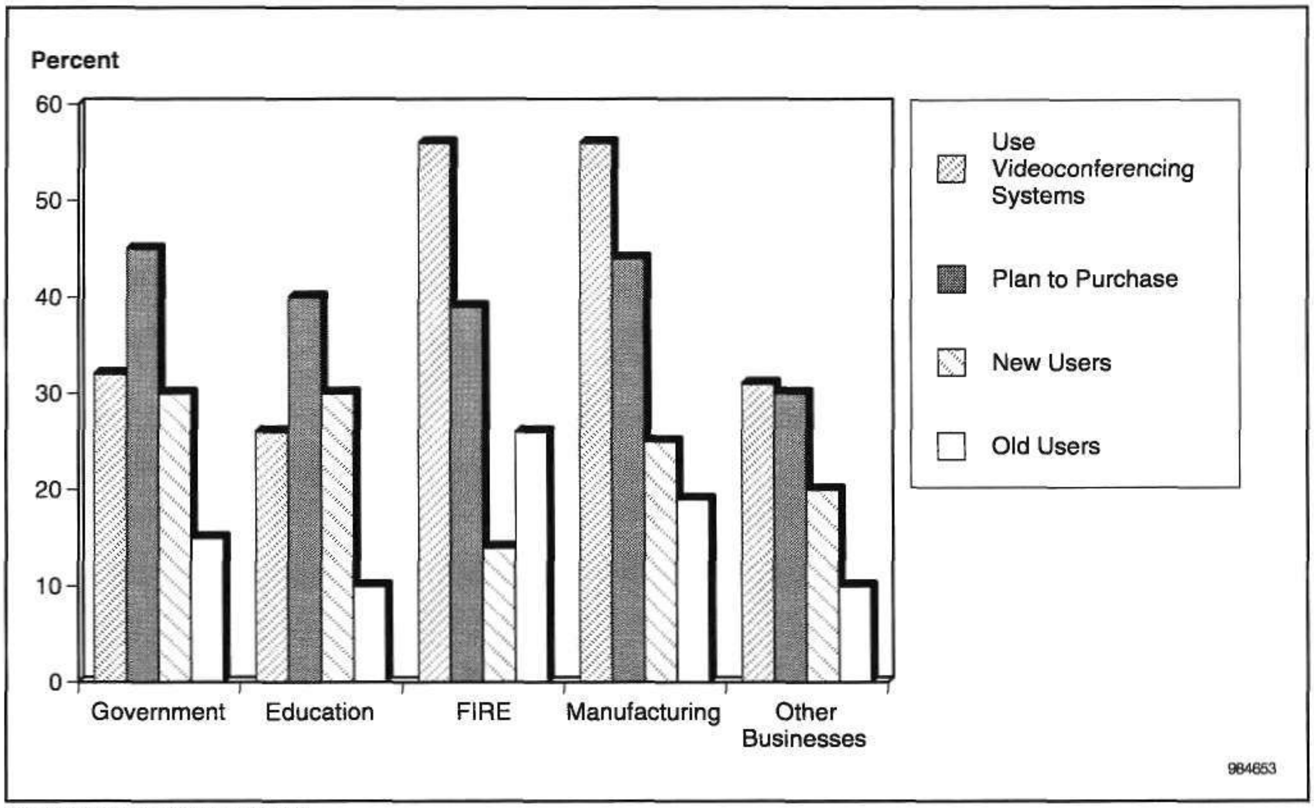


Source: Dataquest (June 1998)

With the introduction of low-priced group systems, the penetration of group systems into the U.S. commercial sector increased 74 percent from 1996 to 1997. In 1996, only 23 percent of U.S. organizations reported using a videoconferencing system. In 1997, this went up to 39 percent (this is after reweighting for different sampling methods used in 1996 and 1997; the figure shows 40 percent without any adjustment). Another 40 percent—of which, two-thirds are new users—expect to purchase videoconferencing systems in the next two years (see Figure 7-2).

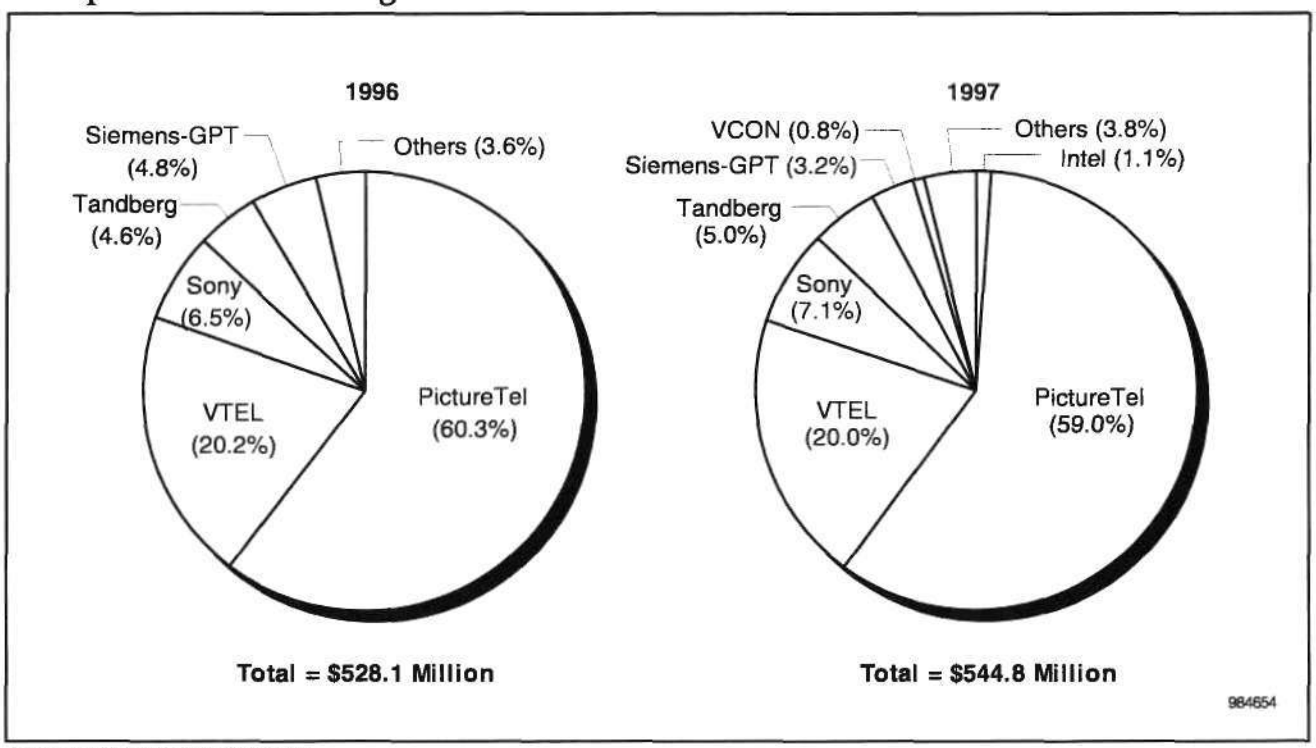
Dataquest continues to find that within the commercial sector, videoconferencing is mostly used for group-to-group communications. Desktop videoconferencing solutions in the $1,000-to-$2,000 range, although relatively more popular in Europe, are primarily niche solutions or are used for group videoconferencing. Most of the vendors in the desktop videoconferencing market have found it difficult to be profitable. PictureTel is now turning to Zydacron to provide the reliable technology it lacks for desktop videoconferencing. Zydacron, a relative newcomer, has established a reputation for the reliability and quality of its systems, something found lacking in the products from established players. At the same time, being a smaller company restricts it from achieving wider distribution for its products and from providing support to its customer base. Zydacron should benefit from PictureTel's strength in these areas. Figure 7-3 shows the market share in terms of revenue in the group videoconferencing market, and Figure 7-4 shows the same for the desktop videoconferencing market.

Figure 7-2
Percentage of New Users versus Old Users of Videoconferencing Systems in U.S. Commercial Sector, 1997



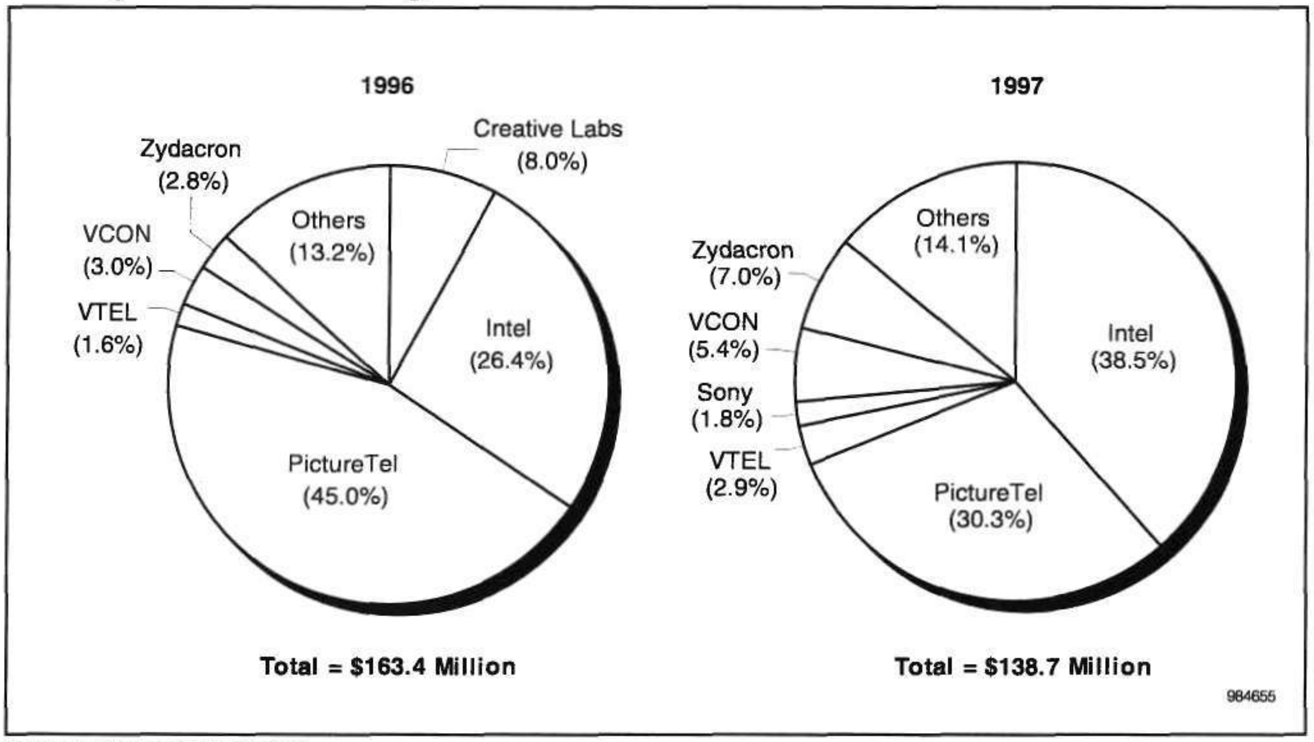
Source: Dataquest (June 1998)

Figure 7-3
Group Videoconferencing Market Share in Terms of Revenue



Source: Dataquest (June 1998)

Figure 7-4
Desktop Videoconferencing Market Share in Terms of Revenue



Source: Dataquest (June 1998)

PC Videoconferencing Kits/Cameras/Set-Tops

Also introduced in 1997 were many form factors for videoconferencing. There are solutions from Panasonic Communications & Systems Company and Siemens AG that use 8x8's Video Communications Processor (VCP) and offerings in the form of video phones. Although these are very user-friendly, they are expensive (in the area of $1,000) and are mostly used in surveillance, in small businesses, or in individual executive offices. Some are plain old telephone service (POTS)-based, and some are integrated services digital network (ISDN)-based.

Another form factor is in the shape of a set-top box sitting on top of a TV. Although, again, it is user-friendly, it is expensive for the average consumer, costing $500. However, the quality of the video at that price is comparatively better. Dataquest believes that there were 350,000 of these set-top box solutions sold in 1997.

The third array of solutions is the most complex of all, targeted at consumers. Although, as the quality improves, it might find its way into the corporate segment, that is still far from coming. Companies such as Intel, 3Com Corporation, Creative Labs, Diamond Multimedia, Panasonic, and Connectix are offering videoconferencing solution kits that are a combination of a PC camera, modem, capture card, and software. Although these are cheap, bandwidth is still a huge limitation. These solutions are potentially very compelling to the consumer market and will continue to grow, albeit slowly, in the near future because of lack of bandwidth and lack of sufficient and necessary PC infrastructure (that is, the proper V.80 modem, H.323-compatible solution, 200-or-more-MHz microprocessor, and video capture card or digital PC camera). Dataquest research shows that the worldwide shipments of PC cameras from 1996 to 1997 remained more or less steady, with 359,634 cameras/kits shipping in 1996 and 356,827 shipping in 1997.

Voice Recognition

The Big Three in Voice Recognition

Voice recognition made big strides in 1997 with the capability of the technology having matured to a level that it received serious consideration for incorporation into many products, such as pagers and automobiles. Although it still has a ways to go before it can become a part of daily life, the impact that this technology will have in the next decade cannot be underestimated.

The three major players in this space are IBM, Lernout & Hauspie Speech Products N.V., and Dragon Systems Inc. The number of units of voice recognition software sold doubled in 1997 (1,076,748 units worldwide), compared to units sold in 1996 (580,323). However, this growth rate is not sustainable because of Microsoft's activities in this area.

Microsoft Operating System and Voice Recognition

Having won the first round with the Department of Justice on the integration of browser capabilities in its operating system, Microsoft's launch of Windows 98 showed a glimpse of things to come with the operating system down the road. Participating as an official partner in its launch was L&H. As an official Microsoft Windows 98 launch partner, L&H's new Voice Xpress Plus speech software was promoted by Microsoft. Anyone buying Windows 98 got a rebate of $20 on L&H's Voice Express Plus (with an estimated street price of $99). Microsoft also invested $45 million in L&H in 1997. The results of this investment are showing up in the support in Windows 98 for speech recognition.

With this official launch partnership, Microsoft is laying the groundwork for speech recognition capabilities built into the operating system. Dataquest believes that this will not happen in 1999. However, Microsoft might start giving away "lite" versions of the software free to initiate consumers into using the product to make the launch of its official, fully-speech-recognition-capable Windows XX successful.

The fact that Microsoft will take away the market that L&H now has is obviously not lost on the company. L&H has positioned itself as a technology provider targeting many potential applications for its speech recognition technologies.

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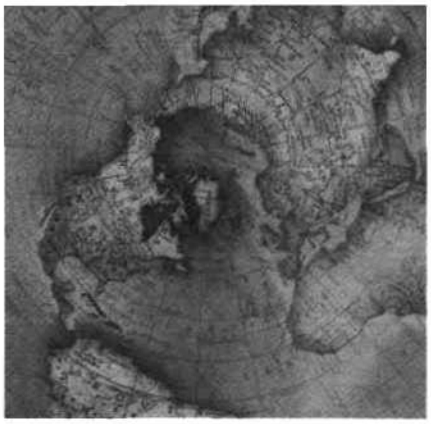

Dataquest

What Does a Company with 93 Percent of the Market Do for an Encore?

Industry Trends

FILE COPY:
MARIA VALENZUELA

Program: Personal Computer Semiconductors and Applications Worldwide
Product Code: PSAM-WW-IT-9802
Publication Date: November 23, 1998
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Chapter 1
Executive Summary

For many vendors of computational microprocessors, 1997 was a watershed year. As the year came to an end, *Time* magazine named Intel Corporation's Andy Grove "Man of the Year." No mean achievement, *Time's* award signaled that the microprocessor, and the computer revolution it drove, had finally been recognized as a world-changing phenomenon. Even as it basked in the afterglow, of Intel readied itself for yet another struggle. Now Intel needed to tackle new markets to restart its growth. These new markets had to be large, they had to possess large profit potential, and they needed to fit with Intel's basic skills—developing, manufacturing, and selling microprocessors that could be sold for incredibly high prices, compared to ordinary semiconductors.

In Dataquest's annual review of trends in the computational microprocessor industry, we review the entire processor market, from the devices used in the smallest handheld computers to those that go into the largest mainframe systems. Unlike past reviews, which focused on "generational transitions" and other technologically focused issues, this report segments the processor industry into a series of submarkets and examines each separately. Our investigations include the markets for desktop and mobile personal computer processors, the market for workstation processors, and finally, the market for processors used in server systems of all sizes. To add further clarity, Dataquest divides the desktop and mobile processor market into three price bands: under $1,000, $1,001 to $1,500, and over $1,500, with separate history, market share, and forecasts for each. Dataquest uses forecasts from its Personal Computers Worldwide program to drive these chip-level forecasts. Next, we apply the same techniques, but with data from our Advanced Desktops and Workstations Worldwide program, to derive a five-year workstation microprocessor forecast. Finally, we repeat this task using data from our Computer Systems and Servers Worldwide program to determine to market for processors in departmental (under $10,000), workgroup ($10,001 to $50,000) and enterprise (over $50,000) servers.

The personal computer microprocessor forecast in this report projects revenue, shipments, and average selling prices (ASPs) for each market segment and also estimates Intel's likely share within each segment. The workstation microprocessor forecast similarly estimates not only overall processor shipment and revenue volumes, but also the split between RISC-based alternatives and x86-based systems. For processors targeted at server markets, we project the split between x86, proprietary mainframe, and RISC alternatives.

Using its computational microprocessor market model, Dataquest provides a complete view of Intel's recent results across its entire microprocessor business and forecasts its processor businesses in all market segments for the next five years. Dataquest's analysis reveals that revenue growth in the personal computer market will slow as users "buy down" and the price mix tilts toward "low cost" and away from "high performance." ASPs for desktop PCs, which have risen for years, will now begin to slowly recede.

In this light, Intel's efforts to carve out a piece of the high-end server business are seen as a vital strategic initiative, rather than a "cream-skimming" or "cherry-picking" exercise. To further enhance the reader's understanding of Intel's strategy, Dataquest takes the position of a fly on the wall in the meeting rooms where Intel identified the need to alter its strategy. We provide a view of the industry as it would have appeared to Intel's planners and project the outcomes of their moves as they might have seen them.

Chapter 2

Intel Eyes the Market for High-End Microprocessors

Intel's phenomenal success in capturing 95.6 percent of the 1996 market for the microprocessors used in personal computers created a serious problem for the company's planners. For years, Intel had grown by finding more and more personal computer buyers, each willing to pay about $200 for the Intel x86 processor inside the PC system. Table 2-1 illustrates just how successful the company had been in building its market. But now, Intel had gained all the market share it could gain, and further growth depended on expanding the size of the personal computer market or finding other markets to pursue. In the past, Intel drove market growth by increasing system performance while holding prices relatively steady, but it was running out of buyers that could afford $2,000 personal computers. Eventually, market dynamics would drive system prices down, which in turn would pressure microprocessor prices. Fortunately, the company had been able to retain the market share already won, thanks in part to a series of missteps on the part of its major x86 competitors, Advanced Micro Devices Inc. and Cyrix Corporation. Although Intel capitalized on such missteps, it could not assume the competition would remain forever at bay.

Intel faced the prospect of eroding market share and eroding prices in the key market that had fueled its rapid growth and awesome profitability. As Table 2-2 and Figure 2-1 illustrate, no matter how one measured market share, Intel's was likely to decline. Figure 2-2 displays the erosion in Intel's ASPs for personal computer microprocessors that Intel will experience over the period. Although competitive pressures play a role, most of the erosion results from a shift in the mix of personal computer system sales. Figure 2-3 projects how the market will flip-flop, from a point in 1997 when 68 percent of units sold for more than $1,500 to a point in 2002 when 70 percent of units will sell for less than $1,500. These less expensive systems use less expensive processors, thus forcing the average down. The microprocessor revenue generated by these lower-priced systems will increase from 16 percent to 42 percent of the total during the period, as shown in Figure 2-4. Changes in Intel's market share within each price band, noted in Figure 2-5, further complicate the picture. The company got off to a slow start in the sub-$1,000 arena but can be expected to gain share there. Conversely, it will lose share in the rapidly growing $1,000-to-$1,500 segment as competitors gain credibility in the market. Intel can retain its traditional share of processors used in high-end personal computers, but this segment will shrink over the period. All in all, Intel is likely to experience a drop in share from 95 percent to 80 percent of all PC-related x86 microprocessor revenue over the period. This loss of share means that Intel's revenue in this segment will grow at only a 7 percent compound annual growth rate (CAGR) over the period, to $21 billion while the overall segment grows at a 10 percent rate to $26.2 billion, as shown in Figure 2-6.

Table 2-1
Intel's Microprocessor Business, by Revenue and Units, 1996-1997 (All Computational Segments)

	1996	1997	Growth (%)
Revenue ($M)	14,675	18,559	26
Units (K)	65,000	83,791	29
ASP	226	221	-2

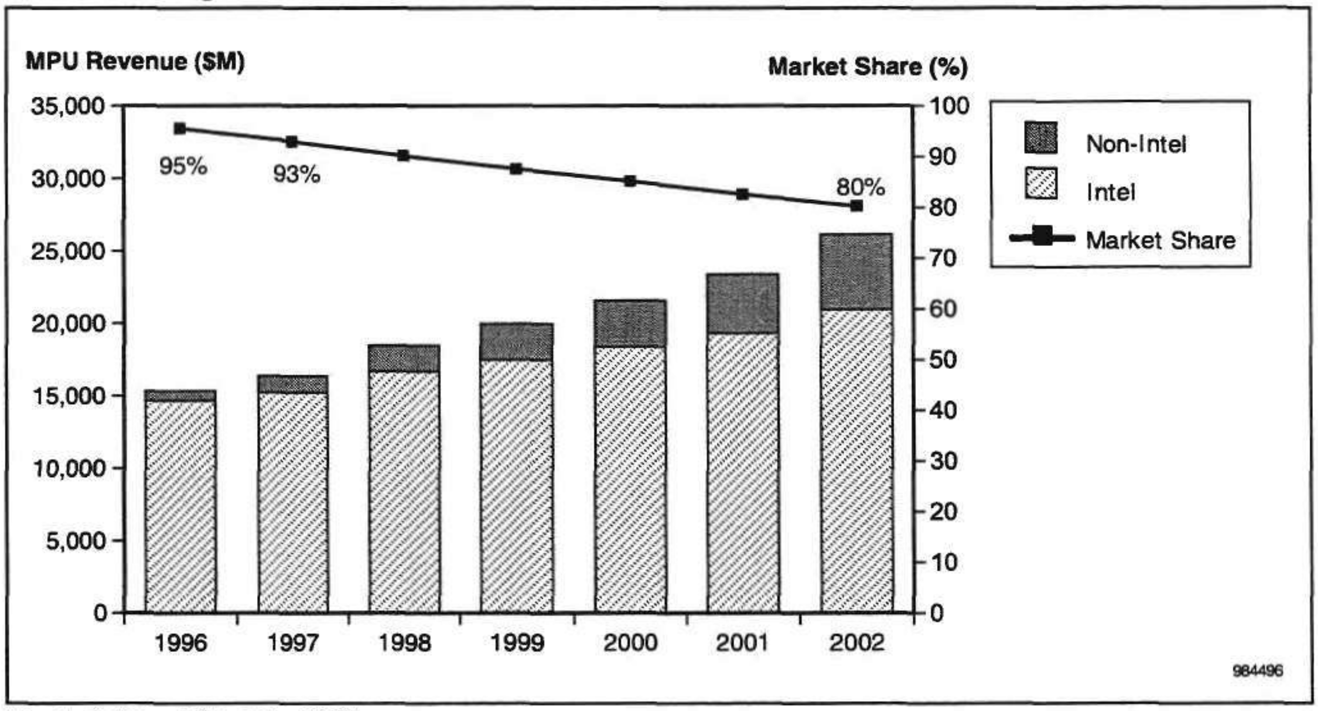
Source: Dataquest (November 1998)

Table 2-2
Intel's PC Microprocessor Market Share, by Revenue and Units, 1996-2002 (Percent)

Intel Market Share as Measured By:	1996	1997	1998	1999	2000	2001	2001
All Personal Computer MPU Revenue	92.2	91.0	88.6	86.2	84.1	81.7	79.5
All x86 PC MPU Revenue	94.9	93.0	90.2	87.6	85.2	82.6	80.2
All Personal Computer MPU Units	78.4	83.0	80.9	77.3	74.9	72.2	69.9
All x86 PC MPU Units	82.3	85.6	82.9	78.7	76.0	73.1	70.5

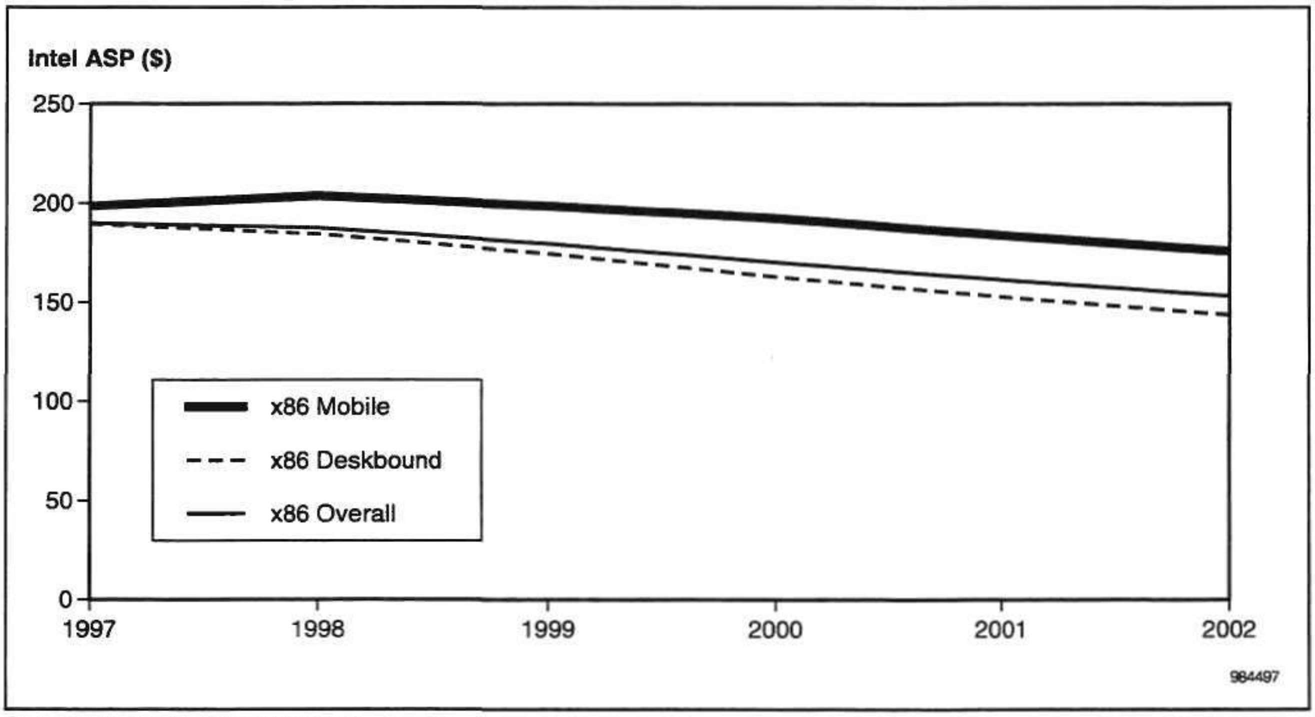
Source: Dataquest (November 1998)

Figure 2-1
x86 PC Microprocessor Revenue, 1996-2002



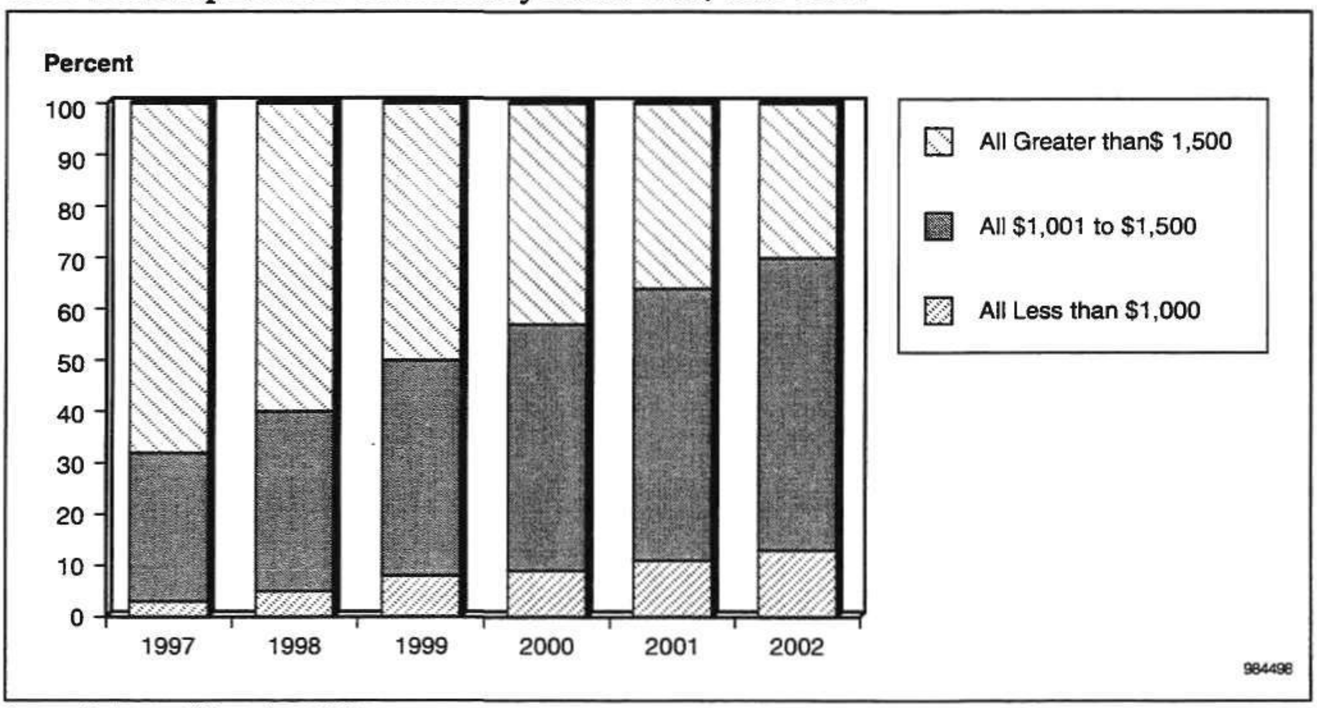
Source: Dataquest (November 1998)

Figure 2-2
Intel x86 PC Microprocessor ASP, 1997-2002



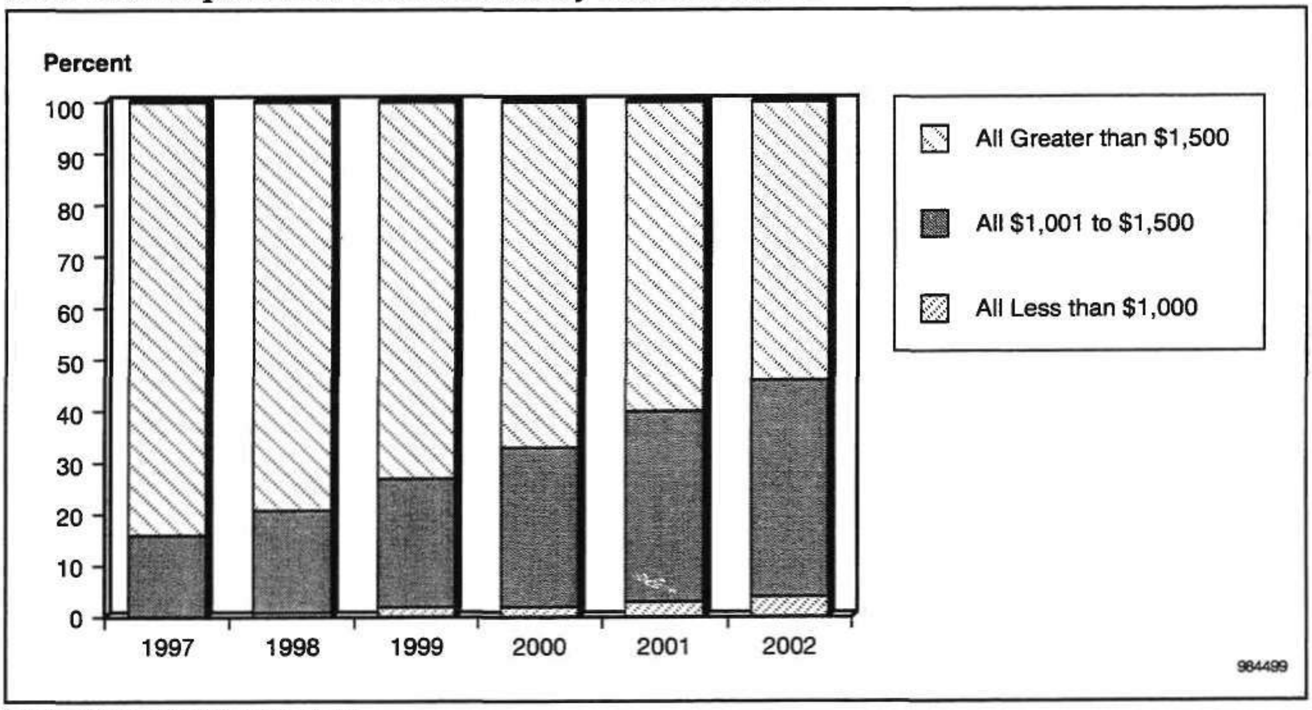
Source: Dataquest (November 1998)

Figure 2-3
x86 PC Microprocessor Unit Mix by Price Band, 1997-2002



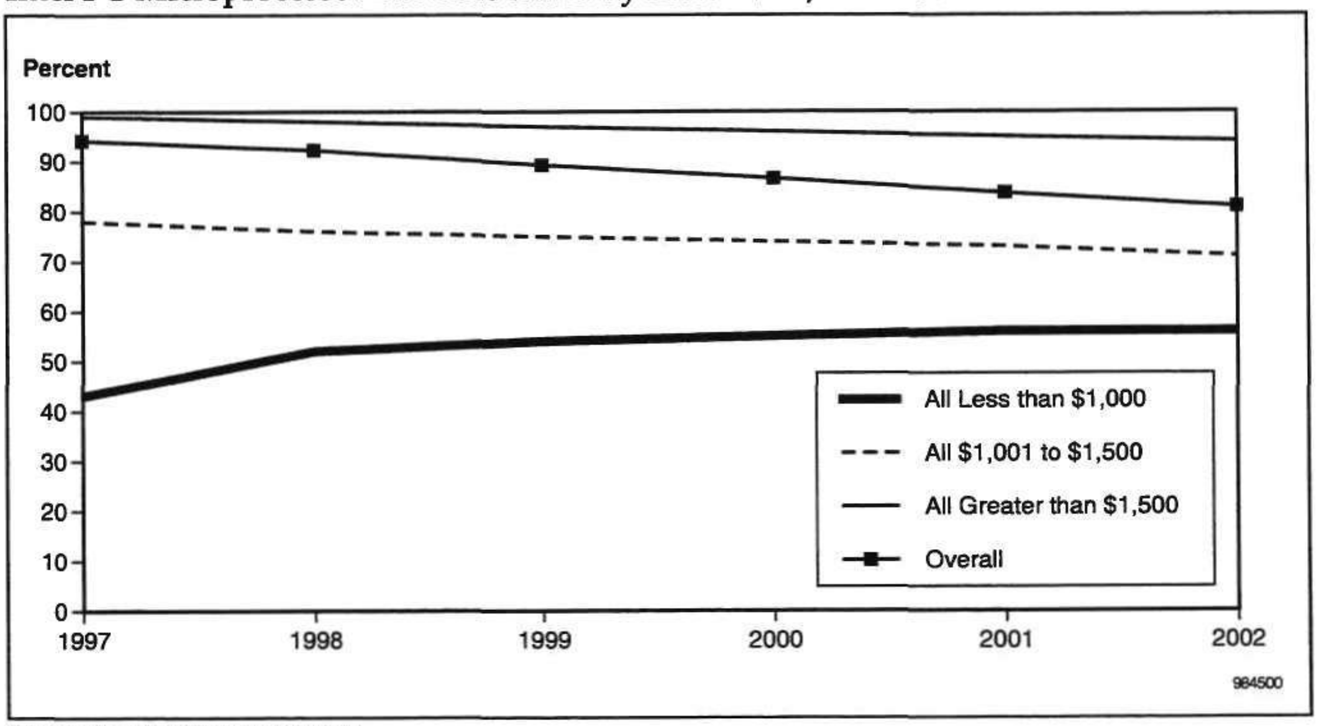
Source: Dataquest (November 1998)

Figure 2-4
x86 PC Microprocessor Revenue Mix by Price Band, 1997-2002



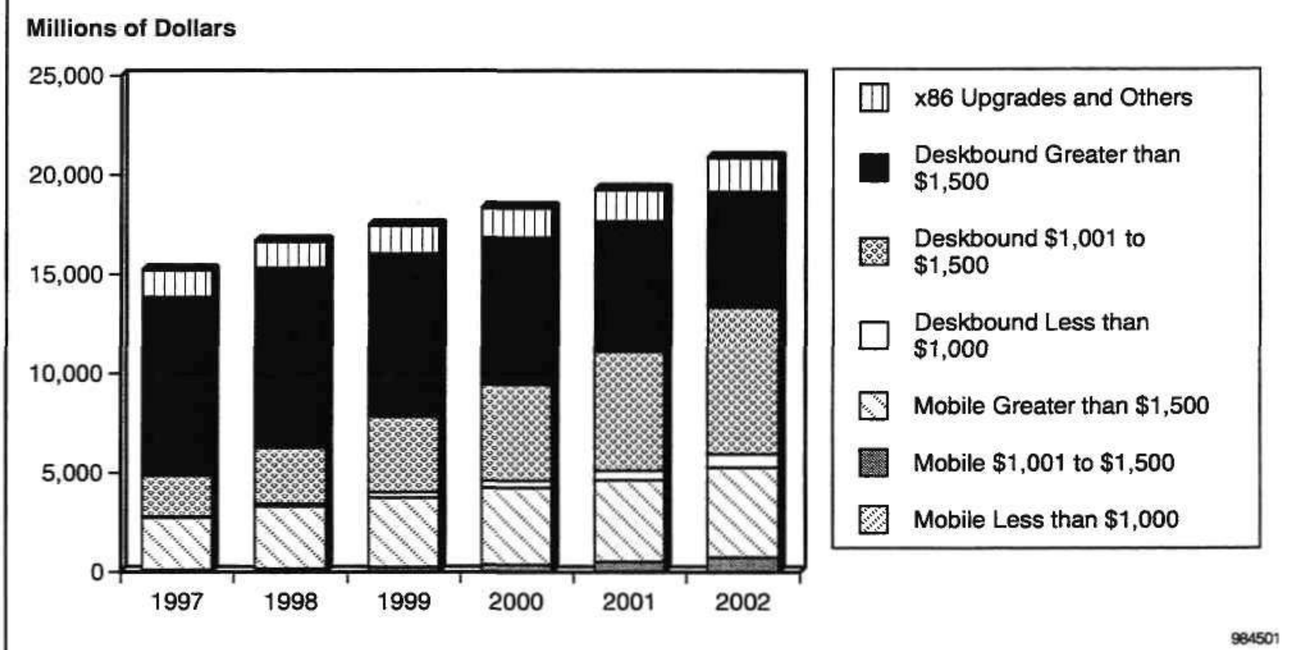
Source: Dataquest (November 1998)

Figure 2-5
Intel PC Microprocessor Revenue Share by Price Band, 1997-2002



Source: Dataquest (November 1998)

Figure 2-6
x86 PC Microprocessor Revenue by Price Band, 1997-2002

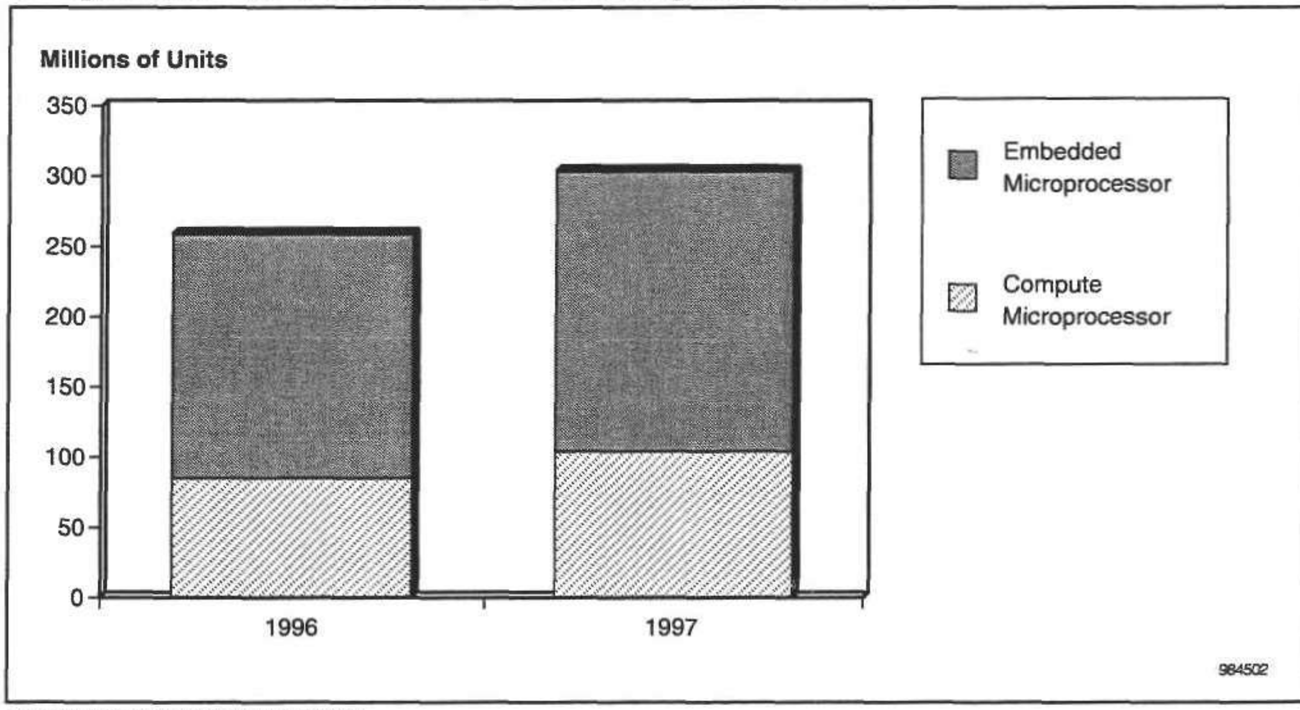


Source: Dataquest (November 1998)

Intel Can No Longer Live by PCs Alone

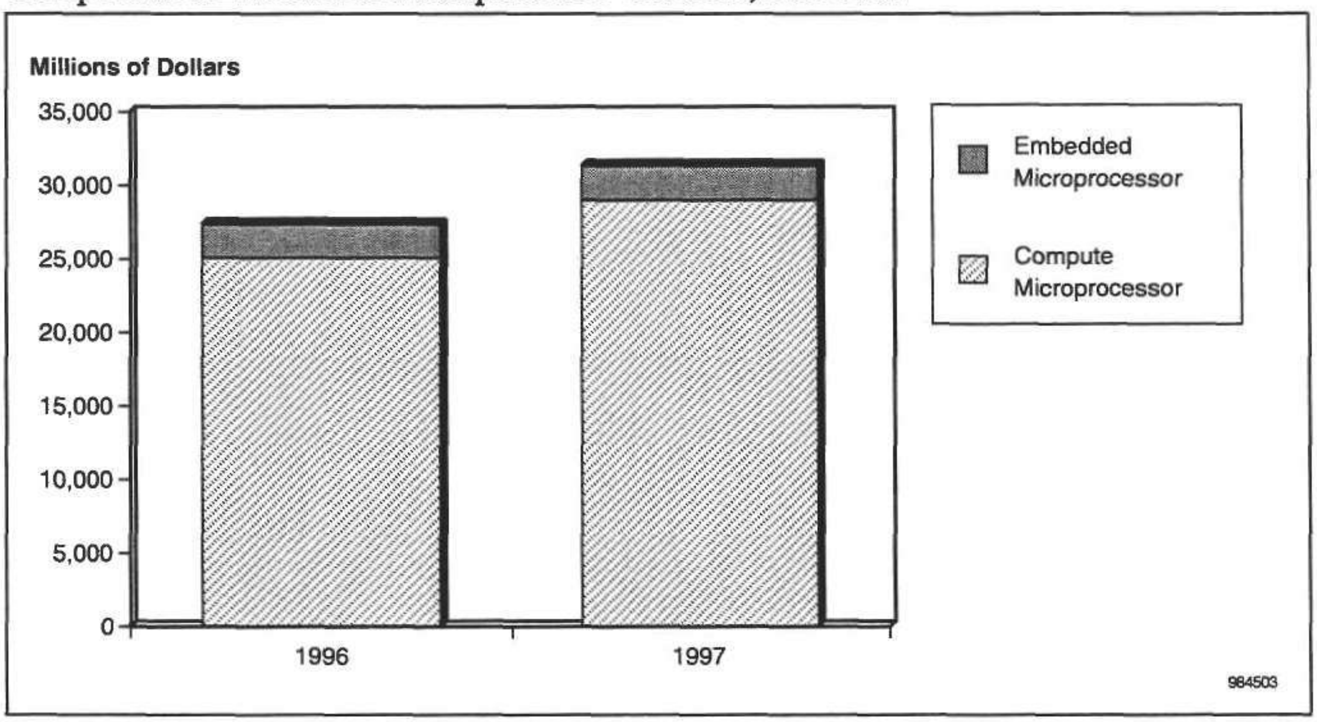
Clearly, Intel needed new markets to fuel continued growth. But where could it find another market that would match its technological and marketing skills? The embedded microprocessor market presented one such opportunity. Unlike the general-purpose devices that go into personal computers, embedded processors go into fixed-function applications, such as controlling laser printers, communications systems, and video games. A quick check of the embedded market, as shown in Figure 2-7, reveals that the embedded microprocessor market dwarfs the compute market, and Intel's share is relatively modest. Unfortunately, as Figure 2-8 shows, despite its enormous unit volume potential, the embedded market provides only moderate revenue opportunities. ASPs for such products are less than one-twentieth those found in the computational market. The engineers who design embedded systems can usually calculate precisely how much computing power they need to accomplish a given task and are unwilling to spend very much for "headroom" above their projected needs. (A laser printer with a four-page-per-minute engine cannot print five pages per minute if a faster, more expensive processor is used in place of less costly alternatives.) This buying psychology differs from that used when personal computer buyers select machines without specific knowledge of the tasks such machines may be called on to perform, thus making performance headroom an appealing insurance policy. Table 2-3 shows the computational and embedded microprocessor market statistics.

Figure 2-7
Compute and Embedded Microprocessor Shipments, 1996-1997



Source: Dataquest (November 1998)

Figure 2-8
Compute and Embedded Microprocessor Revenue, 1996-1997



Source: Dataquest (November 1998)

Table 2-3
Computational and Embedded Microprocessor Market Statistics, 1996-1997

	1996	1997
All Microprocessor Shipments (M Units)	**258.5**	**302.7**
Compute Microprocessor	85.2	103.5
Embedded Microprocessor	173.4	199.2
Compute MPU Share (%)	33	34
All Microprocessor Revenue ($M)	**27,390**	**31,503**
Compute Microprocessor	25,109	29,147
Embedded Microprocessor	2,281	2,356
Compute MPU Share (%)	92	93
All Microprocessor ASP ($)	**106**	**104**
Compute Microprocessor	295	282
Embedded Microprocessor	13	12
Ratio or Compute: Embedded	22.4	23.8

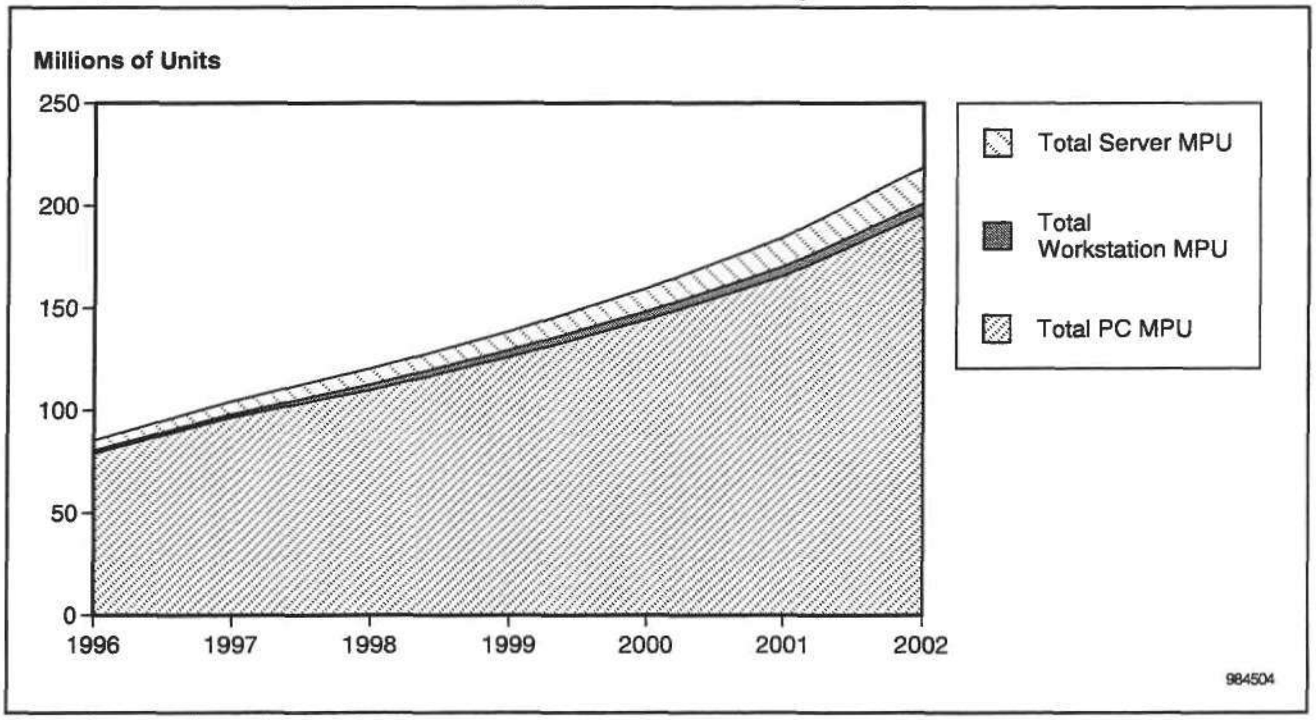
Source: Dataquest (November 1998)

The embedded market could not support Intel's growth objectives, so the planners needed to continue their search for a large market that could afford to pay a lot for powerful microprocessors. They turned to the high end of the computing market, the servers and workstations that Figure 2-9 shows make up just a tiny portion of computing system unit shipments. Unlike the embedded market, with its high volume of low-priced devices, the high-end computing market consists of a low (by Intel standards) number of high-priced devices. Further analysis revealed that the 8 percent of microprocessor units consumed by these markets accounted for 42 percent of overall microprocessor revenue. Dataquest projects that this ratio will shrink only slightly over the next five years, as shown in Figures 2-10 and 2-11. Most of this revenue goes to vendors other than Intel, which made the market especially attractive to Intel's strategists.

Until recently, a variety of technological and marketing barriers precluded Intel's successful entry into the high end of the market. Changes (some wrought by Intel itself) improve the likelihood that Intel can surmount these barriers with its current assault. The barriers fall into the following three major areas:

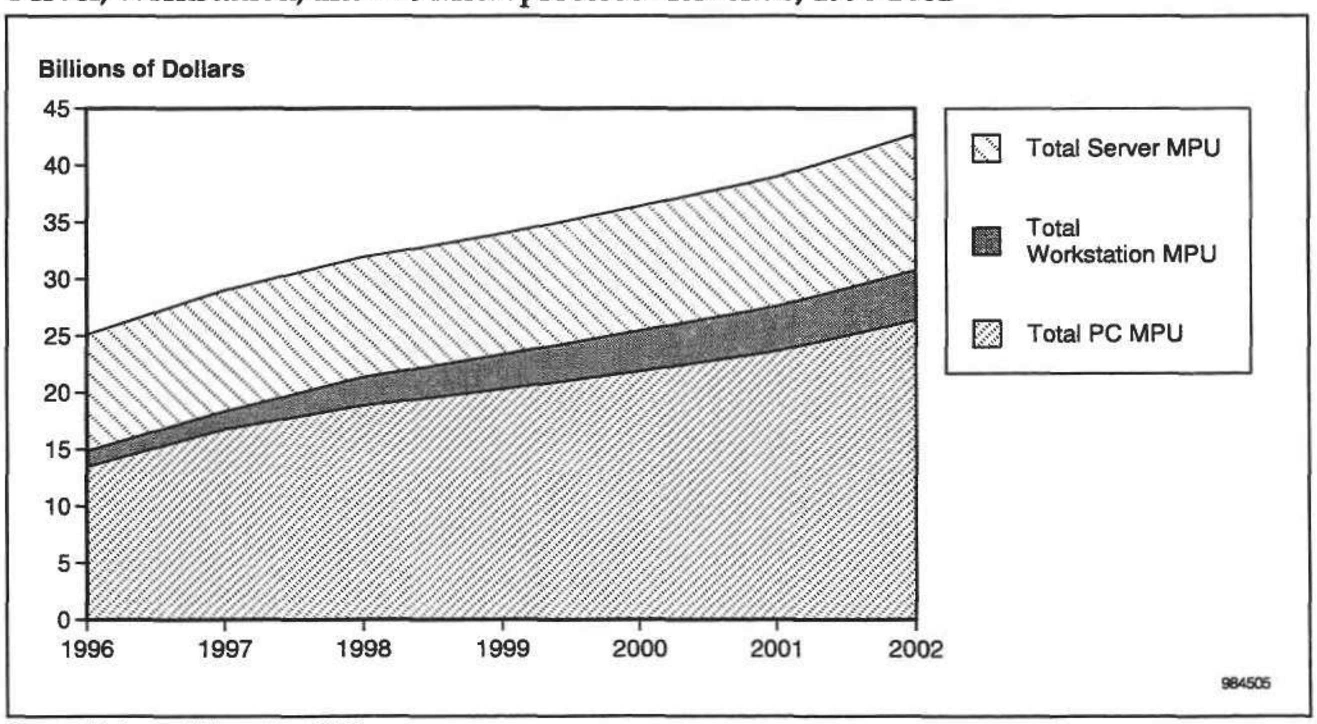
- Software: The huge base of Windows-based software titles that kept the better-performing RISC architectures of the 1980s from gaining any momentum on the desktop provided no assistance for any assault on the workstation or server market. With the advent of Windows NT, Intel and Microsoft Corporation began to breech these walls. Together, they apply relentless pressure that allows them to work their way up into the middle of the high end previously off limits. Their inexpensive, commodity-oriented hardware and software captures the less challenging applications that previously provided easy targets for the more expensive RISC platforms, driving the latter into an ever-decreasing niche, where performance technical requirements are high but opportunities are hard to find.

Figure 2-9
Server, Workstation, and PC Microprocessor Unit Shipments, 1996-2002



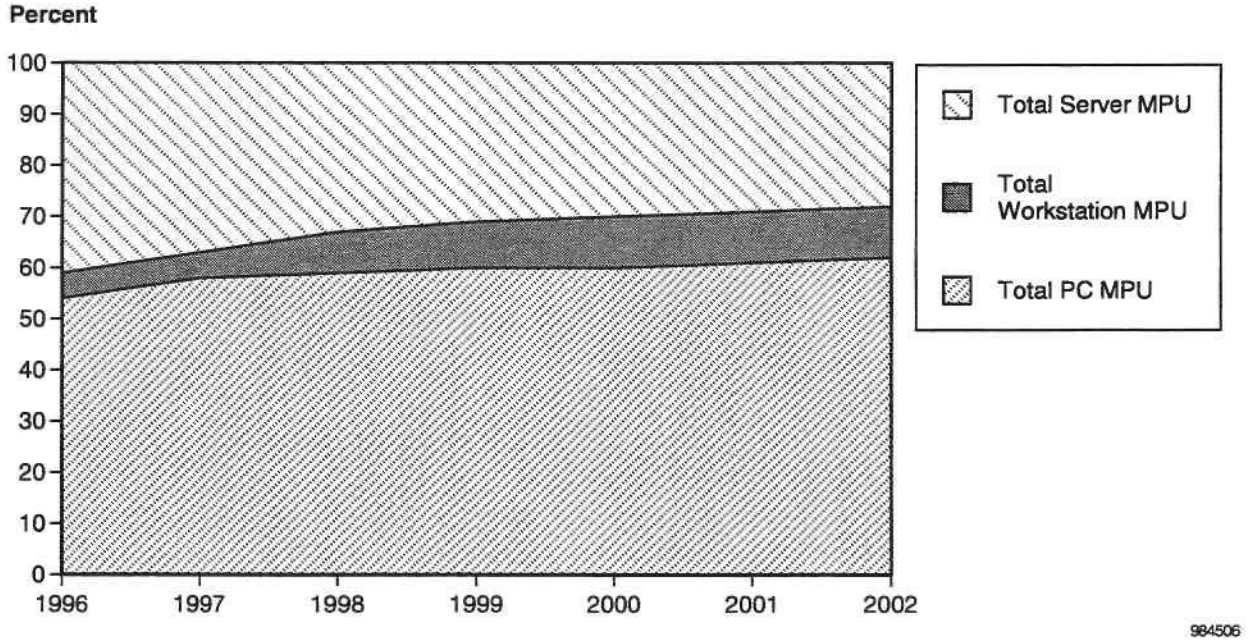
Source: Dataquest (November 1998)

Figure 2-10
Server, Workstation, and PC Microprocessor Revenue, 1996-2002



Source: Dataquest (November 1998)

Figure 2-11
Mix of Server, Workstation and PC Microprocessor Revenue, 1996-2002



Source: Dataquest (November 1998)

- Performance: The use of the highly advanced manufacturing technology and the adoption of many design tricks pioneered by the mainframe and RISC communities allowed Intel to narrow the gap between the performance of its chips and that of the proprietary alternatives. These proprietary processors were sold in tiny volumes but cost substantially more to manufacture and needed to absorb far more development expense on a per-unit basis.
- Price: The high-end market survives by charging relatively high prices for units sold in relatively low volumes, but Intel's desktop processor business model uses continual price reductions to push large numbers of processors into the market. Even chips that start at very high prices rapidly fall to more modest ones; witness the 300-MHz Pentium II introduced at $1,980 in April 1997 that fell to $700 in November and now sells for $209. Intel needed a firewall that would allow it to pursue its traditional strategies on the desktop and still charge premium prices for products targeted at workstation and server markets. The introduction of the "slot 2" Pentium II processors, officially known as Pentium II Xeon, provides just such a firewall. Intel modifies its standard products to provide a bit more performance (10 to 20 percent, on average), and then charges from five to 20 times as much for them. Even with such substantial mark-ups, the systems based on these Intel parts still provide a compelling economic advantage over Intel's more proprietary competitors.

Together, these changes in the relevance and maturity of Windows NT, the narrowing performance gap, and the introduction of market-specific processor packages form the foundation for Intel's assault on the high end of the computer market.

Sizing the High-End Processor Market

The very high ASPs (even by Intel standards) commanded by processors used in servers and workstations makes them an even more interesting target. Many of these proprietary devices are manufactured by captive semiconductor operations in mainframe companies and never appear on the open market. Thus, they remain uncounted by organizations like Dataquest or World Semiconductor Trade Statistics (WSTS). In this report, Dataquest estimates their value by comparing the results of our top-down processor consumption market model with the bottom-up statistics we collect from semiconductor vendors. The difference between these two correlate closely with our estimates for proprietary enterprise and departmental servers, as will be noted later. Table 2-4 outlines these calculations. Figure 2-12 compares ASPs for microprocessors in three distinct markets: personal computer, workstation, and server. Server microprocessor ASPs currently exceed those in the personal computer market by a factor of 10, but Dataquest anticipates that this multiple will shrink as the market becomes increasingly commoditylike. Just as an increase in the mix of low-priced personal computers has pulled down personal computer ASPs from historic levels, so too will the large increase in inexpensive "workgroup servers" lower ASPs for the server market overall. Figure 2-13 highlights these processor ASPs by server market segment. Prices of processors for servers targeted at enterprise applications will decline from just over $5,000 to just over $2,000 during the period, but still remain quite attractive to a semiconductor manufacturer.

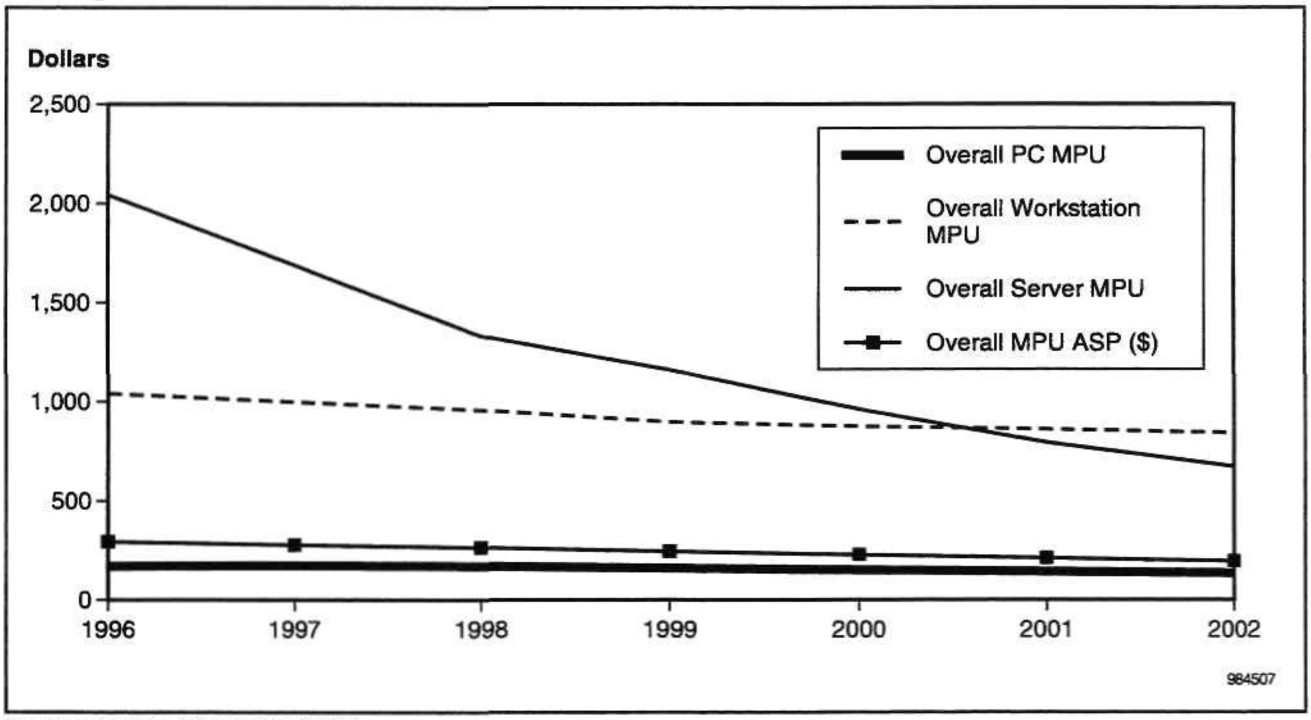
Dataquest's Computer Systems and Servers program anticipates that the market for server systems of all types will grow at a 5 percent rate over the period 1998 to 2002, from $51.4 billion to $62.5 billion. Revenue associated with the microprocessors that power these servers will grow at only a 2 percent rate, from $10.6 billion to $12.0 billion over the same period. While such growth would be unremarkable at best, the manner in which Dataquest actually measures this market distorts the results and makes the growth rate look far higher. Neither Dataquest nor other statistics-gathering organizations can capture the largely proprietary production of processors going into today's mainframes. As these proprietary system products decrease in volume over the next five years, Dataquest can capture the value of the third-party processors that power their replacements. In other words, we cannot capture the erosion of the proprietary processors, but we can capture the growth of the commodity ones. Consequently, microprocessors for servers will appear to grow at a 16 percent rate over the forecast period. Intel's share of the (more broadly defined) market will grow from 26 percent in 1997 to 60 percent in 2002. This translates into an impressive 21 percent rate of revenue growth for Intel in the period. Table 2-5 summarizes this situation.

Table 2-4
Top-Down and Bottom-Up Computational Microprocessor Market Estimates, 1996-1997

	Units (K) 1996	Revenue ($M) 1996	ASP ($) 1996	Units (K) 1997	Revenue ($M) 1997	ASP ($) 1997
Top Down	85,456	25,109	293.83	104,509	29,011	277
Bottom Up	83,908	16,668	198.65	103,156	21,407	207
Invisible Portion	1,548	8,441	5,454.31	1,353	7,604	5,618

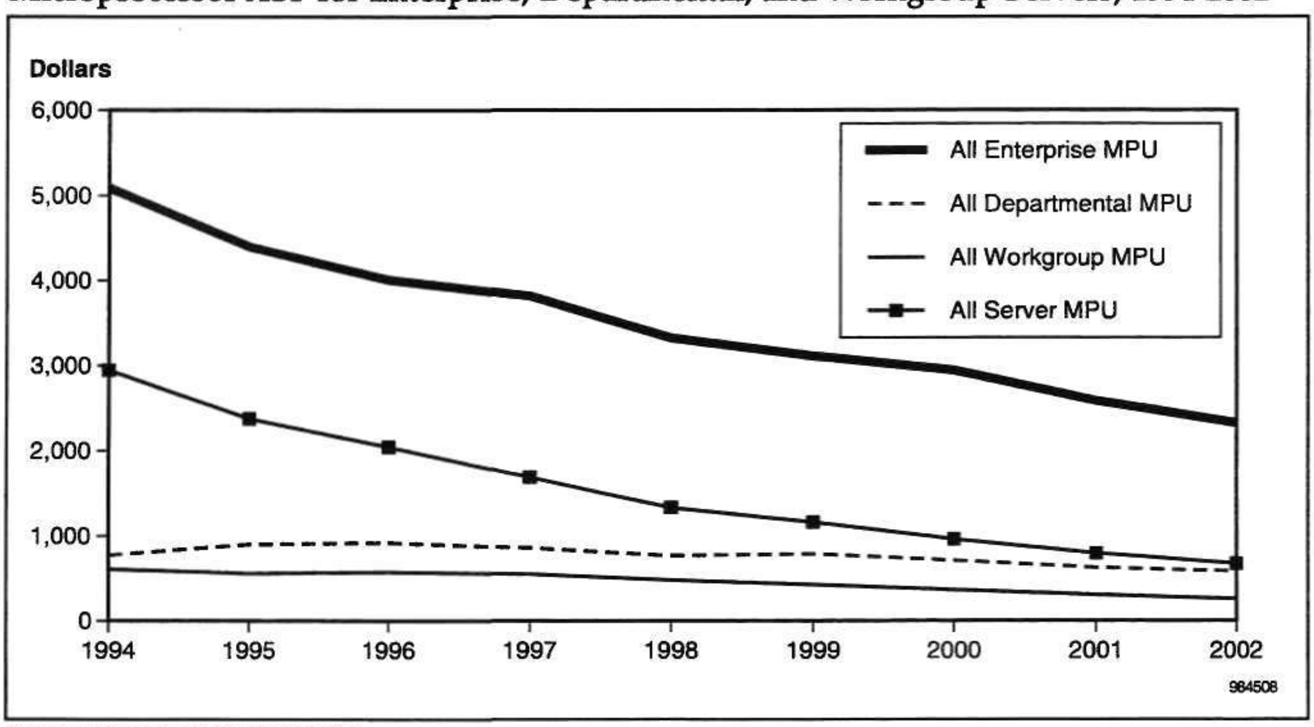
Source: Dataquest (November 1998)

Figure 2-12
Microprocessor ASP for Server, Workstation, and PC Markets, 1996-2002



Source: Dataquest (November 1998)

Figure 2-13
Microprocessor ASP for Enterprise, Departmental, and Workgroup Servers, 1994-2002



Source: Dataquest (November 1998)

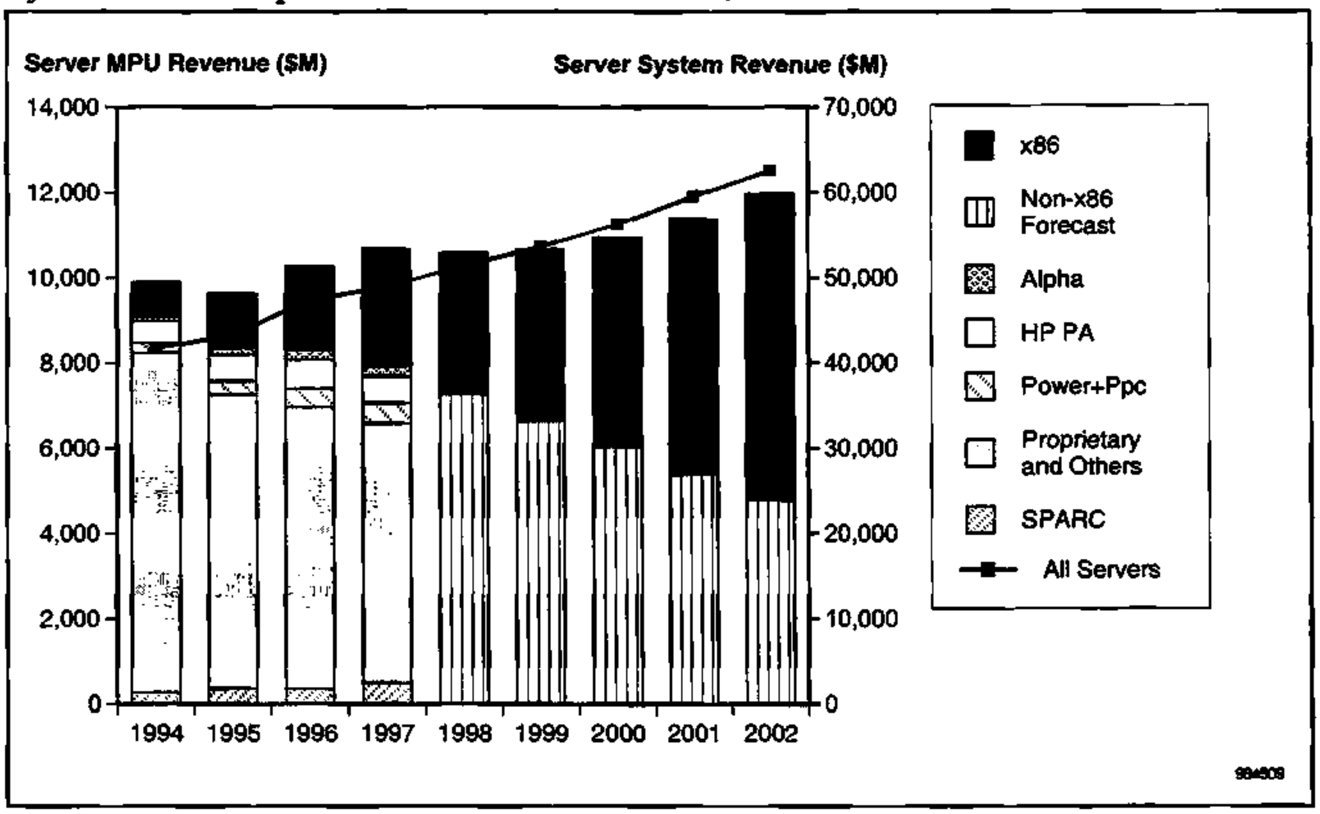
Table 2-5
Microprocessor Revenue for Servers, 1996-2002 (Millions of Dollars)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1996-2002
All Server MPU Revenue	**10,254**	**10,687**	**10,589**	**10,659**	**10,948**	**11,383**	**11,970**	**2**
Proprietary and Other MPU	6,600	6,084	5,124	4,296	3,581	2,967	2,440	-17
All Visible MPU Revenue	3,654	4,602	5,464	6,363	7,366	8,416	9,530	16
x86 Server MPU Revenue	1,959	2,776	3,333	4,020	4,929	6,000	7,189	21
x86 Share of All Server MPU (%)	19	26	31	38	45	53	60	-
x86 Share of Visible Server MPU (%)	54	60	61	63	67	71	75	-

Source: Dataquest (November 1998)

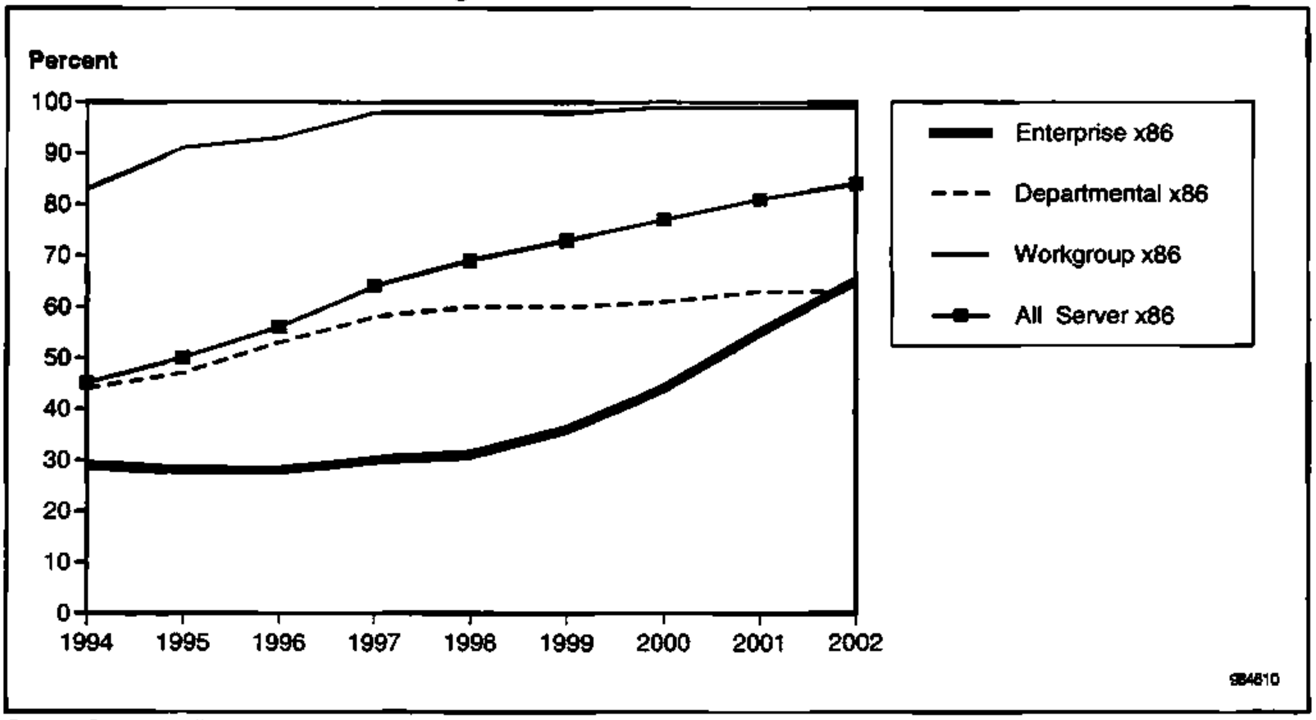
Figure 2-14 illustrates overall server revenue, the value of the processors going into those servers, and the growing proportion of this revenue we expect Intel to capture in this market. As noted in Figures 2-15 and 2-16, the x86 already dominates the low-end workgroup segment. In the departmental segment, Intel accounts for more than half of the processor unit shipments and revenue. But, in the large and pricey enterprise segment, Intel lays claim to only 30 percent of the processor units and less than 10 percent of current revenue.

Figure 2-14
System and Microprocessor Revenue for Servers, 1994-2002



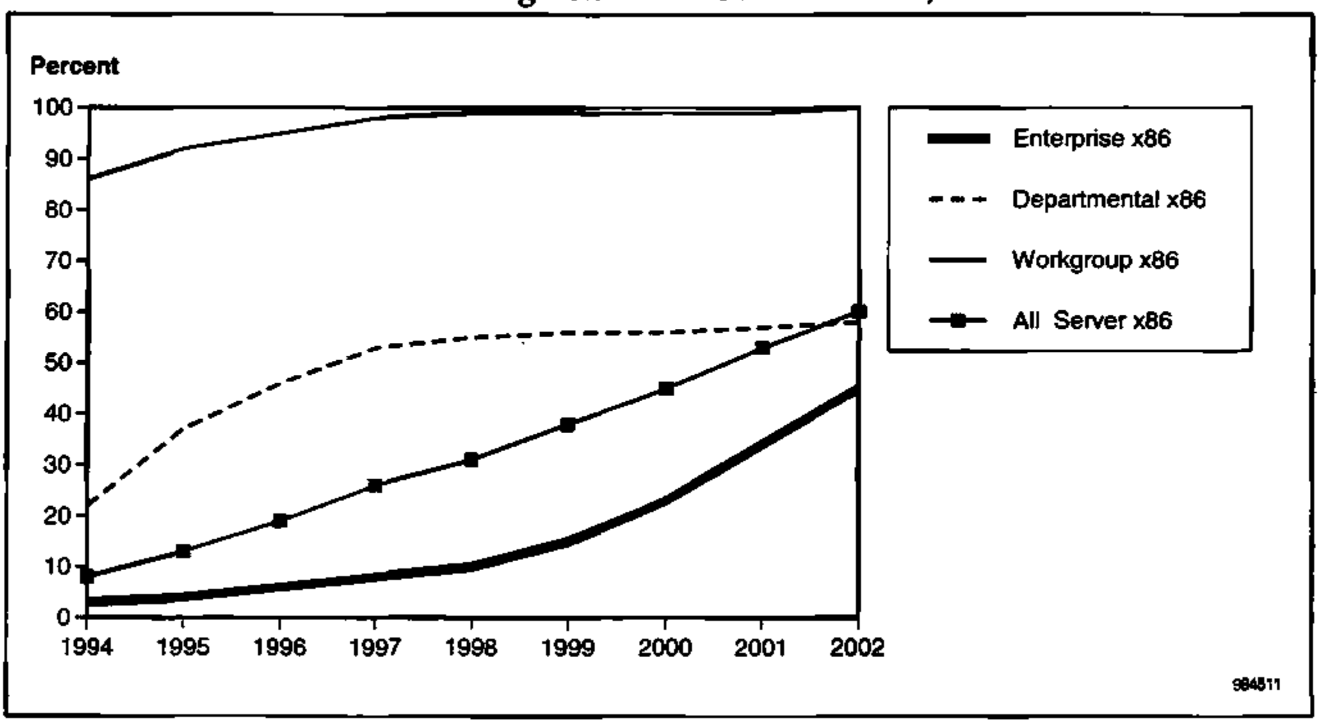
Source: Dataquest (November 1998)

Figure 2-15
x86 Unit Share within Each Segment of the Server Market, 1994-2002



Source: Dataquest (November 1998)

Figure 2-16
x86 Revenue Share within Each Segment of the Server Market, 1994-2002



Source: Dataquest (November 1998)

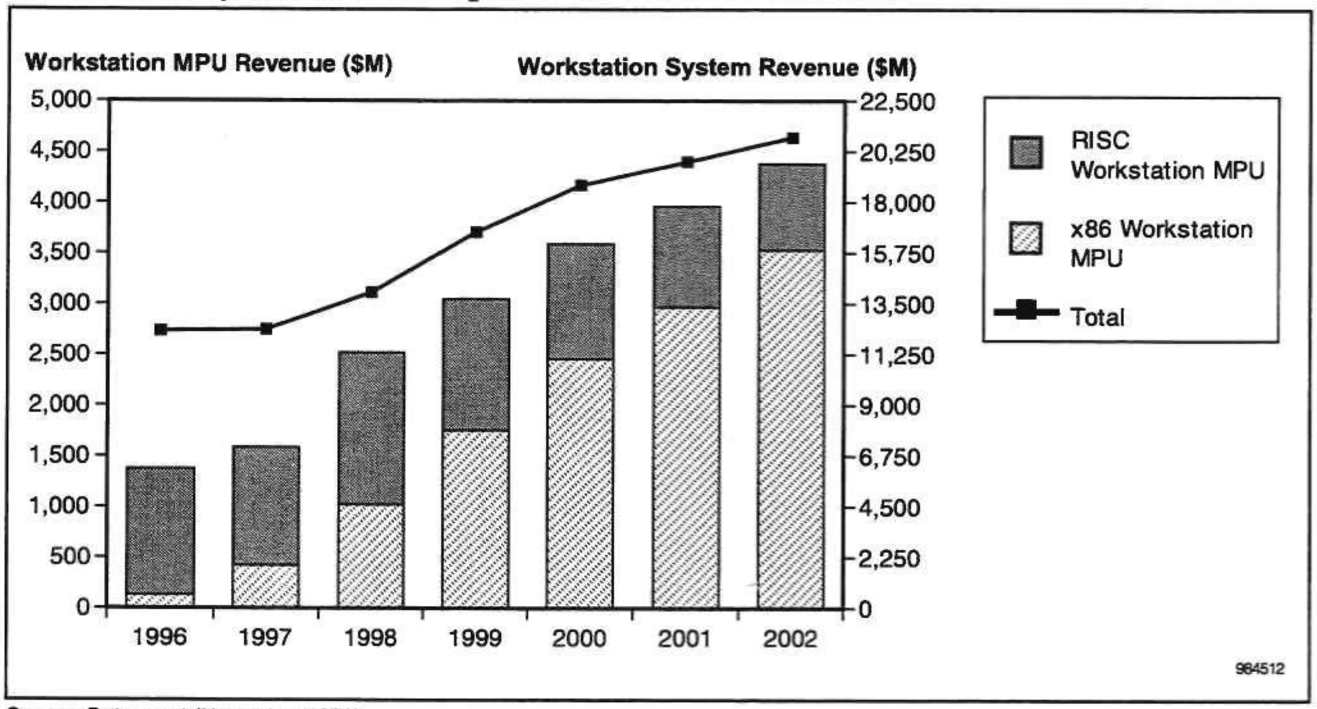
Intel's Projected Growth in the Workstation Market

The same factors that drive Intel's growing share of server markets also are at work in the workstation market. Unit growth of UNIX-based workstations has stalled, while growth accelerates for x86-based workstations running Windows NT. Traditional vendors hold the high end of the market but watch their shares of entry-level and midrange systems erode. The Pentium II Xeon line, with its unique "slot 2" connector, allows Intel to gather premium prices for products that offer a bit more performance than its higher-volume, lower-cost desktop products deliver. These Xeon products cannot match the performance of the fastest proprietary RISC processors, but they come close enough for many users, and they sell at prices dramatically lower than the proprietary systems. These factors will allow x86-based workstations to increase their share of the market from 37 percent in 1997 to 88 percent in 2002. As expensive proprietary workstations give way to inexpensive x86-based systems, workstation system ASPs will plummet at a 14 percent CAGR and workstation processor ASP will fall by 3 percent per year. In other words, as workstations become less proprietary, the processor will grab a larger portion of their overall cost of materials.

A portion of the growth in workstation shipments stems from the definitions market research companies like Dataquest use when collecting data on the workstation market. Prior to the advent of Windows NT, the software gulf between personal computers and workstations was so wide that users of one type of device rarely migrated to the other. This allowed vendors such as Sun Microsystems Inc. to sell inexpensive SPARC-compatible workstations along with their more powerful models, while PC vendors could offer beefy versions of their PC products to users pushing the machines to their limits. Windows NT blurs the distinctions between these product classes and lets users deploy the same application packages in both environments. This, in turn, lets them migrate easily between workstation-class systems and personal computers. In the Wintel world, a low-end workstation gets counted as a personal computer and a high-end PC, marketed as a workstation, gets counted as a workstation. In effect, Windows NT workstation growth comes at the expense of both proprietary workstations and high-end personal computers.

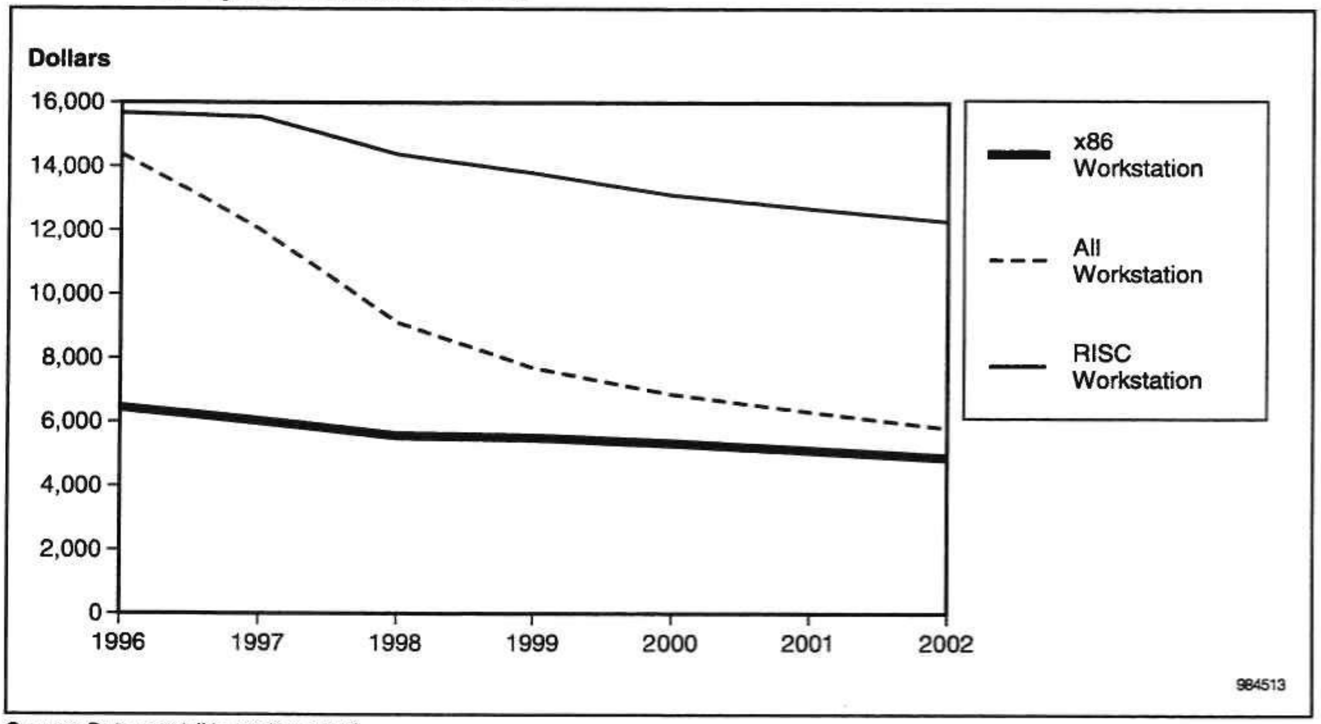
Figure 2-17 displays revenue growth for the overall workstation segment, as projected by Dataquest's Advanced Desktops and Workstations program, along with the split of revenue for the x86 and non-x86 microprocessors used in these systems. Figures 2-18 and 2-19 depict the ASPs of these systems and the processors they use. In both cases, the prices for each class of product or component remains relatively constant, but the ASP falls as the mix shifts from mostly expensive proprietary systems to mostly inexpensive commercialized ones. Finally, Figure 2-20 lays out the growing market share for x86-based units, as measured by units and revenue, over the forecast period.

Figure 2-17
Workstation System and Microprocessor Revenue, 1996-2002



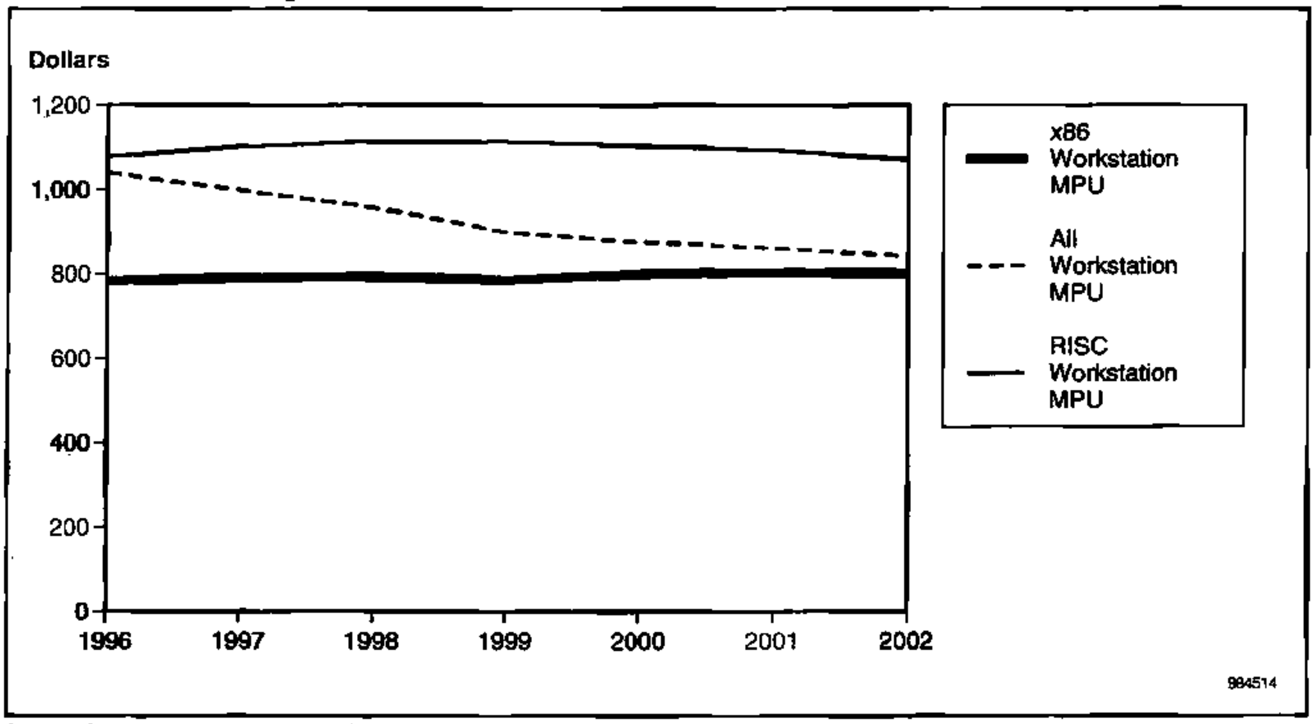
Source: Dataquest (November 1998)

Figure 2-18
Workstation System ASP, 1996-2002



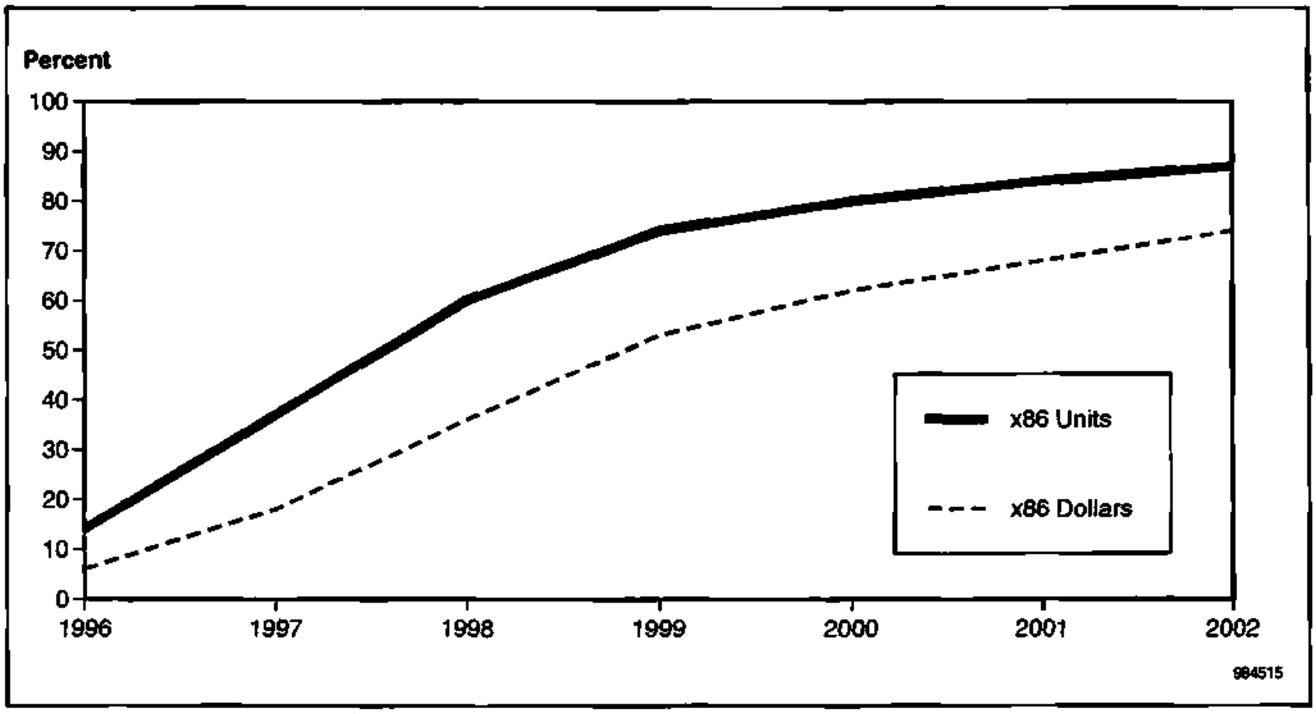
Source: Dataquest (November 1998)

Figure 2-19
Workstation Microprocessor ASP, 1996-2002



Source: Dataquest (November 1998)

Figure 2-20
Market Share for x86-Based Workstation Microprocessors, by Units and Processor Revenue, 1996-2002



Source: Dataquest (November 1998)

Intel's Position in the Computational Microprocessor Market

Intel's overall share of the computational microprocessor market will increase from 63 percent to 74 percent as the company extends its presence in workstation and server processor markets over the next five years. As it gains share at the high end, it will lose share at the low end, but the revenue it gains more than offsets that lost. As noted earlier, a portion of its new revenue will come at the expense of proprietary processors that now go uncounted by Dataquest. All signs will point to an expansion of the market, but in reality, units and revenue will just move from vendors that we cannot track to ones we can. The money will end up in Intel's treasury, regardless of how we count it. To the extent the current set of high-end system vendors merely replace their current proprietary products with new systems based on more standard hardware, their revenue may not reflect this subtle change in system composition. Their gross margins most likely will, since these vendors will contribute less added value to the systems they sell and will most likely see margins fall. Some vendors will adapt their business models to such new realities and generate more profit than ever before. Others will cling to their earlier models and watch their profitability erode until they figure it out.

Over the next five years, microprocessor unit volumes will more than double, from 105 million units to 219 million, a 16 percent CAGR, but revenue will grow at only an 8 percent CAGR, from $29 billion to $42.7 billion. Intel's unit growth will lag the industry at a 13 percent CAGR, but its move up market will drive above-average revenue growth of 11 percent per year, from $18.4 billion in 1997 to 31.7 billion in 2002. It is difficult to predict the impact Intel's move into high-end markets will have on the company's overall profitability. Dataquest estimates that the margins on these new products will be higher than those Intel has achieved on the desktop, and certainly better than what could be achieved on the desktop, as prices continue to erode.

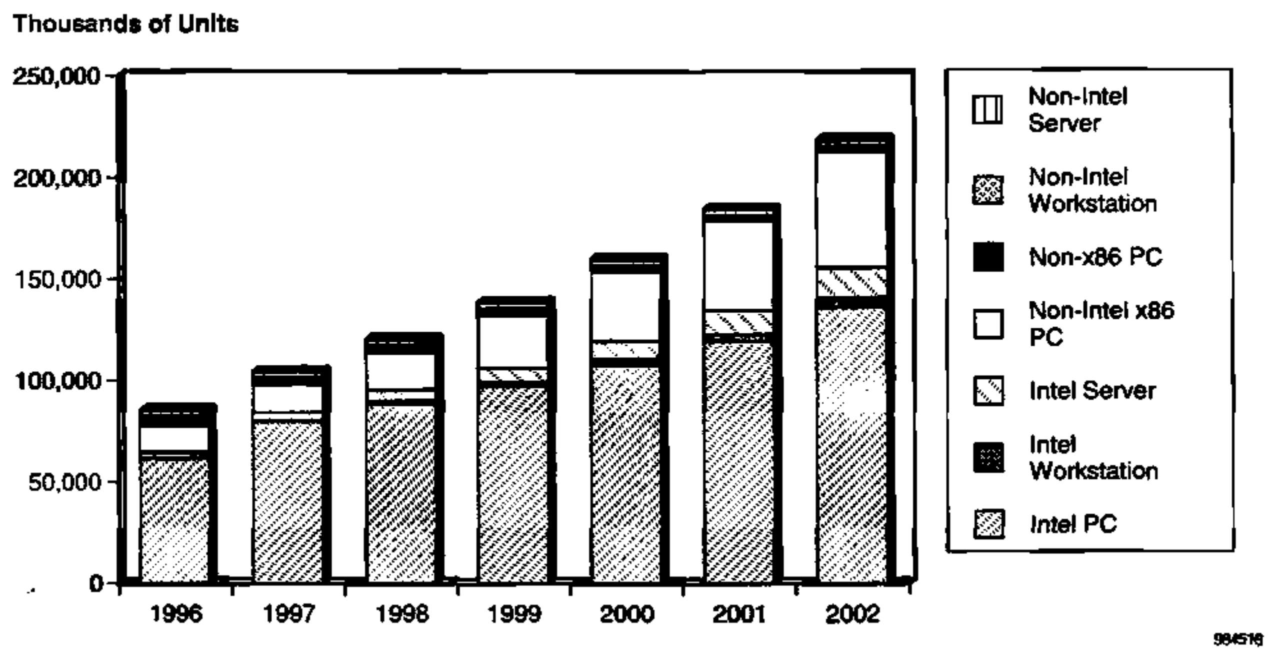
As Intel captures share in the high-ASP/low-volume portion of the market, its x86 competitors will take share in the low-ASP/high-volume desktop segment. Much of this business will be transacted at prices lower than those Intel has accepted in the past, and Dataquest anticipates that Intel will continue to leave such opportunities to others. Intel might decide to pursue such business in the future, either to absorb excess capacity or to thwart competitive inroads. Such a move would dramatically slow the growth of the x86 competitors, but would have only a small impact on Intel's growth. (The competitors can report high growth rates because they are measuring from a small base.)

Figure 2-21 presents Dataquest's view of the growth in unit shipments of microprocessors by Intel and its collective competition in all markets over the next five years. Not surprisingly, the high volumes of desktop products shipped by Intel and its x86 competitors dominate this chart. Figure 2-22 displays the revenue associated with these units. By the end of the period, one-third of Intel's revenue will come from workstations and servers, up from only 17 percent last year. The non-Intel contingent will see its mix of high-end (and presumably, high-margin) sales drop to 51 percent of revenue, from 86 percent last year. Figures 2-23 and 2-24 display Intel's dollar and unit shares, respectively, by market segment.

As has been noted before, Dataquest expects Intel to see its overall unit share decrease while its overall dollar share increases. In the personal computer segment, we anticipate that it will lose both dollar share and unit share, although its absolute volume of units and revenue will continue to increase.

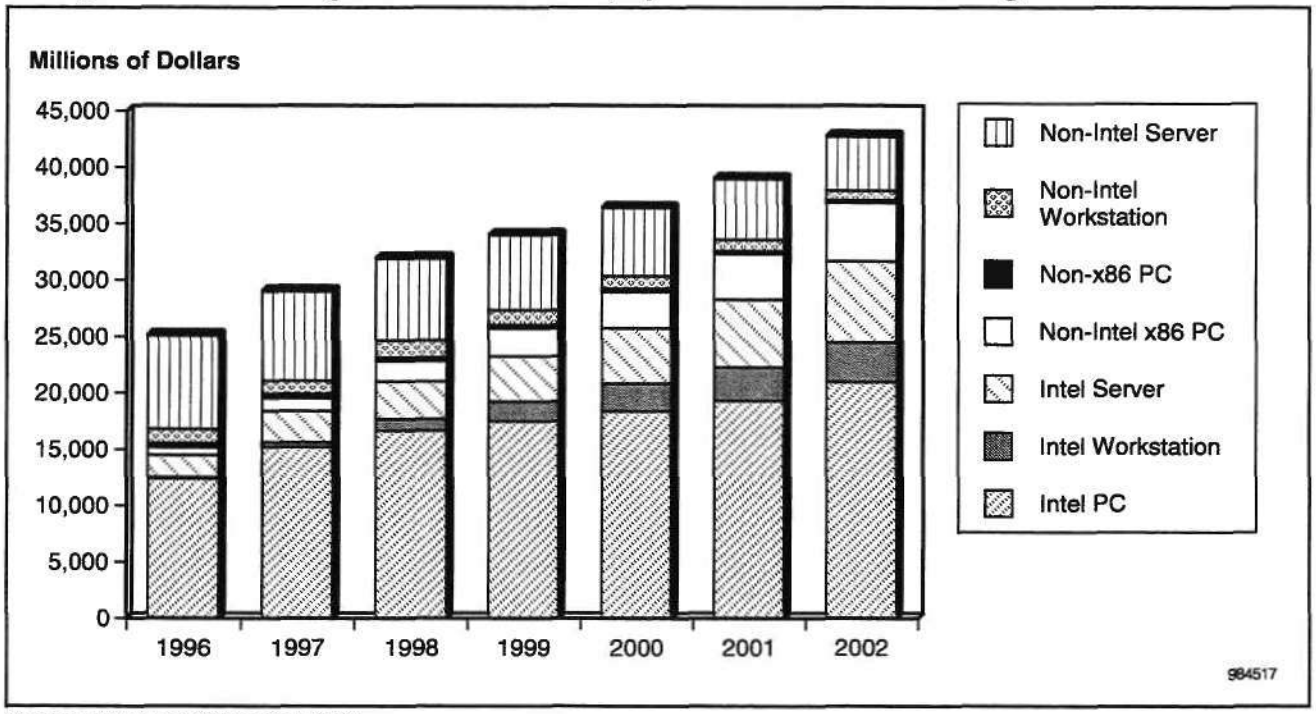
Finally, Figure 2-25 reviews the ASPs for Intel's processors in each of the market segments it plans to serve. Processors targeted at desktop and mobile personal computers will experience slight ASP erosion of 4 percent per year, from $190 to $153, as the company ships more inexpensive MPUs and fewer pricey ones. Workstation processor ASP remains flat at $800; users looking for less expensive workstations will end up using personal computers, perhaps configured with Windows NT instead. The ASP for processors for servers will drop 7 percent per year, from $693 to $492. This figure, somewhat surprising in light of Pentium II Xeon processors priced from $1,100 to $4,000 each, results from the overwhelming preponderance of low-end workgroup servers in the mix. Dataquest anticipates that such devices will often use conventional desktop processors to reduce costs. ASPs for enterprise servers clearly contain more excitement, as Dataquest will detail in the latter section of this report that focuses on servers.

Figure 2-21
Computational Microprocessor Unit Shipments, by Vendor and Market Segment, 1996-2002



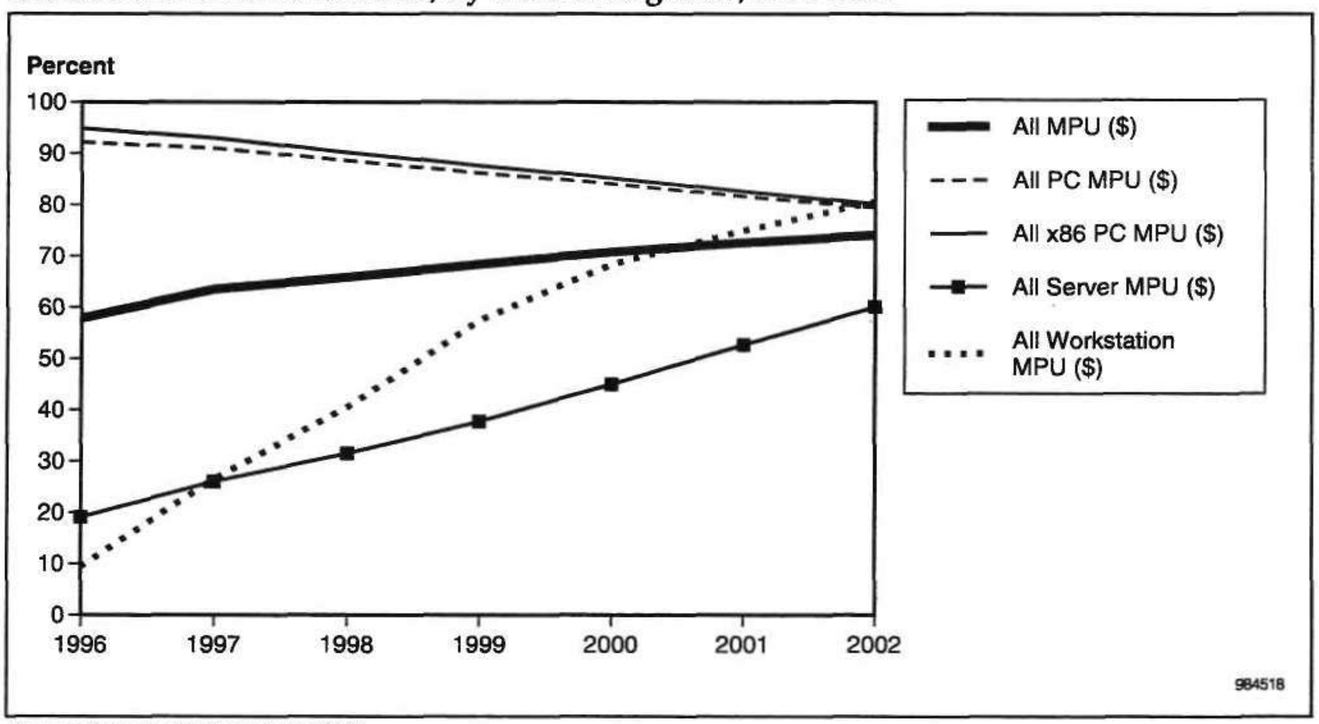
Source: Dataquest (November 1998)

Figure 2-22
Computational Microprocessor Revenue, by Vendor and Market Segment, 1996-2002



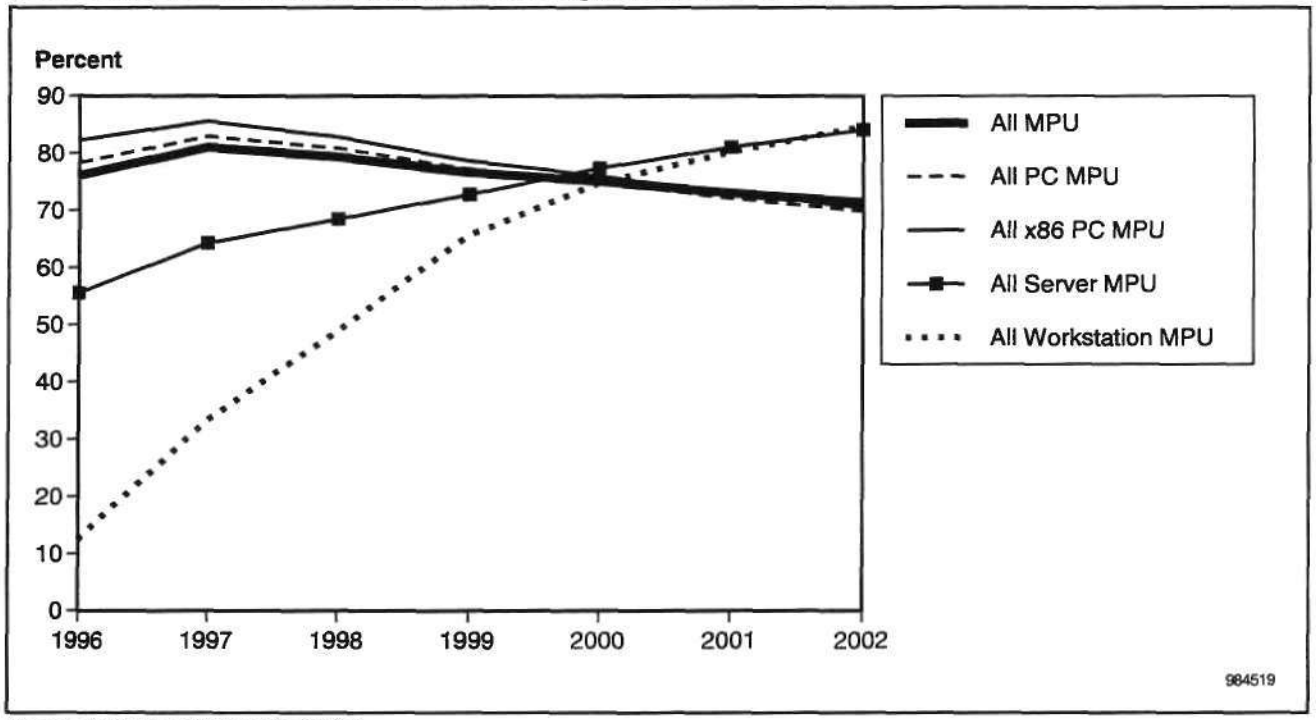
Source: Dataquest (November 1998)

Figure 2-23
Intel Revenue Market Share, by Market Segment, 1996-2002



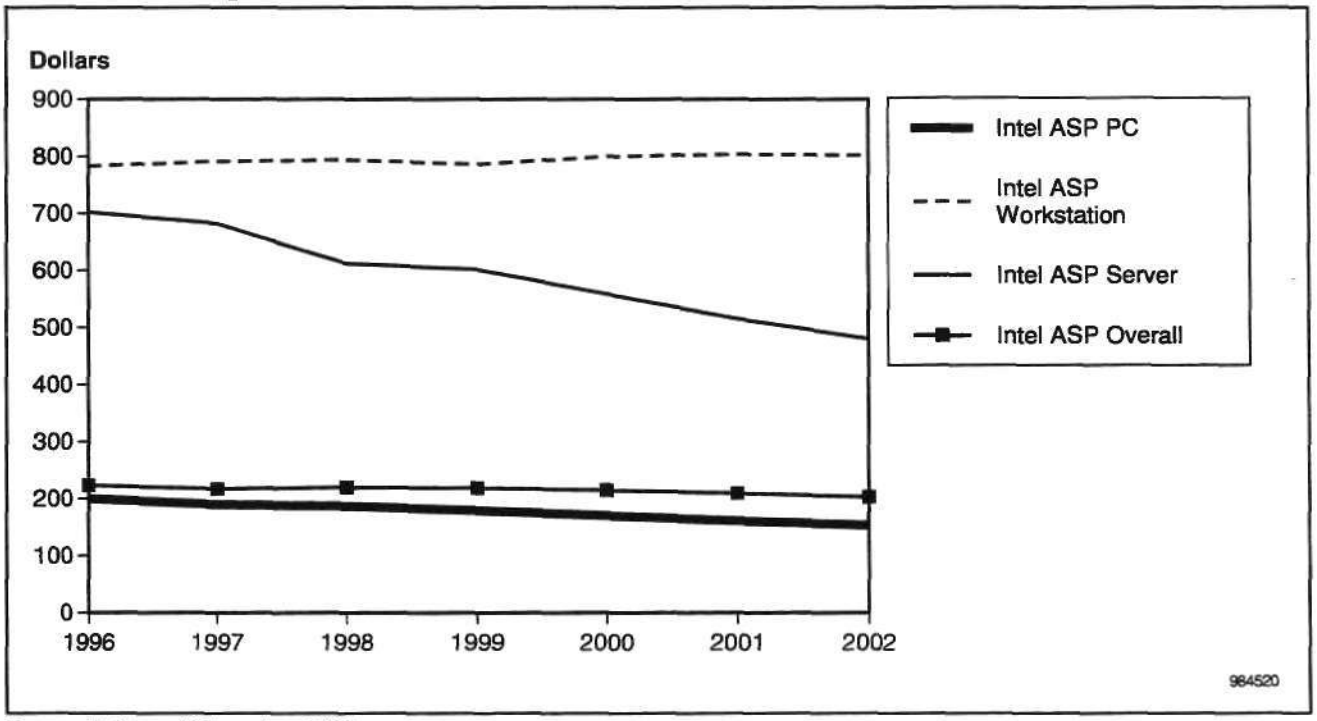
Source: Dataquest (November 1998)

Figure 2-24
Intel Unit Market Share, by Market Segment, 1996-2002



Source: Dataquest (November 1998)

Figure 2-25
Intel x86 Microprocessor ASPs, 1996-2002



Source: Dataquest (November 1998)

Chapter 3

Microprocessors for Personal Computers

1997 in Review

The year 1997 will be remembered as the year Intel's x86 competitors came close to getting their acts together and the year that Apple dashed any remaining hope that the desktop might play an important role in the future of the PowerPC. It is hard to believe that it has only been 18 months since Intel rolled out the first Pentium processors with MMX technology. This move rapidly made all inventories of non-MMX processors look old before their time, even though few software titles took advantage of the new MMX instructions. Intel followed with the launch of its MMX-enhanced sixth-generation product, the Pentium II. AMD countered with its own MMX-enhanced AMD-K6 and might have impacted Intel in a serious manner had it been able to ramp the chip's volume more quickly. For AMD, the refrain was once again "wait until next year." Cyrix finally landed a major OEM when Compaq introduced its $999 Presario 2100, based on the highly integrated Cyrix MediaGX chip. Compaq shipped over a million of these units, and let the low-price genie out of the bottle in the process. The industry will never be the same. A few months later, Cyrix launched its own MMX-enhanced 6x86MX, a follow-on to the earlier 6x86. Although it found no major OEM customers for this part in 1997, the part achieved moderate success with smaller resellers, who could obtain it at highly attractive prices. IBM piggybacked on the Cyrix 6x86MX bandwagon but lacked marketing rights to the Cyrix MediaGX and thus sat on the sidelines of the sub-$1,000 battle during the year. All in all, Intel gained a little in unit share (thanks to AMD's manufacturing woes), but lost a little in dollar share as AMD and Cyrix finally offered buyers something that did not immediately sink to the bottom of the barrel. Table 3-1 summarizes the year's results in the x86 arena.

Table 3-1
Computational x86 Market Statistics for 1997

Company	Units (K) 1996	Revenue ($M) 1996	Units (K) 1997	Revenue ($M) 1997	Unit Growth (%) 1997/1996	Revenue Growth (%) 1997/1996	Unit Share (%) 1997	Revenue Share (%) 1997
AMD	8,802	310	8,108	682	-8	120	11.2	2.0
Cyrix	1,920	160	3,700	310	93	94	2.5	1.0
IBM	1,721	174	1,700	151	-1	-13	2.2	1.1
Intel	65,000	14,675	83,791	18,559	29	26	83.0	95.6
Other	895	26	26	26	-97	0	1.1	0.2
Total	**78,338**	**15,345**	**97,325**	**19,728**	**24**	**29**	**100**	**100**

Source: Dataquest (November 1998)

The news was decidedly mixed in the Macintosh arena. The year 1997 was when the Common Hardware Reference Platform, popularly known as CHRP, was to arrive. This specification would have given the Macintosh clone vendors (Power Computing, Motorola, and UMAX) more degrees of freedom in the design of their Mac-compatible platforms than they initially possessed. Instead, as a result of the turmoil inside Apple Computer Inc., and the return of its prodigal founder, Steve Jobs, the company shut off its licensing program entirely. This move put the clone vendors out of business and put a lid on future sales of Macintosh computers and the PowerPC chips that drive them. The only good news on the PowerPC front in 1997 was the arrival of the G3 processor, which provides performance close to that of Intel's Pentium II line. This product, and the resulting Macintosh G3 configurations, sparked Apple's sales late in the year and gave loyal "Macolytes" a reason to hang on for yet another year.

IBM and Motorola Incorporated continued to share the PowerPC market, and both jockeyed for position as Apple's key supplier. The end result was close to a draw; they split the unit share 51:49, and the revenue share 49:51. Both can claim leadership in a market likely to decline from this point on. Early in 1998, IBM and Motorola announced they would sever their joint PowerPC development activities, carried out primarily at the jointly owned Somerset laboratory. Motorola received custody of the facility and its developers, while both agreed to share custody of the PowerPC specifications for computational and embedded versions of the product.
Table 3-2 summarizes the year's action in the PowerPC processor market.

Forecast for PC Microprocessors

Dataquest has refined the personal computer x86 forecast model that it introduced last spring and recalibrated the model to reflect the final market share data collected over the past several months. Each category in the model and each price band in the PC models is characterized by an ASP for the MPUs in that category and a unit volume forecast, provided by the appropriate Dataquest systems group. This allows Dataquest to reconcile MPU consumption with system sales. We have aggregated personal computer systems priced above $1,500 into one category, rather than maintaining separate groups at $500 intervals as in the spring, in order to simplify the presentation and comprehension of the overall market dynamic.

Table 3-2
Computational PowerPC Market Statistics for 1997

Company	Units (K) 1996	Revenue ($M) 1996	Units (K) 1997	Revenue ($M) 1997	Unit Growth (%) 1997/1996	Revenue Growth (%) 1997/1996	Unit Share (%) 1997	Revenue Share (%) 1997
IBM	2,510	439	1,800	329	-28	-25	51	49
Motorola	1,507	209	1,700	346	13	66	49	51
Total	**4,017**	**648**	**3,500**	**675**	**-13**	**4**	**100**	**100**

Source: Dataquest (November 1998)

Table 3-3 and Figure 3-1 contain Dataquest's forecast for MPU units in each personal computer price band. We anticipate substantial erosion in the desktop and mobile unit shipments in the price bands above $1,500. These shifts result primarily from a dearth of new computationally intensive applications that have (at least in the past) driven users to purchase ever more powerful systems at more or less constant price points. The need to spend more to purchase meaningful performance advantages is absent, and users will spend less in this regard. Dataquest earnestly hopes such applications will appear and will revisit its forecast whenever they begin to appear. Until that time, we will continue to project a continuing shift of personal computer sales from higher- to lower-priced systems. Figure 3-2 illustrates the dramatic shift that will occur between high- and low-end systems.

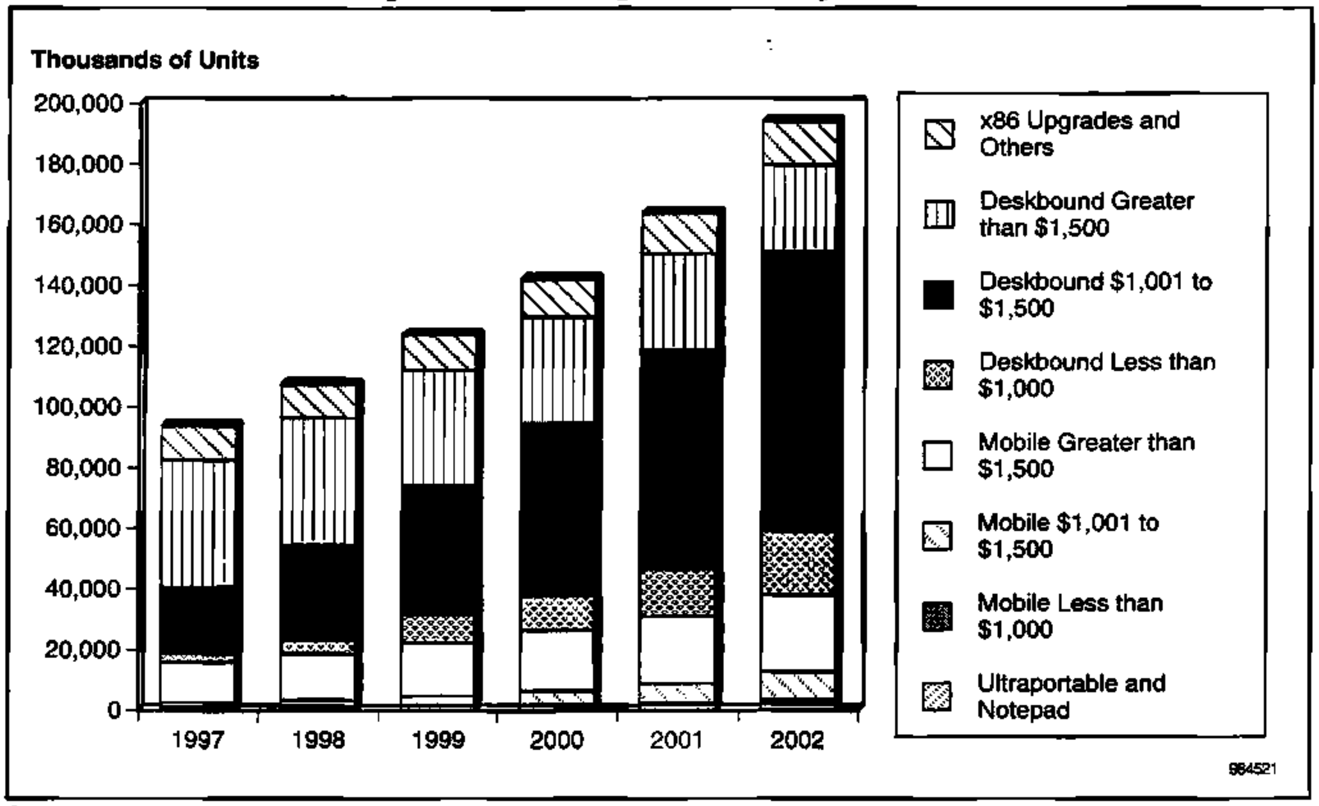
Table 3-4 and Figure 3-3 contain Dataquest's forecast for x86 MPU revenue in each category. Overall revenue growth of 10 percent (compared with 17 percent for unit growth) reflects severe erosion of desktop MPU prices, primarily as a result of the shifting mix to lower-priced personal computers. The microprocessors used in lower-priced systems cost, on average, less than those used in more expensive systems, and thus the shifting system mix dramatically impacts microprocessor revenue, regardless of whether these processors are sold by Intel or Intel's competitors, as we will examine later in this section. Figure 3-4 illustrates the manner in which processor revenue from low-end systems gain in importance over the period, while the contribution from high-priced systems ebbs.

Table 3-3
Forecast of Personal Computer x86 Microprocessor Shipments, 1997-2002 (Thousands of Units)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Ultraportable and Notepad	1,226	1,327	1,541	1,788	2,055	2,362	14
Mobile under $1,000	103	140	188	248	582	1,366	68
Mobile $1,001 to $1,500	1,326	2,040	3,134	4,460	6,399	9,180	47
Mobile over $1,500	13,305	15,260	17,572	20,072	22,105	25,176	14
Subtotal—Mobile	**15,960**	**18,767**	**22,435**	**26,568**	**31,141**	**38,083**	**19**
Desk under $1,000	2,664	4,663	8,968	11,353	15,423	20,952	51
Desk $1,001 to $1,500	21,982	31,084	43,045	56,767	72,367	92,254	33
Desk over $1,500	41,946	41,962	37,664	35,092	31,669	28,609	-7
Subtotal—Deskbound	**66,592**	**77,709**	**89,677**	**103,212**	**119,459**	**141,815**	**16**
x86 Upgrades and Others	11,113	10,879	11,658	12,385	13,140	14,181	5
Total Units	**82,552**	**96,476**	**112,112**	**129,780**	**150,600**	**179,898**	**17**

Source: Dataquest (November 1998)

Figure 3-1
Forecast of Personal Computer x86 Microprocessor Shipments, 1997-2002



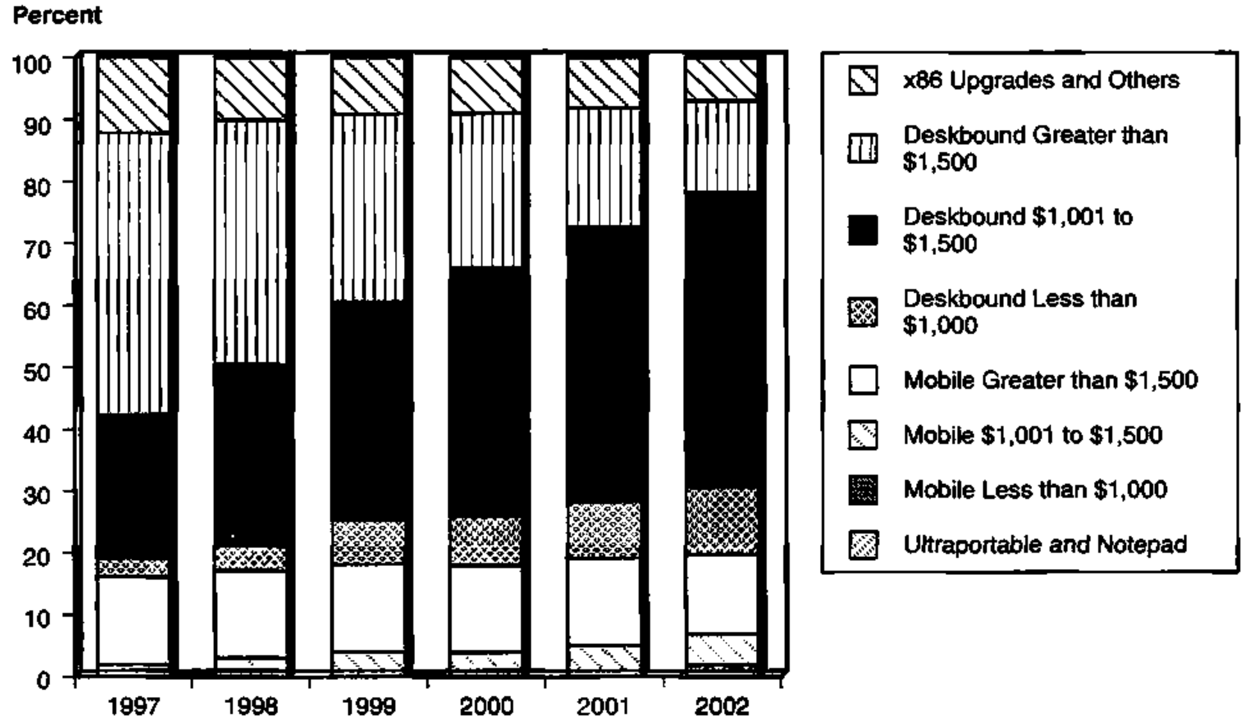
Source: Dataquest (November 1998)

Table 3-5 and Figure 3-5 contain Dataquest's forecast for x86 microprocessor ASPs in each category. Mobile processors tend to cost slightly more than deskbound equivalents. Within each band, the processor ASP remains relatively constant over time, since the system's price greatly influences how much the manufacturer can spend on the microprocessor for a specific system. Nevertheless, the overall ASP continues to decline as the mix shifts more and more toward the lower price bands. Consequently, deskbound processors will collectively decline to $125 at a 7 percent CAGR, while mobile units will fall to $160 at a 3 percent per year rate.

Intel's Competitors Will Gain Market Share

Our discussion up to this point has focused on the overall x86 microprocessor market, an arena in which Intel plays a major role. Although Dataquest does not normally forecast individual company market shares, we make an exception in the x86 microprocessor arena, where, for many years, Intel has been the market. This will change over the next few years.

Figure 3-2
Mix of Personal Computer x86 Microprocessor Units, 1997-2002



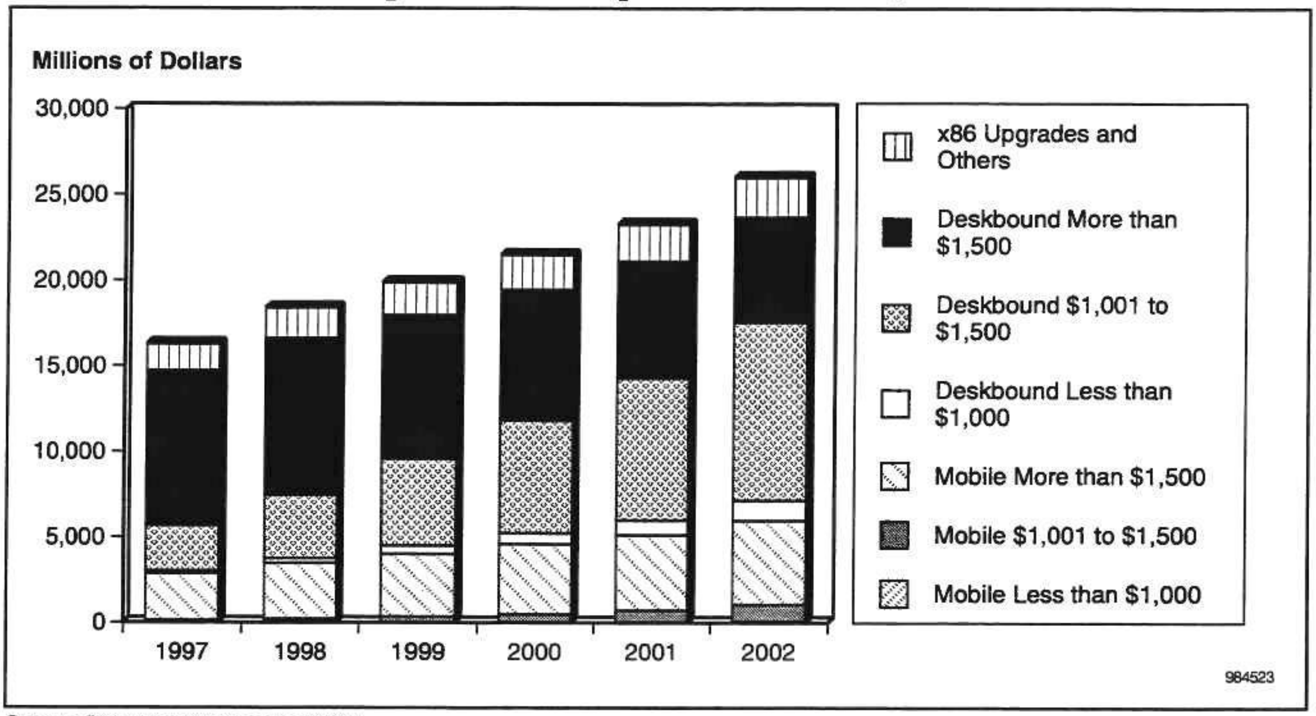
Source: Dataquest (November 1998)

Table 3-4
Forecast of Personal Computer x86 Microprocessor Revenue, 1997-2002
(Millions of Dollars)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Ultraportable and Notepad	72	82	93	106	121	139	14
Mobile under $1,000	6	8	10	14	33	77	69
Mobile $1,001 to $1,500	144	221	339	481	690	988	47
Mobile over $1,500	2,721	3,255	3,661	4,104	4,401	4,902	12
Subtotal—Mobile	**2,942**	**3,566**	**4,102**	**4,705**	**5,244**	**6,105**	**16**
Desk under $1,000	143	262	505	642	874	1,191	53
Desk $1,001 to $1,500	2,656	3,708	5,063	6,583	8,275	10,400	31
Desk Over $1,500	9,060	9,174	8,397	7,637	6,844	6,142	-7
Subtotal—Deskbound	**11,859**	**13,144**	**13,965**	**14,862**	**15,993**	**17,733**	**8**
x86 Upgrades and Others	1,568	1,779	1,906	2,025	2,148	2,318	8
Total Revenue	**16,369**	**18,488**	**19,973**	**21,592**	**23,384**	**26,157**	**10**

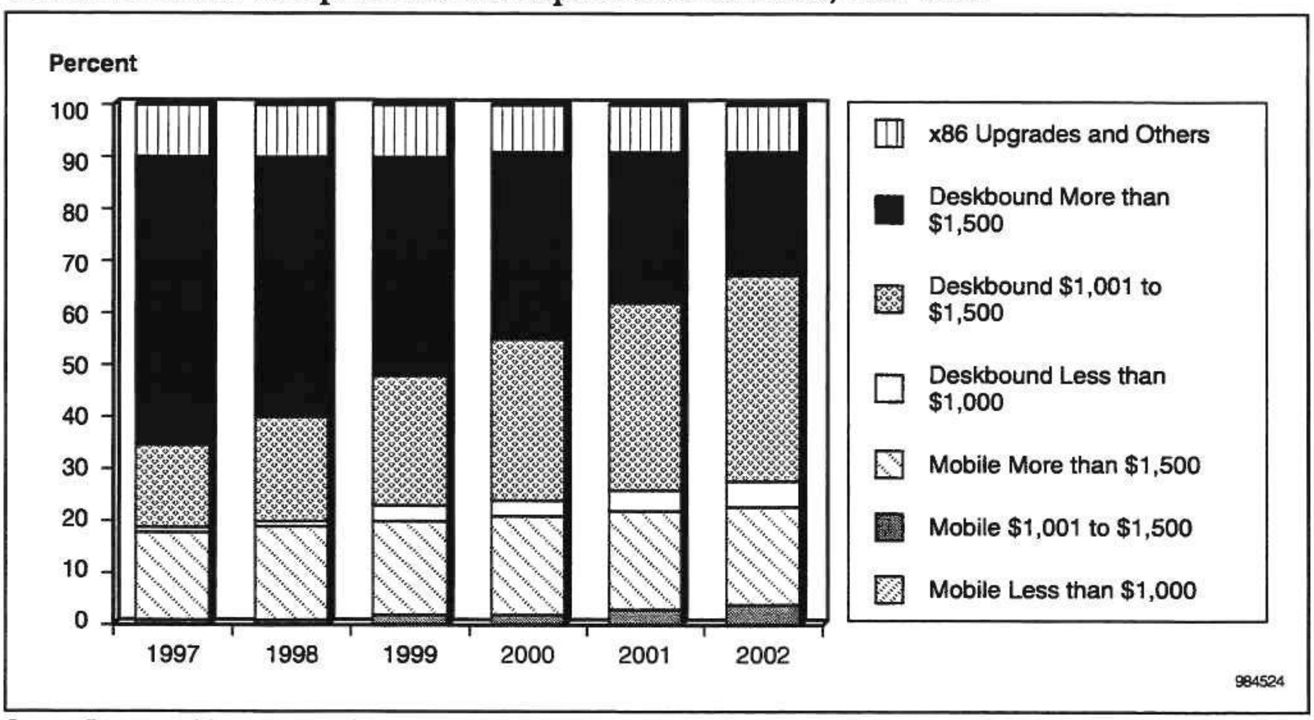
Source: Dataquest (November 1998)

Figure 3-3
Forecast of Personal Computer x86 Microprocessor Revenue, 1997-2002



Source: Dataquest (November 1998)

Figure 3-4
Mix of Personal Computer x86 Microprocessor Revenue, 1997-2002



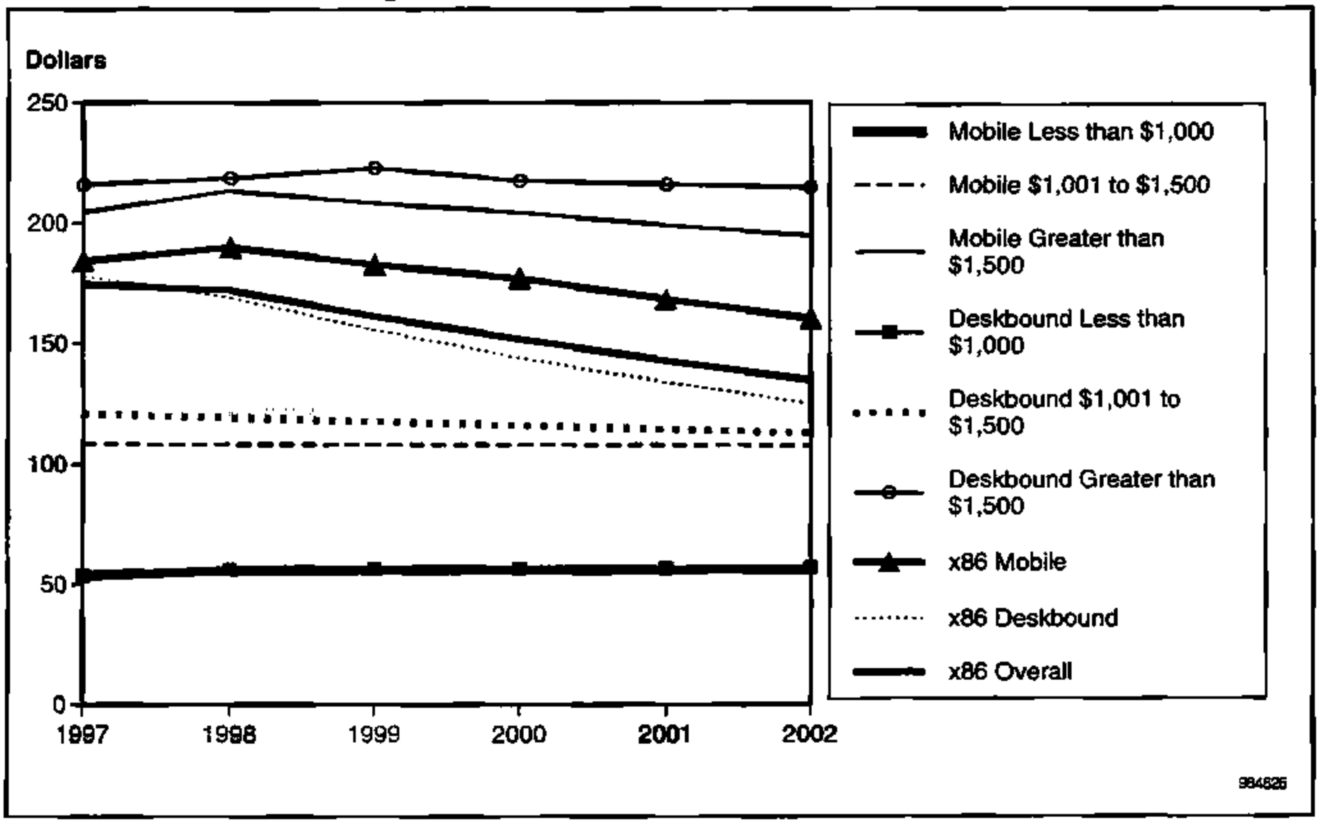
Source: Dataquest (November 1998)

Table 3-5
Forecast of Personal Computer x86 ASPs, 1997-2002 (Dollars)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Ultraportable and Notepad	59	62	60	59	59	59	0
Mobile under $1,000	54	56	56	56	56	56	1
Mobile $1,001 to $1,500	108	108	108	108	108	108	0
Mobile over $1,500	204	213	208	204	199	195	-1
Mobile Average	**184**	**190**	**183**	**177**	**168**	**160**	**-3**
Desk under $1,000	54	56	56	57	57	57	1
Desk $1,001 to $1,500	121	119	118	116	114	113	-1
Desk over $1,500	216	219	223	218	216	215	0
Deskbound Average	**178**	**169**	**156**	**144**	**134**	**125**	**-7**
x86 Upgrades and Others	141	141	141	141	141	141	0
x86 Overall	**175**	**172**	**161**	**152**	**143**	**135**	**-5**

Source: Dataquest (November 1998)

Figure 3-5
Forecast of Personal Computer x86 ASPs, 1997-2002

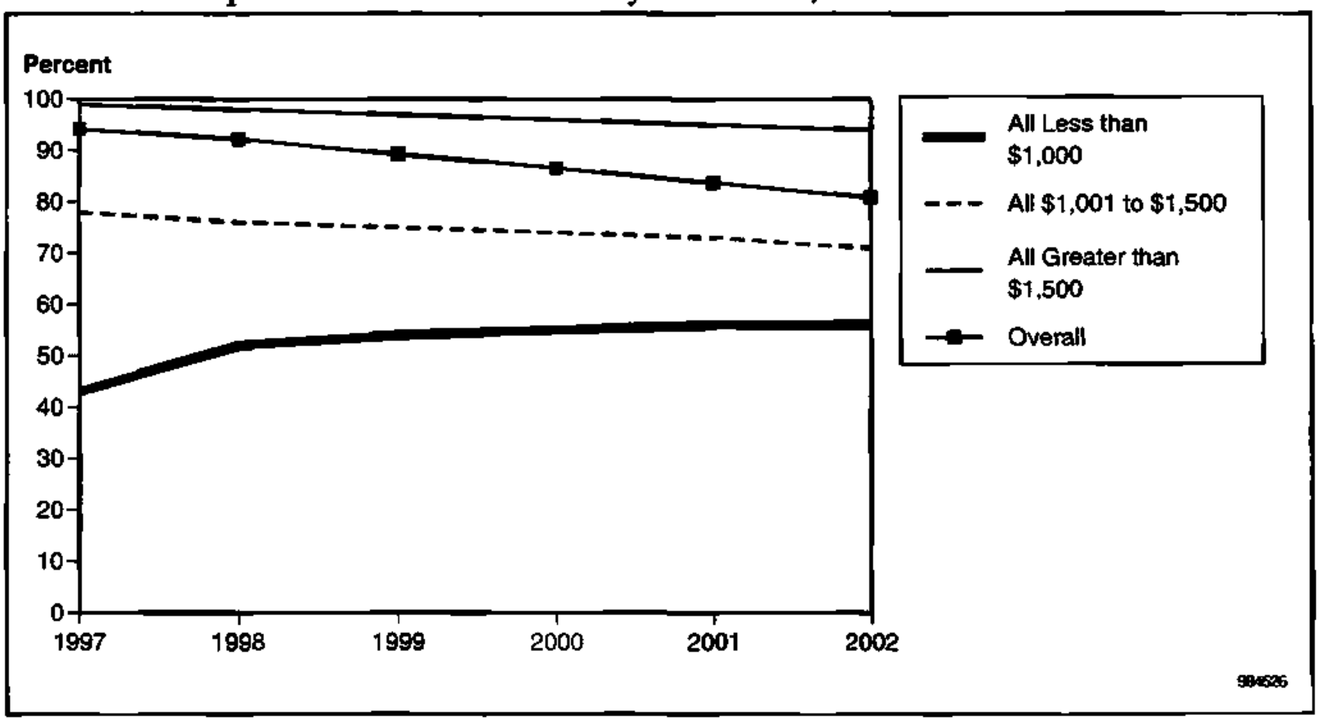


Source: Dataquest (November 1998)

The emerging battle for market share in the PC microprocessor market will be fought on three separate battlefields. At the high end of the market, buyers favor performance over price. For the foreseeable future, this segment remains strongly in Intel's control. In the midrange, buyers balance price and performance, and Dataquest expects the battle to become quite energized over the next two years. At the low end, buyers favor price over performance as long as the machine is fast enough to start up in a reasonable amount of time. Intel's competitors have been willing to sell their low-priced products at lower prices than Intel, and thus they have the majority of this low-price (sub-$1,000 system) area. Intel plans to respond to this challenge by reducing the cost of its products through high levels of integration and has the resources to pull this off. Dataquest anticipates that Intel will gain some share in this segment, the only one in which it needs to come from behind. Figure 3-6 provides our estimate of Intel's evolving market share in each of these segments.

Dataquest forecasts that Intel's x86-based competitors (AMD, National/Cyrix, IDT/Centaur, and others to be named at a later date) will compete primarily at the lower end of the market. These competitors will retain at least some of the market share recently gained (at great pain) in traditional desktop and mobile PC segments. As the overall mix of systems shifts downward, the overall unit share of these Intel alternatives will grow. Consequently, while overall x86 personal computer microprocessor shipments will grow at a 16 percent CAGR, Intel's shipments into this segment will grow only 11 percent CAGR. Price erosion will eat into revenue, limiting Intel's revenue growth to only 7 percent CAGR. Intel's competitors, starting from a much smaller base, can grow at the much higher 35 percent CAGR. Table 3-6 and Figure 3-7 show the forecast of personal computer x86 microprocessor shipments by vendor. Table 3-7 and Figure 3-8 show the forecast of personal computer x86 microprocessor revenue by vendor.

Figure 3-6
Intel PC Microprocessor Revenue Share by Price Band, 1997–2002



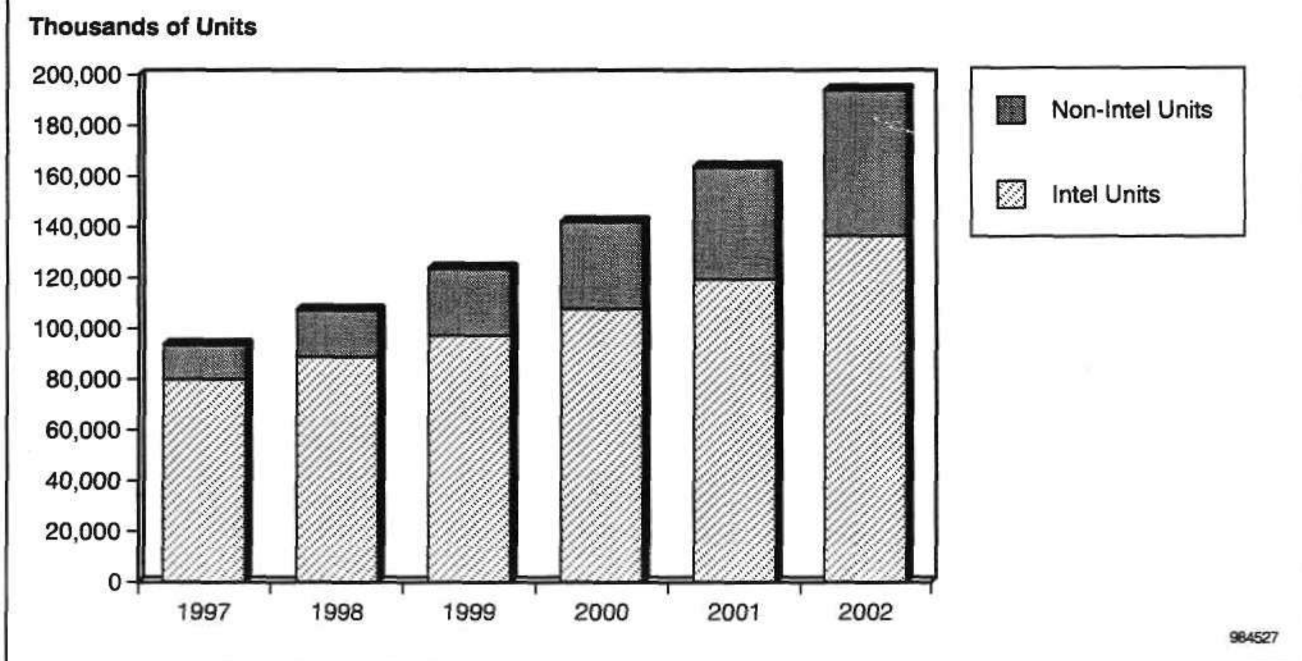
Source: Dataquest (November 1998)

Table 3-6
Forecast of Personal Computer x86 Microprocessor Shipments by Vendor, 1997-2002 (Thousands of Units)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Intel Units	80,157	88,999	97,469	108,050	119,682	136,810	11
Non-Intel Units	13,508	18,356	26,301	34,116	44,058	57,270	33
Total Units	**93,665**	**107,355**	**123,770**	**142,165**	**163,740**	**194,080**	**16**
Intel's Unit Share (%)	86	83	79	76	73	70	-

Source: Dataquest (November 1998)

Figure 3-7
Forecast of Personal Computer x86 Microprocessor Shipments by Vendor, 1997-2002



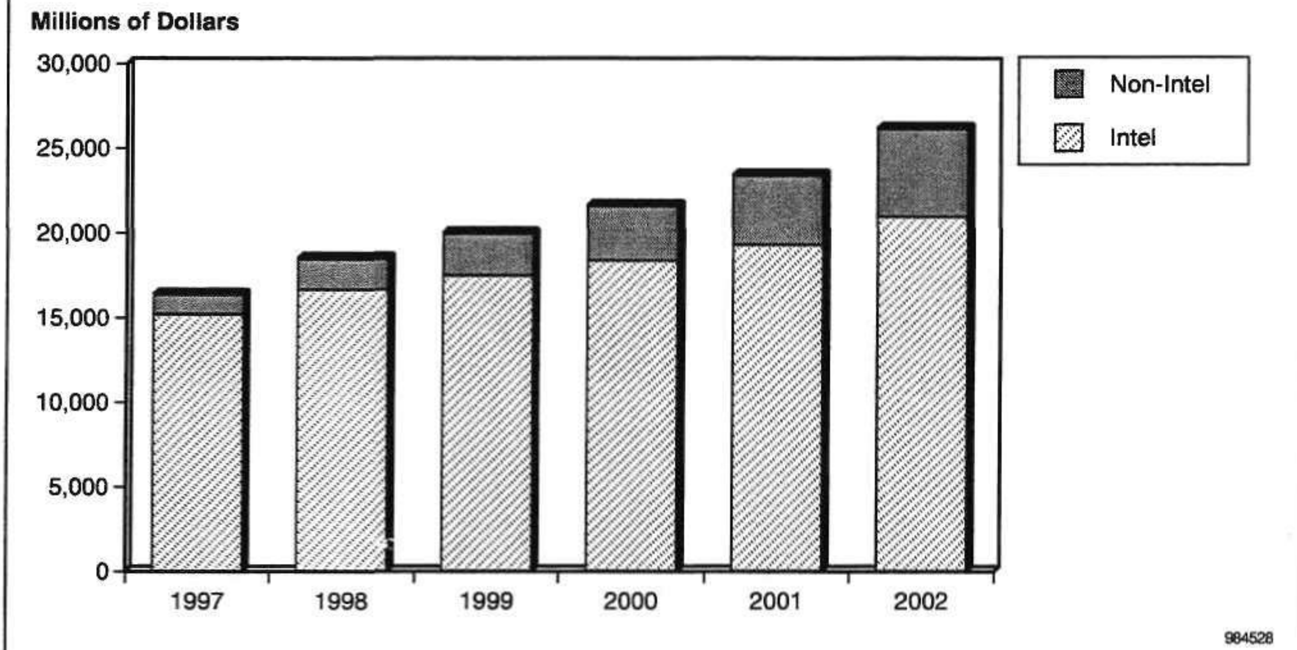
Source: Dataquest (November 1998)

Table 3-7
Forecast of Personal Computer x86 Microprocessor Revenue by Vendor, 1997-2002 (Millions of Dollars)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Intel Revenue	15,227	16,677	17,490	18,392	19,322	20,966	7
Non-Intel Revenue	1,143	1,811	2,483	3,200	4,062	5,190	35
Total Revenue	**16,369**	**18,488**	**19,973**	**21,592**	**23,384**	**26,157**	**10**
Intel's Dollar Share (%)	93	90	88	85	83	80	-

Source: Dataquest (November 1998)

Figure 3-8
Forecast of Personal Computer x86 Microprocessor Revenue by Vendor, 1997-2002



Source: Dataquest (November 1998)

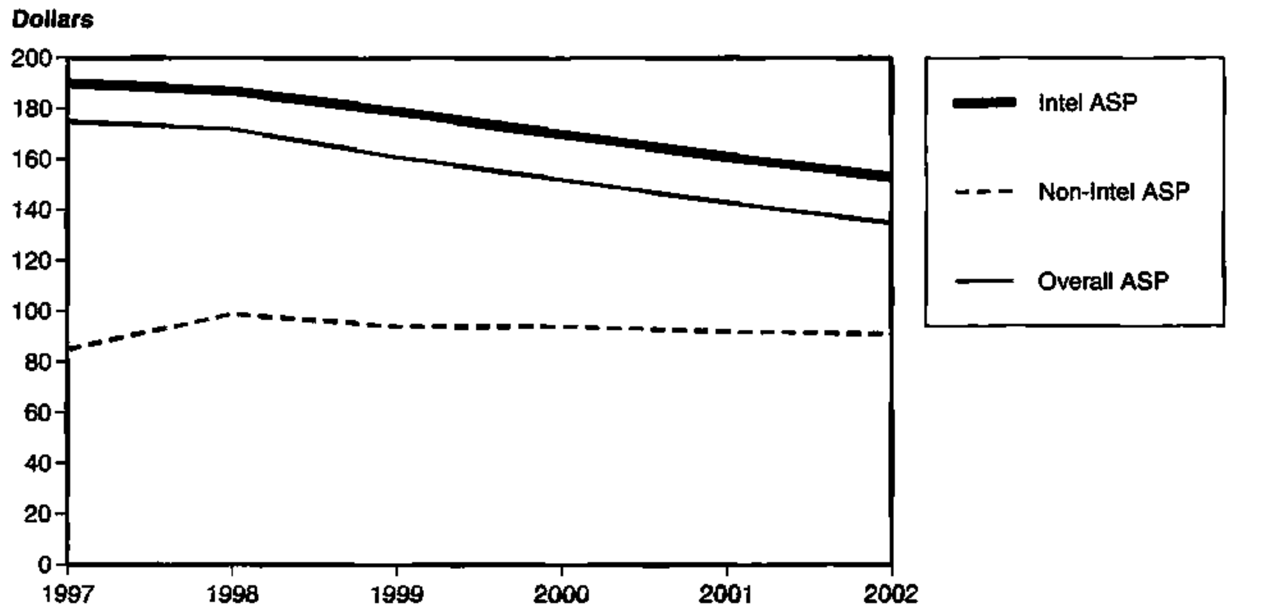
Dataquest anticipates that the long-term trend of increasing x86 ASPs will finally give way to system price pressures. Even Intel will experience 4 percent erosion in the personal computer segment. Intel's competitors have become accustomed to sub-$100 ASPs and would love to preserve pricing in the $80 and $90 range. We expect little change in their ASP over the period. Table 3-8 and Figure 3-9 provide the details behind these assumptions.

Table 3-8
Forecast of Personal Computer x86 Microprocessor ASP by Vendor, 1997-2002 (Dollars)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Intel ASP	190	187	179	170	161	153	-4
Non-Intel ASP	85	99	94	94	92	91	1
Overall ASP	**175**	**172**	**161**	**152**	**143**	**135**	**-5**

Source: Dataquest (November 1998)

Figure 3-9
Forecast of Personal Computer x86 Microprocessor ASP by Vendor, 1997-2002



Source: Dataquest (November 1998)

Intel's Personal Computer x86 Business Will Grow More Slowly than the Overall Market

Shifting market preferences for lower-priced personal computers negatively impact Intel's processor business in two distinct ways. First, although Intel retains overwhelming market share, its customers will be buying a larger number of inexpensive processors and a smaller number of expensive ones, thus driving its overall ASP down. Second, Intel's competitors now generate the bulk of their sales in these lower segments and have their highest market share there. As the market moves toward these segments and they retain most of their market share, their unit shipments will grow rapidly. Dataquest projects that Intel will pick up some share at the lowest end of the market but nevertheless will grow more slowly than the overall market with regard to both units and revenue as the low end expands for all vendors.

Table 3-9 and Figure 3-10 contain Dataquest's projections for Intel's personal computer processor revenue over the next five years. Although the growth rates for revenue from systems priced under $1,000 are high, the absolute values in this segment remain small. The growth in systems priced from $1,001 to $1,500 has far greater impact, as does the erosion in revenue from the high-priced processors that go into a shrinking market. Figure 3-11 combines Intel's desktop and mobile personal computer revenue and then splits them by price band.

Table 3-10 and Figure 3-12 contain Dataquest's projections for Intel's personal computer microprocessor unit shipments. Intel's unit shipments will grow at a slightly lower rate than the overall market, but ASP erosion will limit the company's ability to grow revenue as quickly as units.

Figure 3-13 combines Intel's desktop and mobile personal computer shipments and then splits them by price band. In 1997, processors for systems priced under $1,500 accounted for only 25 percent of units and 16 percent of Intel's revenue, but these low-priced units will account for 75 percent of units and 46 percent of revenue by 2002. Conversely, the high-end processors that now generate 84 percent of revenue will shrink to just 54 percent of personal computer revenue five years from now.

Table 3-11 and Figure 3-14 contain Dataquest's projections for Intel's personal computer microprocessor ASPs in desktop and mobile markets and by price band for both markets combined. Mobile processors sell at a premium to the desktop counterparts, and the shift to lower-priced systems will be less pronounced in the mobile space than on the desktop. These two factors combine to widen the gap between the ASP for mobile units above that for desktops.

Alternative x86 Suppliers Will Grow Rapidly But Will Not Threaten Intel's Dominance

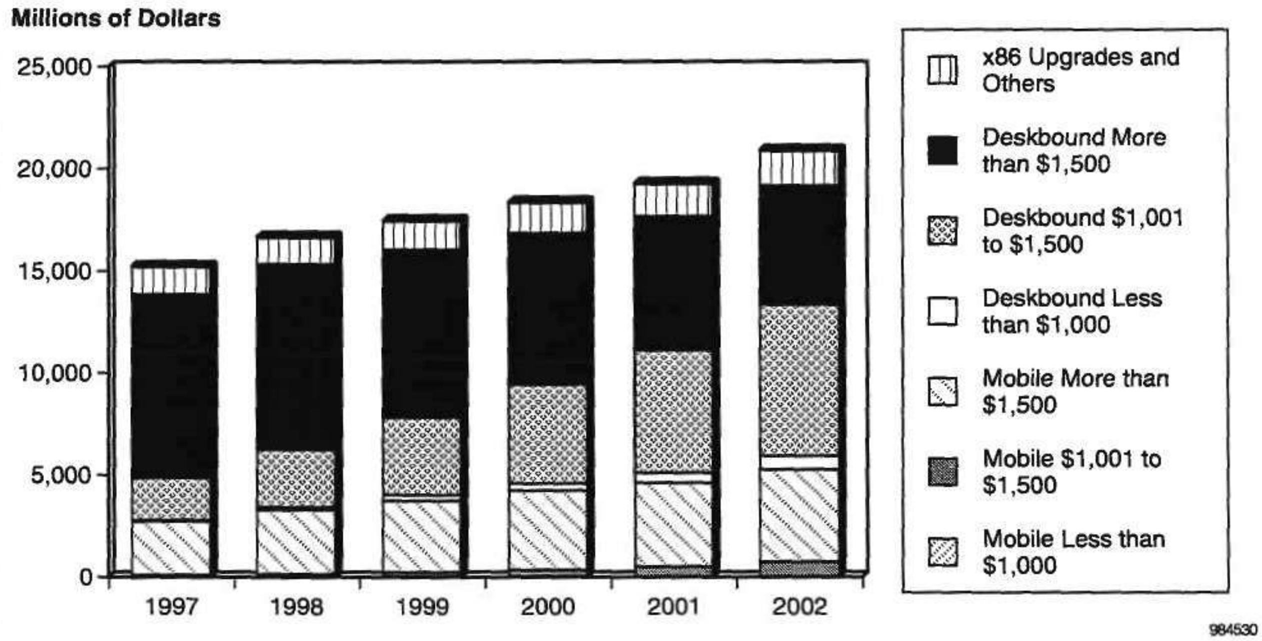
Even if the Federal Trade Commission (FTC) concludes its review of Intel's business and takes no action, Intel's days as the only serious supplier of personal computer microprocessors have come to an end. Its principal competitors, AMD and National's Cyrix subsidiary, have gained a beachhead and will continue to nibble at Intel's lead. These competitors rarely had the ability to compete with Intel on the basis of performance and evolved business models that allowed them to compete—just barely—on the basis of price. In the last two years, these vendors have upgraded their development resources and their product lines so that they can offer products that match Intel's performance, at least in some markets, at all but the highest end of Intel's product line. They still have to sell their products at prices substantially below that of Intel in order to motivate system vendors and end users to take their chips instead of Intel's more established brand, but value-conscious buyers appear to have accepted their marketing propositions.

Table 3-9
Forecast of Intel PC Microprocessor Revenue by Price Band, 1997-2002 (Millions of Dollars)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Ultraportable and Notepad	19	24	34	46	63	86	35
Mobile under $1,000	2	3	4	6	14	37	84
Mobile $1,001 to $1,500	111	169	256	361	513	728	46
Mobile over $1,500	2,633	3,139	3,498	3,888	4,115	4,522	11
Subtotal—Mobile	**2,765**	**3,334**	**3,791**	**4,301**	**4,705**	**5,373**	**14**
Desk under $1,000	62	139	273	353	489	678	61
Desk $1,001 to $1,500	2,065	2,830	3,798	4,851	5,987	7,385	29
Desk over $1,500	9,003	9,070	8,230	7,402	6,565	5,830	-8
Subtotal—Deskbound	**11,130**	**12,039**	**12,301**	**12,606**	**13,042**	**13,893**	**5**
x86 Upgrades and Others	1,332	1,304	1,397	1,485	1,575	1,700	5
Total Intel PC Revenue	**15,227**	**16,677**	**17,490**	**18,392**	**19,322**	**20,966**	**7**

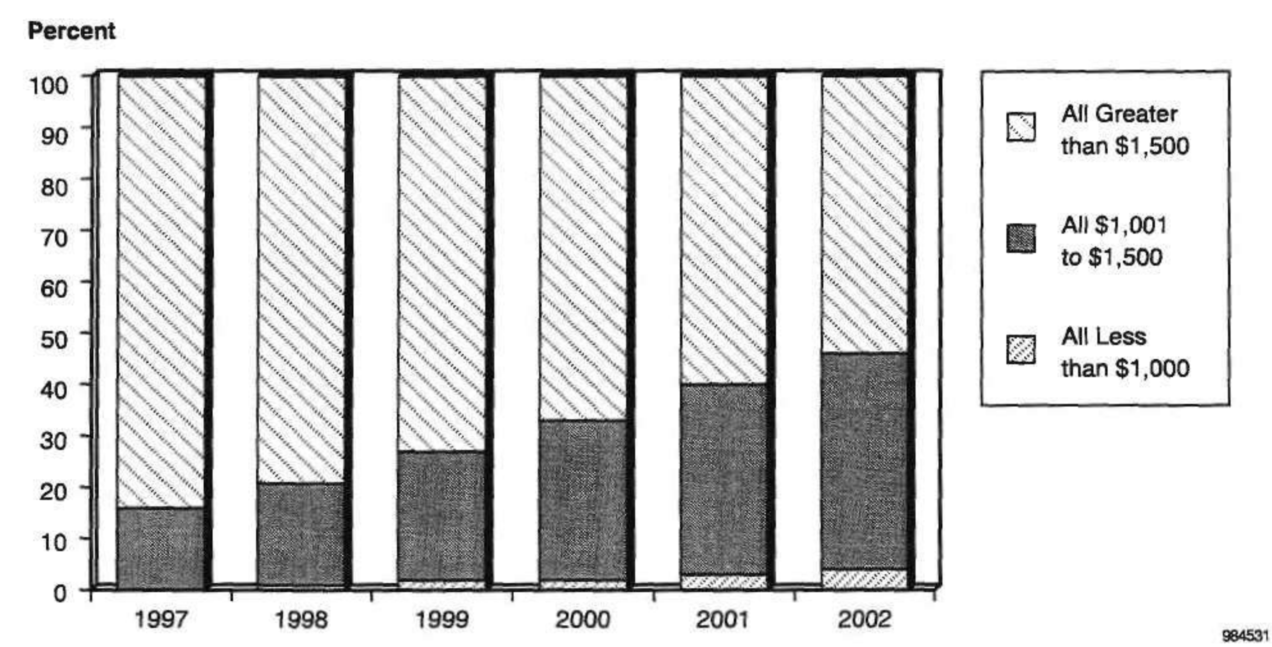
Source: Dataquest (November 1998)

Figure 3-10
Forecast of Intel PC Microprocessor Revenue by Price Band, 1997-2002



Source: Dataquest (November 1998)

Figure 3-11
Mix of Intel PC Microprocessor Revenue by Price Band, 1997-2002



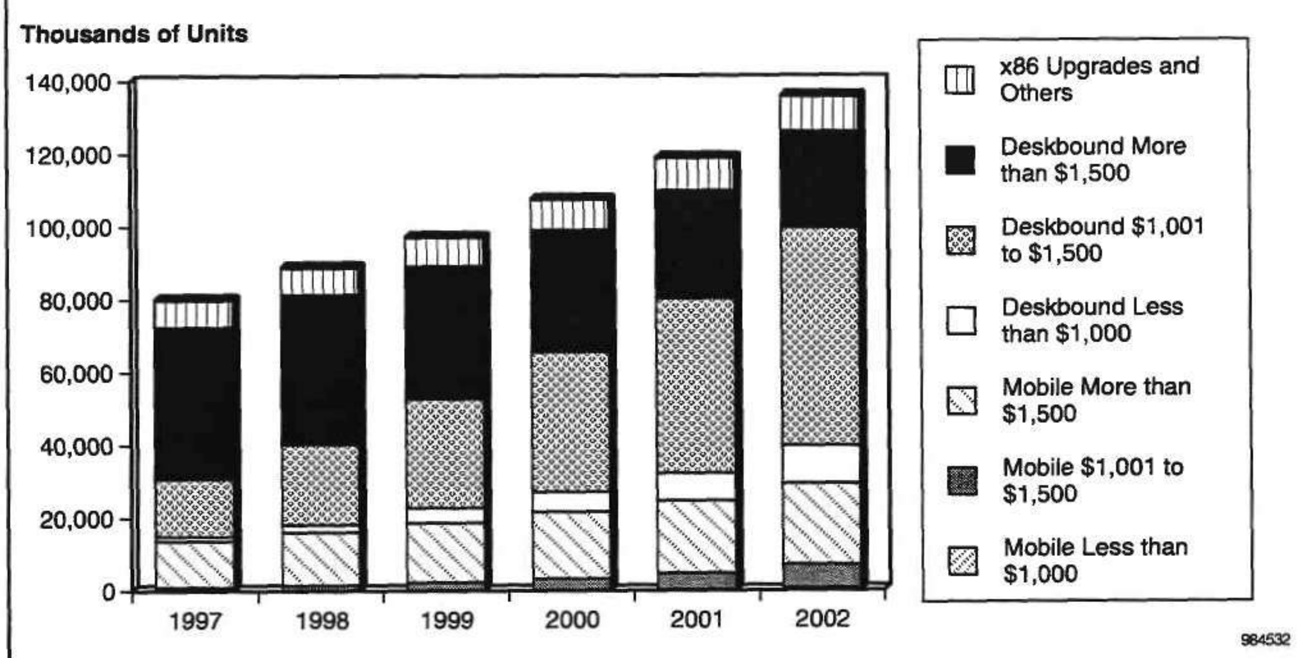
Source: Dataquest (November 1998)

Table 3-10
Forecast of Intel PC Microprocessor Shipments by Price Band, 1997-2002 (Thousands of Units)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Ultraportable and Notepad	200	271	393	570	818	1,176	43
Mobile under $1,000	30	45	66	96	248	640	84
Mobile $1,001 to $1,500	979	1,491	2,268	3,195	4,538	6,445	46
Mobile over $1,500	12,721	14,569	16,382	18,478	19,973	22,312	12
Subtotal—Mobile	**13,930**	**16,376**	**19,109**	**22,339**	**25,577**	**30,572**	**17**
Desk under $1,000	1,194	2,137	4,199	5,429	7,529	10,438	54
Desk $1,001 to $1,500	15,882	21,992	29,809	38,460	47,943	59,734	30
Desk over $1,500	41,668	41,169	36,503	33,482	29,785	26,515	-9
Subtotal—Deskbound	**58,744**	**65,298**	**70,510**	**77,371**	**85,257**	**96,688**	**10**
x86 Upgrades and Others	7,483	7,326	7,850	8,340	8,848	9,549	5
Total Units	**80,157**	**88,999**	**97,469**	**108,050**	**119,682**	**136,810**	**11**

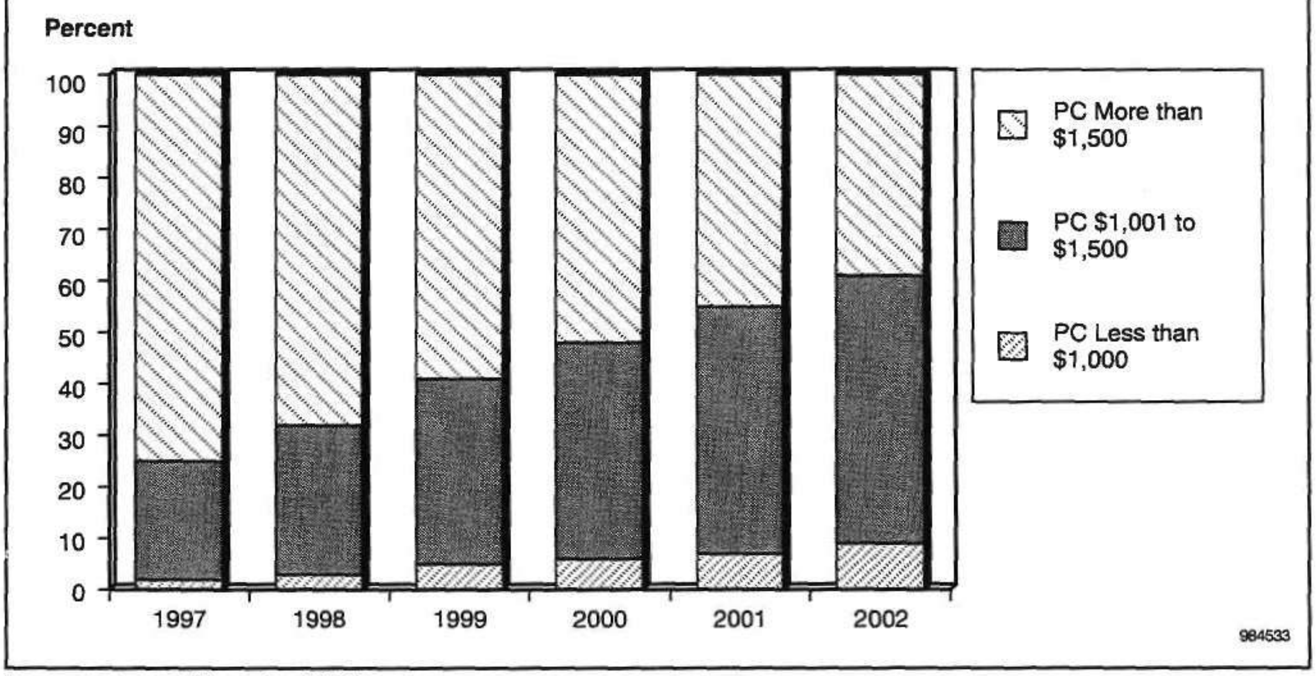
Source: Dataquest (November 1998)

Figure 3-12
Forecast of Intel PC Microprocessor Shipments by Price Band, 1997-2002



Source: Dataquest (November 1998)

Figure 3-13
Mix of Intel PC Microprocessor Shipments by Price Band, 1997-2002



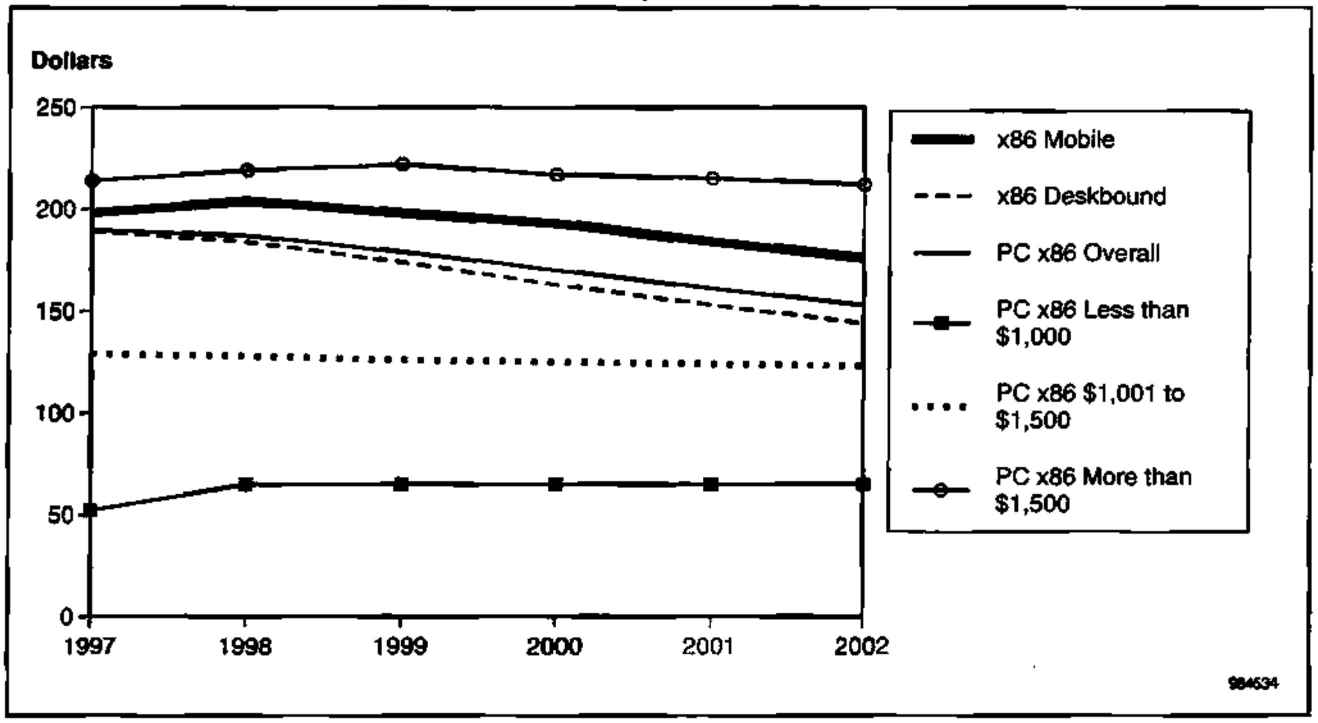
Source: Dataquest (November 1998)

Table 3-11
Forecast of Intel PC Microprocessor ASP by Price Band, 1997-2002 (Dollars)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Ultraportable and Notepad	95	90.25	85.74	81.45	77.38	73.51	-5
Mobile under $1,000	58	58	58	58	58	58	0
Mobile $1,001 to $1,500	113	113	113	113	113	113	0
Mobile over $1,500	207	215	214	210	206	203	0
x86 Mobile	**198**	**204**	**198**	**193**	**184**	**176**	**-2**
Desk under $1,000	52	65	65	65	65	65	5
Desk $1,001 to $1,500	130	128.70	127.41	126.14	124.88	123.63	-1
Desk over $1,500	216	220	225	221	220	220	0
x86 Deskbound	**189**	**184**	**174**	**163**	**153**	**144**	**-5**
x86 Upgrades and Others	178	178	178	178	178	178	0
PC x86 Overall	190	187	179	170	161	153	-4
PC x86 under $1,000	52	65	65	65	65	65	4
PC x86 $1,001 to $1,500	129	128	126	125	124	123	-1
PC x86 over $1,500	**214**	**219**	**222**	**217**	**215**	**212**	**0**

Source: Dataquest (November 1998)

Figure 3-14
Forecast of Intel PC Microprocessor ASP by Price Band, 1997-2002



Source: Dataquest (November 1998)

In 1997, alternative x86 suppliers really gained credibility. The action began when Compaq Computer Corporation shook up the low-end market by introducing its Presario 2100, based on the Cyrix MediaGX, at a $999 price point. There had always been low-cost systems in the past, but they usually came off as performance laggards and old technology. The Presario 2100 was neither, and Compaq sold more than 1 million of them. As the market expressed its preference for MMX-enhanced processors, Cyrix attempted to add this feature to its MediaGX, but Compaq decided it could not wait for the MediaGXM (with MMX), and switched to AMD's K6 for the follow-on version of its low-priced line. In the first half of 1998, IBM moved many of its Aptiva models to the K6 and K6-2, and Hewlett-Packard Company offered a line of K6-2-based Pavillions. Cyrix scored another coup when Packard Bell NEC revamped its line around the enhanced M II processor, and Compaq incorporated the revised Media-GXM into its Presario notebook line. Both AMD and Cyrix needed to price their products very aggressively to win these major OEM customers, and it will be interesting to see if they can improve their pricing as they gain credibility in the market.

Table 3-12 and Figure 3-15 contain Dataquest's projections for all alternative x86 suppliers' personal computer processor revenue over the next five years. The vast majority of this revenue already goes into systems priced under $1,500, and we anticipate little change in this regard. As systems priced from $1,001 to $1,500 grow far faster than the overall market, these suppliers, already well positioned (out of necessity) at the low end, will experience rapid growth. Figure 3-16 illustrates that these suppliers' revenue mix by price band will not change substantially over the forecast period.

Table 3-13 and Figure 3-17 contain Dataquest's projections for alternative x86 suppliers' personal computer microprocessor unit shipments. With a CAGR of 33 percent for unit shipments, they will grow far faster than the overall market, but from a much smaller base.

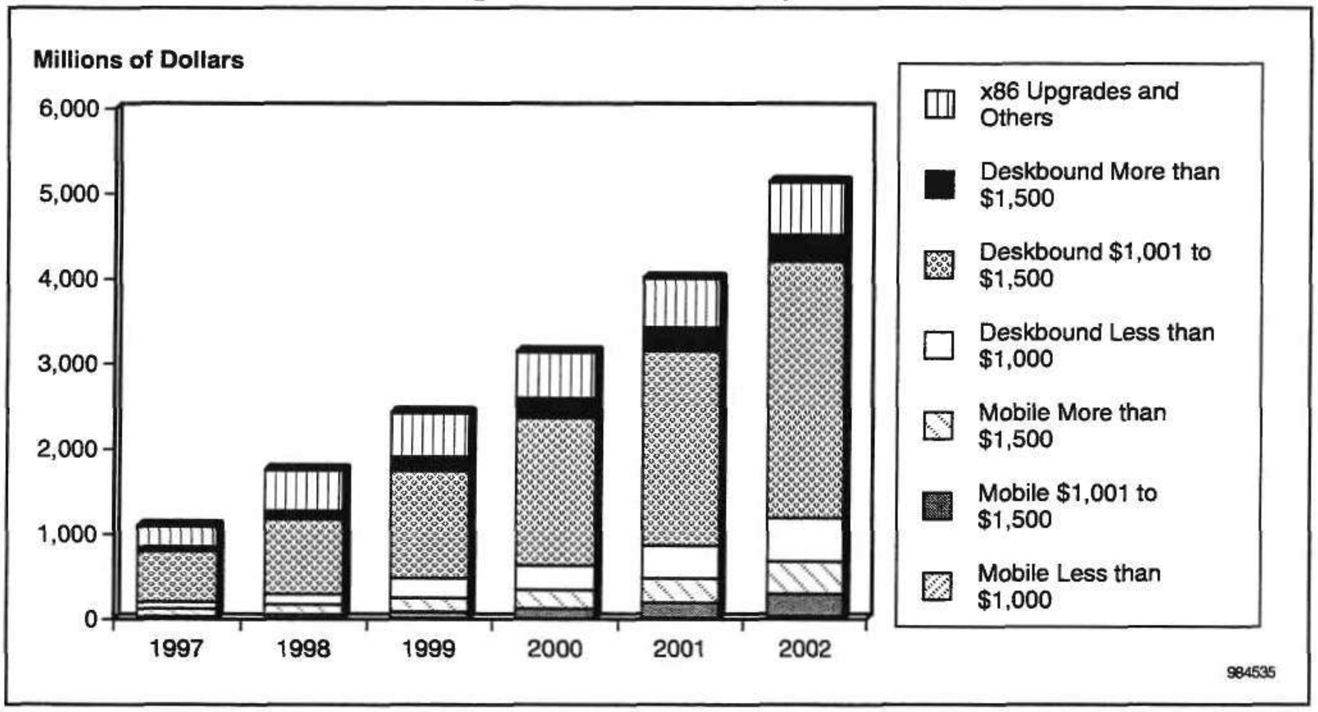
Table 3-14 and Figure 3-18 contain Dataquest's projections for alternative x86 suppliers' personal computer microprocessor ASPs, compared with Intel's offerings. These vendors had hoped to sell their products at a 25 percent discount to Intel's prices. Their experience to date has been that they have many buyers at chip prices below $100 and few at prices above $100, regardless of Intel's pricing structure or the relative performance of their chips and Intel's. This may change as these vendors gain credibility in the market, although it is Dataquest's experience that prices rarely move upward. To put this in a more positive perspective, these prices have little room to fall, and thus these vendors should be able to translate their high unit growth rates into comparably high rates of revenue growth.

Table 3-12
Forecast of Non-Intel PC Microprocessor Revenue by Price Band, 1997-2002 (Millions of Dollars)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Ultraportable and Notepad	53	57	59	60	57	52	0
Mobile under $1,000	4	5	7	8	18	40	60
Mobile $1,001 to $1,500	33	52	82	120	177	260	51
Mobile over $1,500	88	117	163	216	286	380	-
Subtotal—Mobile	**178**	**231**	**311**	**404**	**538**	**732**	33
Desk under $1,000	81	123	232	289	385	513	45
Desk $1,001 to $1,500	592	878	1,265	1,732	2,287	3,015	38
Desk over $1,500	56	104	166	235	279	312	41
Subtotal—Deskbound	**729**	**1,105**	**1,664**	**2,256**	**2,951**	**3,840**	39
x86 Upgrades and Others	236	474	508	540	573	618	21
Total Non-Intel PC Revenue	**1,143**	**1,811**	**2,483**	**3,200**	**4,062**	**5,190**	35

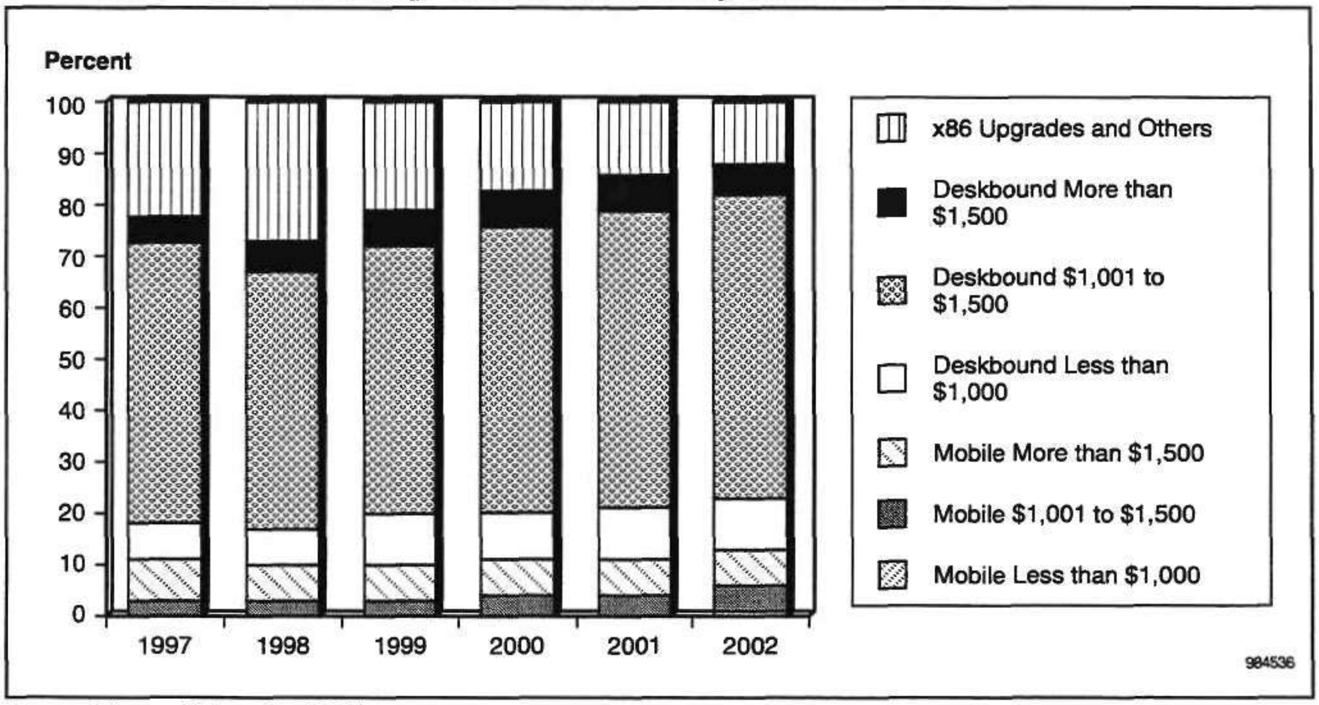
Source: Dataquest (November 1998)

Figure 3-15
Forecast of Non-Intel PC Microprocessor Revenue by Price Band, 1997-2002



Source: Dataquest (November 1998)

Figure 3-16
Mix of Non-Intel PC Microprocessor Revenue by Price Band, 1997-2002



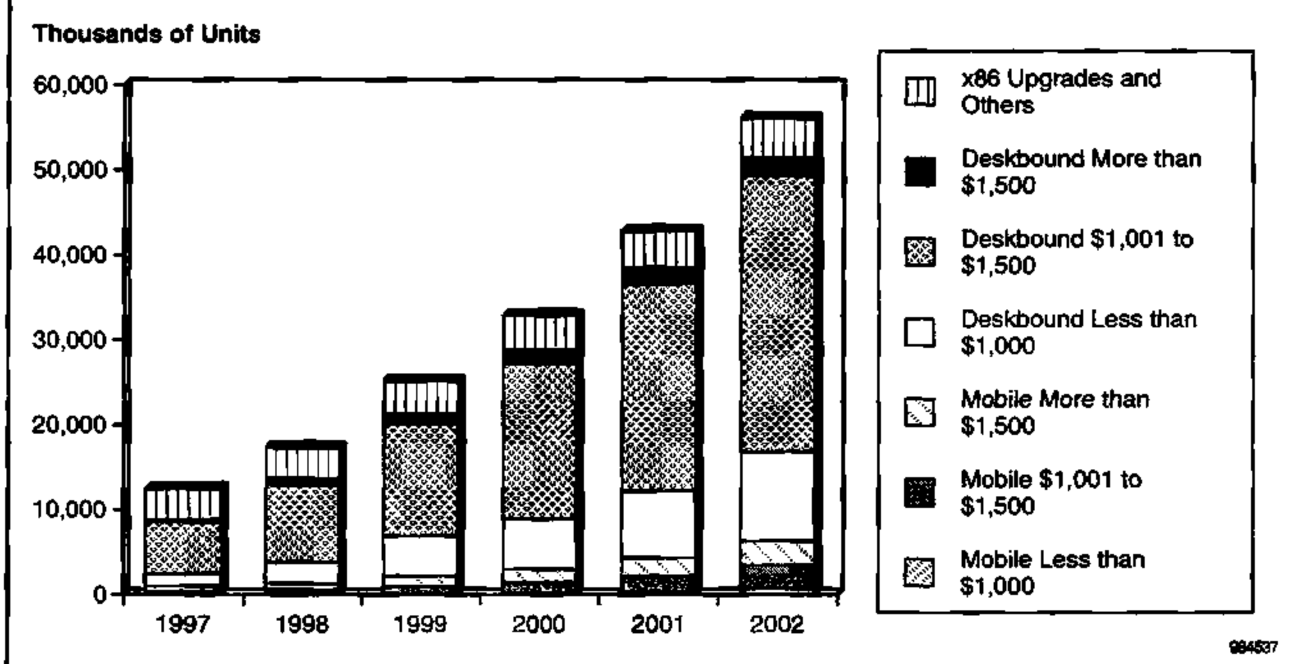
Source: Dataquest (November 1998)

Table 3-13
Forecast of Non-Intel PC Microprocessor Shipments by Price Band, 1997-2002 (Thousands of Units)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Ultraportable and Notepad	1,026	1,056	1,148	1,218	1,237	1,186	3
Mobile under $1,000	73	95	122	152	334	726	58
Mobile $1,001 to $1,500	347	549	866	1,265	1,861	2,735	51
Mobile over $1,500	584	691	1,190	1,593	2,133	2,864	37
Subtotal—Mobile	**2,030**	**2,391**	**3,326**	**4,229**	**5,564**	**7,511**	**30**
Desk under $1,000	1,470	2,526	4,769	5,924	7,894	10,514	48
Desk $1,001 to $1,500	6,100	9,092	13,236	18,307	24,424	32,520	40
Desk over $1,500	278	793	1,161	1,610	1,884	2,093	50
Subtotal—Deskbound	**7,848**	**12,411**	**19,167**	**25,841**	**34,202**	**45,127**	**42**
x86 Upgrades and Others	3,630	3,554	3,808	4,046	4,292	4,632	5
Total Non-Intel Units	**13,508**	**18,356**	**26,301**	**34,116**	**44,058**	**57,270**	**33**

Source: Dataquest (November 1998)

Figure 3-17
Forecast of Non-Intel PC Microprocessor Shipments by Price Band, 1997-2002



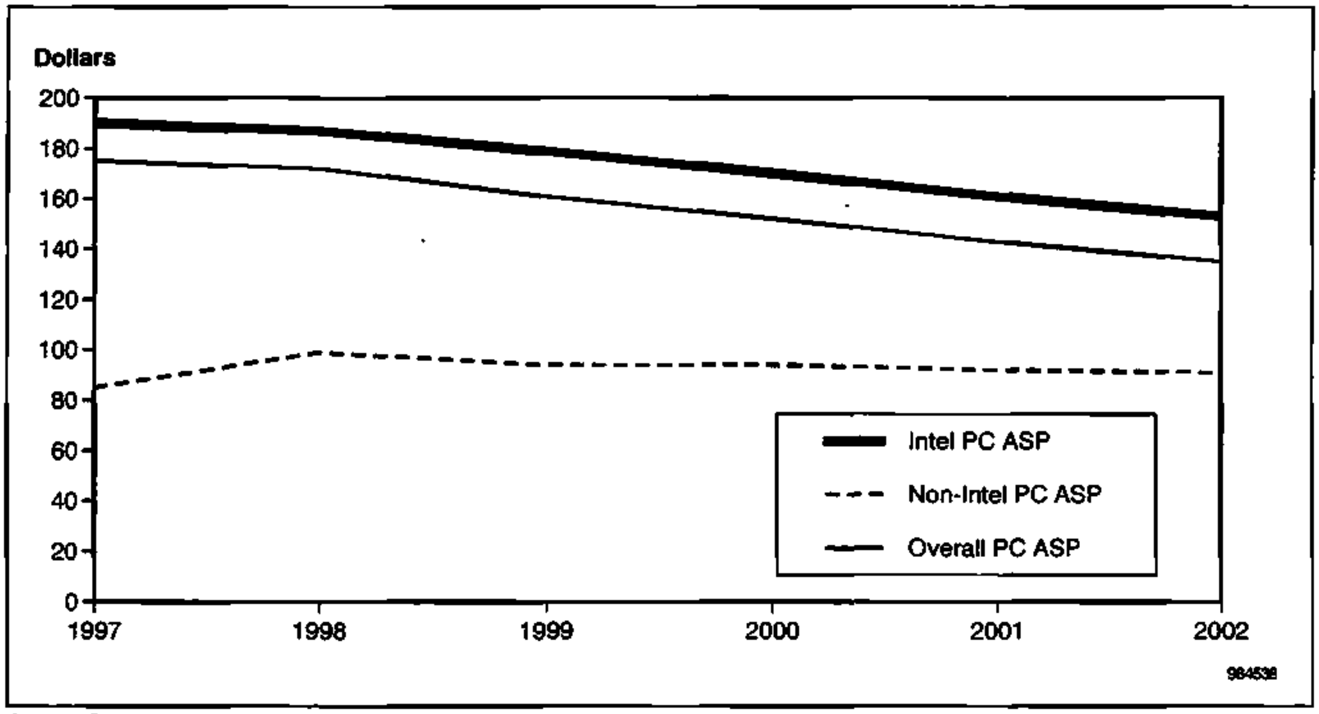
Source: Dataquest (November 1998)

Table 3-14
Comparison of Intel and Non-Intel PC Microprocessor ASP, 1997-2002 (Dollars)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Intel PC ASP	190	187	179	170	161	153	-4
Non-Intel PC ASP	85	99	94	94	92	91	1
Overall PC ASP	**175**	**172**	**161**	**152**	**143**	**135**	**-5**

Source: Dataquest (November 1998)

Figure 3-18
Comparison of Intel and Non-Intel PC Microprocessor ASP, 1997-2002



Source: Dataquest (November 1998)

Chapter 4
Microprocessors for Workstations

A wave of Windows NT workstations containing x86 processors has swept through the workstation industry during the past two years. The difference between the cost structures of the traditional workstation market and the volume economics of the PC market that underlie the Intel/Microsoft workstation market has forever changed the landscape of the overall workstation market. The RISC/UNIX vendors have been forced to slash prices and increase discounts to remain competitive, while the inherently lower ASPs in the Intel/Microsoft world have produced less income despite the healthy growth in unit shipments.

From a vendor perspective, the incursion of Intel/Microsoft technologies into the workstation market has enabled the entrance of new players and caused many of the traditional players with existing PC product divisions to launch their own Windows NT-based workstation product lines. Compaq and Dell Computer Corporation have joined the list of leading workstation vendors. Even Silicon Graphics Inc., never a player in the PC market, has signaled its intention to offer x86-based products later this year.

Both the increased power of Intel's high-end processors and the increased flexibility of the Windows NT environment have driven this transition. For the first time ever, in the fourth quarter of 1997, workstation vendors shipped more Windows NT units (55 percent) than UNIX-based systems (45 percent). This event signals a fundamental shift in the balance of power, although the market penetration measured by revenue remains about half that as measured by units.

Some of this growth stems from the definitions Dataquest uses when collecting data on the workstation market. Prior to the advent of Windows NT, the huge software gulf between personal computers and workstations precluded the migration of users from one type of device to the other. Vendors such as Sun could sell inexpensive SPARC-compatible workstations along with their more powerful models. PC vendors could offer beefy PC configurations for users that pushed machines to their limits. Windows NT blurs the distinctions between these product classes and lets users deploy the same application packages in both environments. This makes it easy for users to migrate between workstation-class systems and personal computers but complicates the task of counting them.

Dataquest uses strict definitions to divide personal computers and workstations, but users do not. For example, Dataquest counts all SPARCstations (the most and least expensive and everything in between) as workstations. But we count Windows NT/x86 systems as workstations only when vendors market them in that manner. Junior engineers might have personal computers with Windows NT on their desks, while their more senior counterparts might have workstations with Windows NT on theirs. Conversely, a graphic artist who might once have sought out the highest-end PC available may now purchase an x86-based workstation instead. Growth in the x86/Windows NT workstation market results from the capture of RISC-workstation seats and high-end personal computer seats. The statistics regarding this market's actual size are more difficult to capture, especially at the low end, where users can easily substitute personal computers for workstations.

Since the 1995 introduction of Pentium Pro, the Windows NT market itself has undergone significant change from a microprocessor perspective. When Windows NT was developed, RISC-based architectures offered significantly more computing power than Intel's designs. Consequently, Windows NT was designed to support multiprocessor architectures to fulfil the requirements of power users. As Pentium Pro and its successors in the Pentium II family approach the raw performance of the RISC designs, the advantage has shifted more and more in Intel's favor. Although Windows NT at one point supported four processor architectures (x86, MIPS, Alpha, and PowerPC), the list has withered to just x86 and Alpha. Alpha's workstation results have been anemic at best. At least in the workstation market, Windows NT, for all practical purposes, is an x86-only environment. It is also a multiprocessor environment. The lack of multiprocessor features in AMD and Cyrix x86 devices makes Windows NT an Intel-only environment for the foreseeable future.

Table 4-1 and Figure 4-1 present workstation vendor revenue by architecture for 1996 and 1997 and Dataquest's five-year forecast for these systems. Total 1997 revenue showed little difference from the prior year, but beneath the surface, the RISC-based system revenue declined 13 percent, while the x86-based revenue tripled. Our forecast calls for a continuation of this trend, with RISC-based revenue falling 11 percent per year, while x86 revenue grow 46 percent per year.

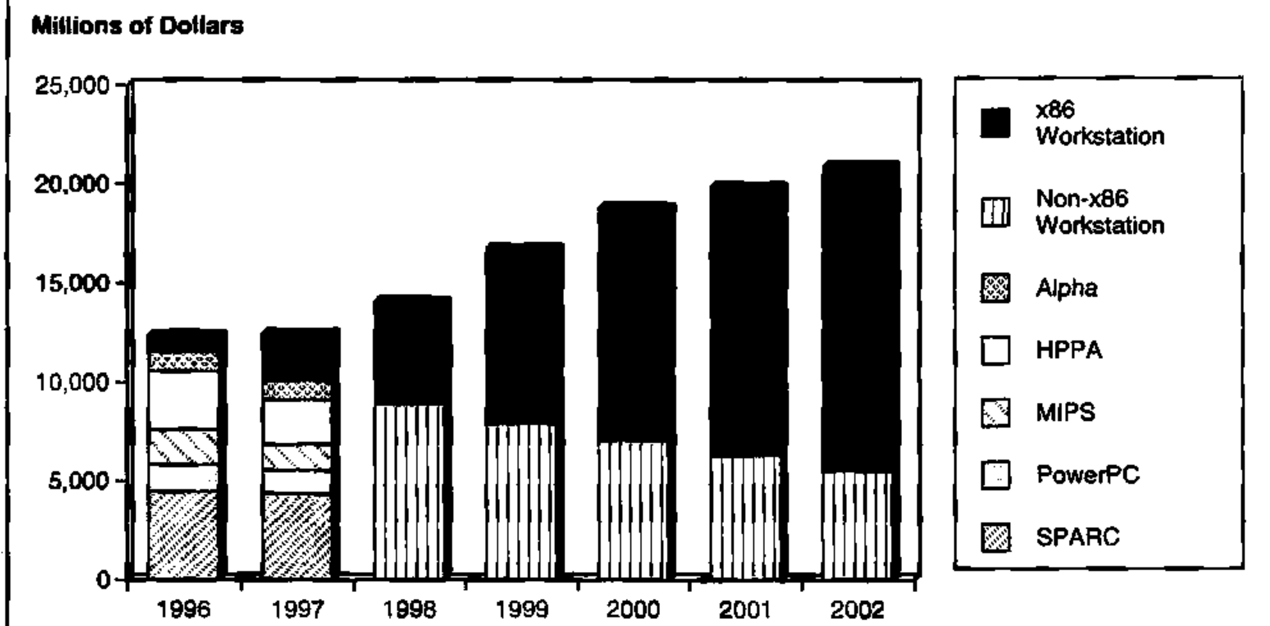
Table 4-2 and Figure 4-2 present workstation vendor shipments by architecture for 1996 and 1997 and Dataquest's five-year forecast for such shipments. Shipments from 1997 grew 20 percent from the prior year. RISC-based system shipments, like revenue, declined 13 percent while the x86-based shipments more than tripled. Our forecast calls for a continuation of this trend, with RISC-based shipments decreasing 7 percent per year, while x86 shipments grow 53 percent per year.

Table 4-1
Workstation System Revenue by Processor Architecture, 1996-2002 (Millions of Dollars)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Alpha	971	964	-	-	-	-	-	-
HP PA	2,951	2,240	-	-	-	-	-	-
MIPS	1,760	1,317	-	-	-	-	-	-
PowerPC	1,380	1,201	-	-	-	-	-	-
SPARC	4,476	4,362	-	-	-	-	-	-
x86 Workstation	762	2,279	5,105	8,765	11,691	13,496	15,348	46
Non-x86 Workstation	11,537	10,084	8,905	7,910	7,069	6,305	5,528	-11
Total	**12,299**	**12,363**	**14,010**	**16,675**	**18,761**	**19,801**	**20,876**	**11**

Source: Dataquest (November 1998)

Figure 4-1
Workstation System Revenue by Processor Architecture, 1996-2002



Source: Dataquest (November 1998)

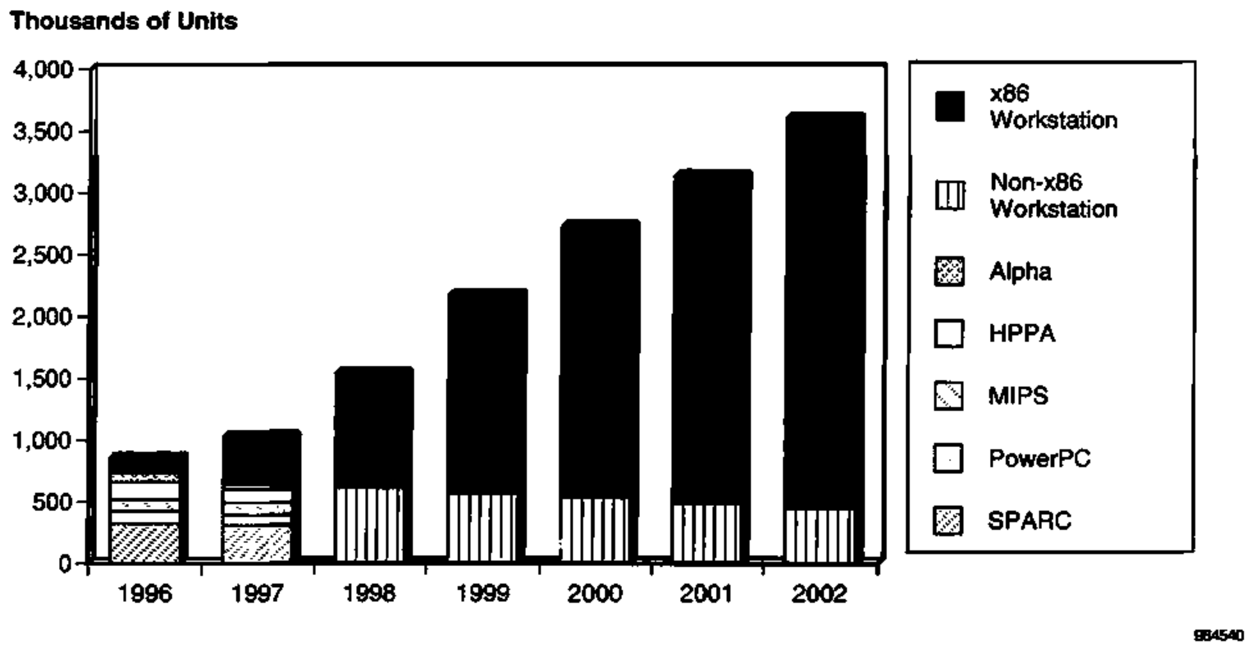
Table 4-2
Workstation System Shipments by Processor Architecture, 1996-2002
(Thousands of Units)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Alpha	71	44	-	-	-	-	-	-
HP PA	143	107	-	-	-	-	-	-
MIPS	94	100	-	-	-	-	-	-
PowerPC	98	85	-	-	-	-	-	-
SPARC	330	312	-	-	-	-	-	-
x86 Workstation	118	378	918	1,593	2,192	2,638	3,144	53
Non-x86 Workstation	737	649	619	573	539	497	450	-7
Total	**855**	**1,027**	**1,537**	**2,166**	**2,731**	**3,135**	**3,594**	**28**

Source: Dataquest (November 1998)

Table 4-3 and Figure 4-3 present workstation system ASP by architecture for 1996 and 1997 and Dataquest's five-year price forecast. x86-based systems sell for less than half their RISC counterparts. This difference drives the rapid growth of the category and explains the stall in the RISC-based segment. Although vendors have reduced prices for many of their RISC-based products, users still opt for the x86 alternative unless they need the power of a high-end RISC system. Thus, ASPs in the RISC segment will remain high, but ASPs for the overall market will fall as the RISC products decline in terms of units and revenue.

Figure 4-2
Workstation System Shipments by Processor Architecture, 1996-2002



Source: Dataquest (November 1998)

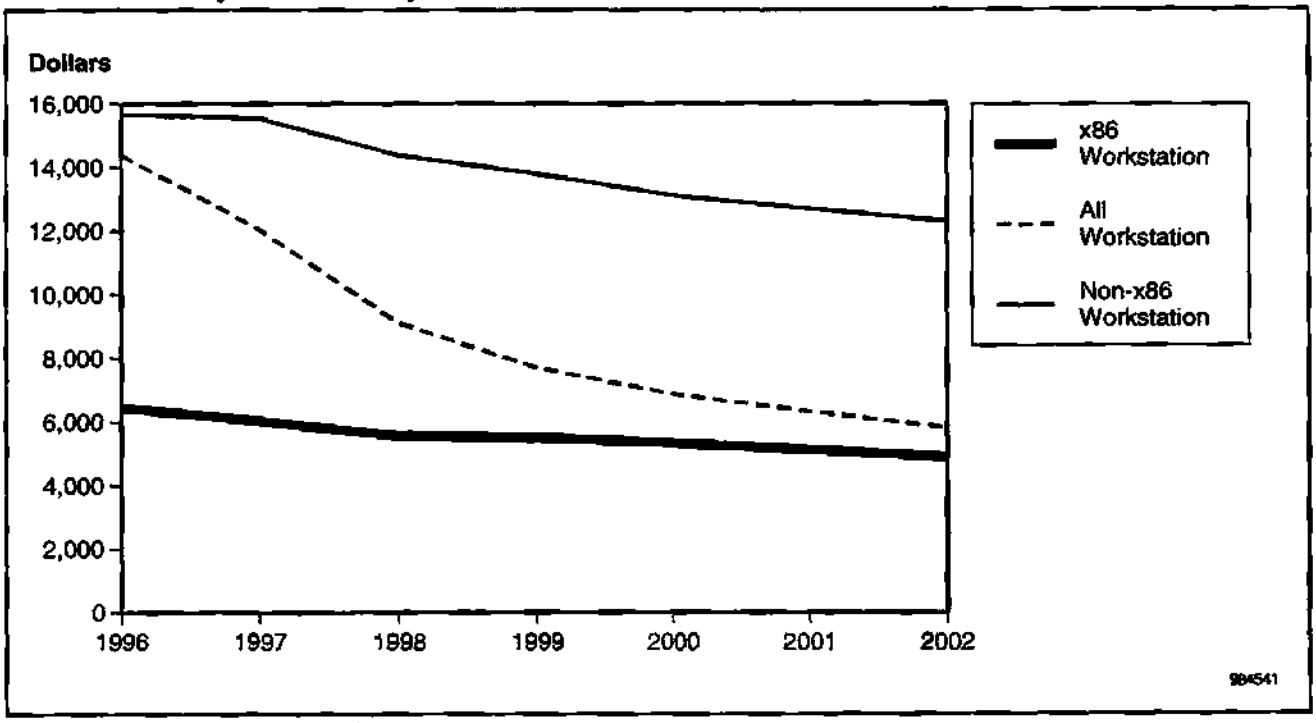
Table 4-3
Workstation System ASP by Processor Architecture, 1996-2002 (Dollars)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Alpha	13,744	21,783	-	-	-	-	-	-
HP PA	20,688	20,857	-	-	-	-	-	-
MIPS	18,658	13,164	-	-	-	-	-	-
PowerPC	14,007	14,159	-	-	-	-	-	-
SPARC	13,546	13,965	-	-	-	-	-	-
x86 Workstation	6,450	6,022	5,561	5,502	5,333	5,115	4,882	-4
All Workstations	**14,391**	**12,034**	**9,113**	**7,698**	**6,868**	**6,316**	**5,809**	**-14**
Non-x86 Workstation	15,665	15,541	14,379	13,799	13,112	12,695	12,290	-5

Source: Dataquest (November 1998)

Table 4-4 and Figure 4-4 present workstation microprocessor revenue by architecture for 1996 and 1997 and Dataquest's forecast for these revenue over the next five years. In 1997, processor revenue increased 15 percent overall as Intel's revenue more than tripled, while RISC revenue declined. This trend will continue as RISC revenue falls 6 percent per year, while x86 revenue grows 53 percent per year.

Figure 4-3
Workstation System ASP by Processor Architecture, 1996-2002



Source: Dataquest (November 1998)

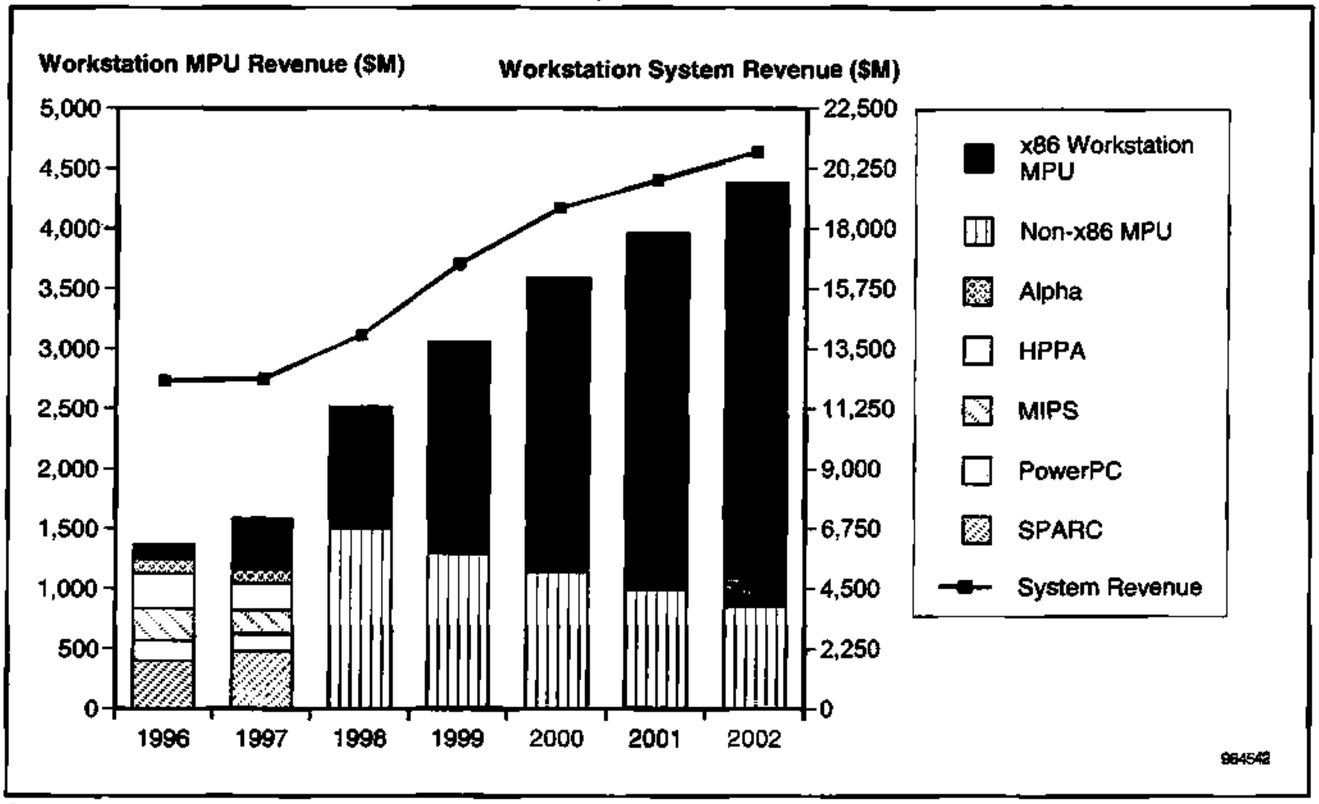
Table 4-4
Workstation Microprocessor Revenue by Processor Architecture, 1996-2002 (Millions of Dollars)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Alpha	117	120	-	-	-	-	-	-
HP PA	295	224	-	-	-	-	-	-
MIPS	264	198	-	-	-	-	-	-
PowerPC	166	144	-	-	-	-	-	-
SPARC	403	480	-	-	-	-	-	-
x86 Workstation MPU	129	419	1,021	1,753	2,455	2,969	3,530	53
Non-x86 Workstation MPU	1,244	1,165	1,497	1,296	1,135	991	850	-6
All Workstation MPU	**1,373**	**1,584**	**2,517**	**3,049**	**3,589**	**3,960**	**4,379**	**23**

Source: Dataquest (November 1998)

Table 4-5 and Figure 4-5 present processor shipments by architecture for 1996 and 1997 and Dataquest's forecast for these shipments. Processor shipments of 1997 grew 20 percent from the prior year. RISC processor shipments declined 9 percent, while x86 units more than tripled. Our forecast calls for a continuation of this trend; RISC shipments will fall 6 percent per year as x86 shipments increase 53 percent per year.

Figure 4-4
Workstation Microprocessor Revenue by Processor Architecture, 1996-2002



Source: Dataquest (November 1998)

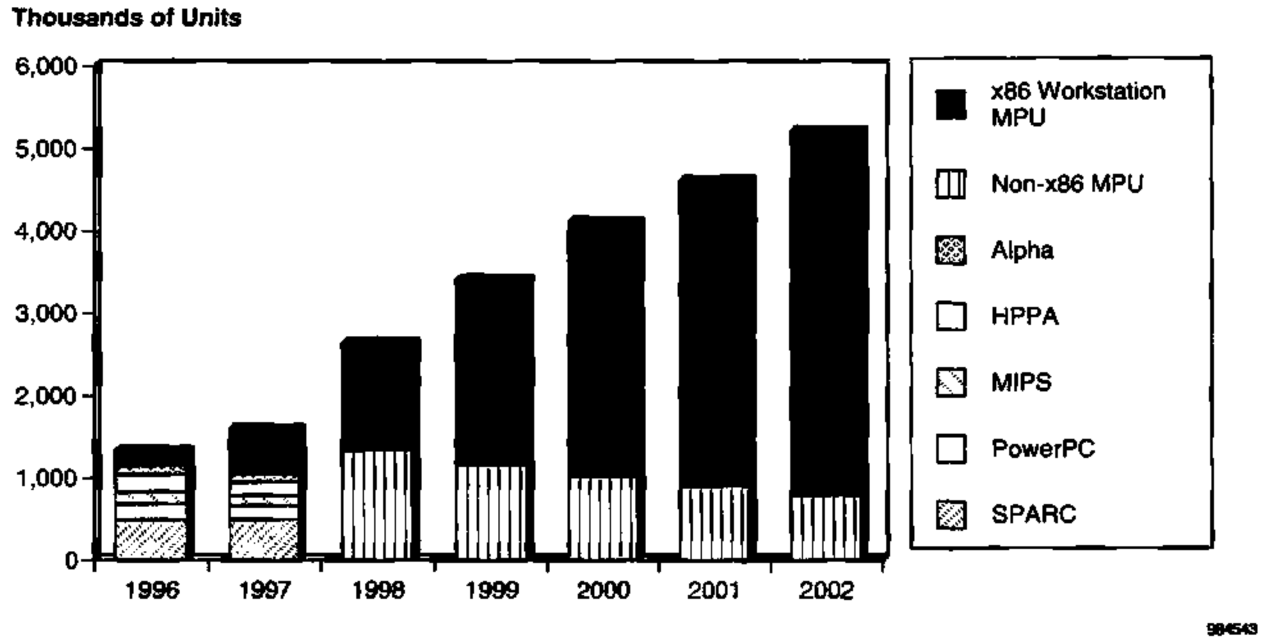
Table 4-5
Workstation Microprocessor Units by Processor Architecture, 1996-2002
(Thousands of Units)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Alpha	106	102	-	-	-	-	-	-
HP PA	214	161	-	-	-	-	-	-
MIPS	142	125	-	-	-	-	-	-
PowerPC	197	170	-	-	-	-	-	-
SPARC	496	500	-	-	-	-	-	-
x86 Workstation MPU	165	530	1,285	2,230	3,069	3,694	4,402	53
Non-x86 Workstation MPU	1,154	1,057	1,344	1,164	1,027	906	793	-6
All Workstation MPU	**1,319**	**1,587**	**2,629**	**3,394**	**4,096**	**4,600**	**5,194**	**27**

Source: Dataquest (November 1998)

Table 4-6 and Figure 4-6 present workstation processor ASP by architecture for 1996 and 1997, along with Dataquest's five-year forecast. Although x86-based systems sell at a substantial discount to RISC-based ones, microprocessor ASP accounts for only a small portion of the difference. Dataquest expects x86 and proprietary prices to remain stable over the forecast period, but the average will fall slowly as the x86 presence increases.

Figure 4-5
Workstation Microprocessor Units by Processor Architecture, 1996-2002



Source: Dataquest (November 1998)

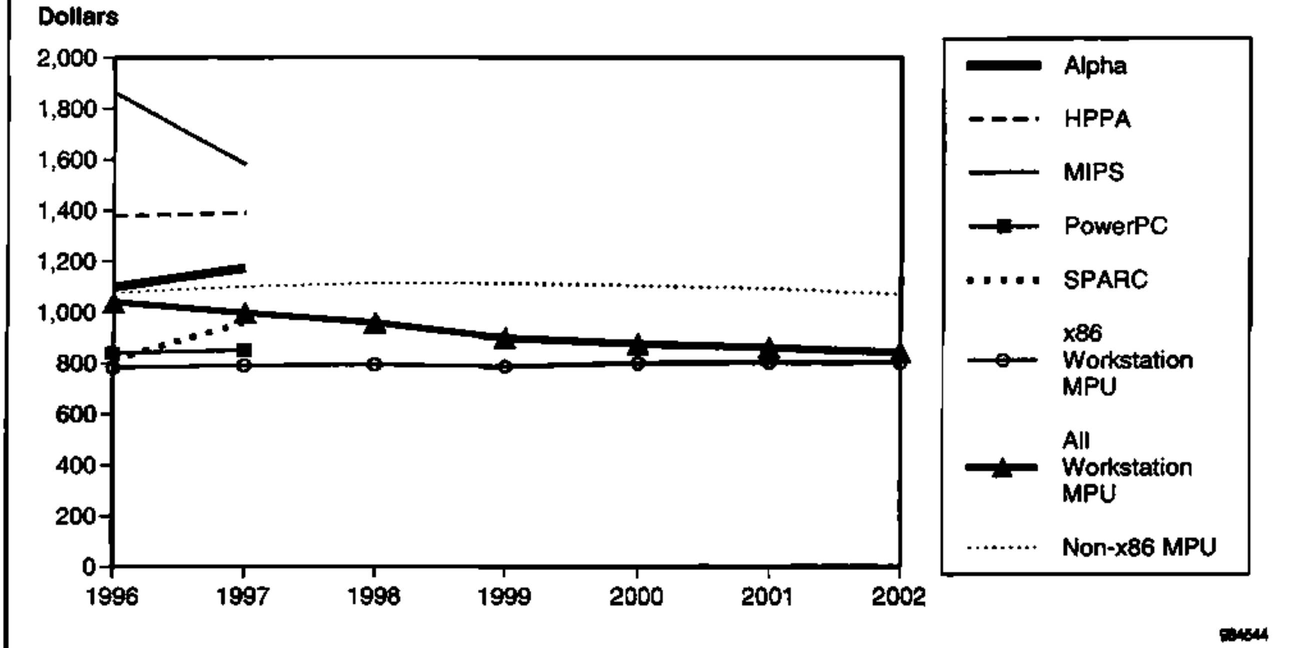
Table 4-6
Workstation Microprocessor ASP by Processor Architecture, 1996-2002 (Dollars)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Alpha	1,100	1,174	-	-	-	-	-	-
HP PA	1,379	1,390	-	-	-	-	-	-
MIPS	1,866	1,580	-	-	-	-	-	-
PowerPC	840	850	-	-	-	-	-	-
SPARC	813	960	-	-	-	-	-	-
x86 Workstation MPU	783	791	794	786	800	804	802	0
All Workstation MPU	**1,041**	**998**	**958**	**898**	**876**	**861**	**843**	**-3**
Non-x86 Workstation MPU	1,078	1,102	1,114	1,114	1,105	1,094	1,072	-1

Source: Dataquest (November 1998)

Finally, Table 4-7 and Figure 4-7 summarize the increasing share of microprocessor revenue and shipments that x86-based devices will capture from RISC alternatives over the next five years. The laws of arithmetic require that as the x86 captures more and more share, the rate at which its share grows will decrease. Nevertheless, by 2002, the x86 will be almost as pervasive in the workstation market as it is today in the personal computer market.

Figure 4-6
Workstation Microprocessor ASP by Processor Architecture, 1996-2002



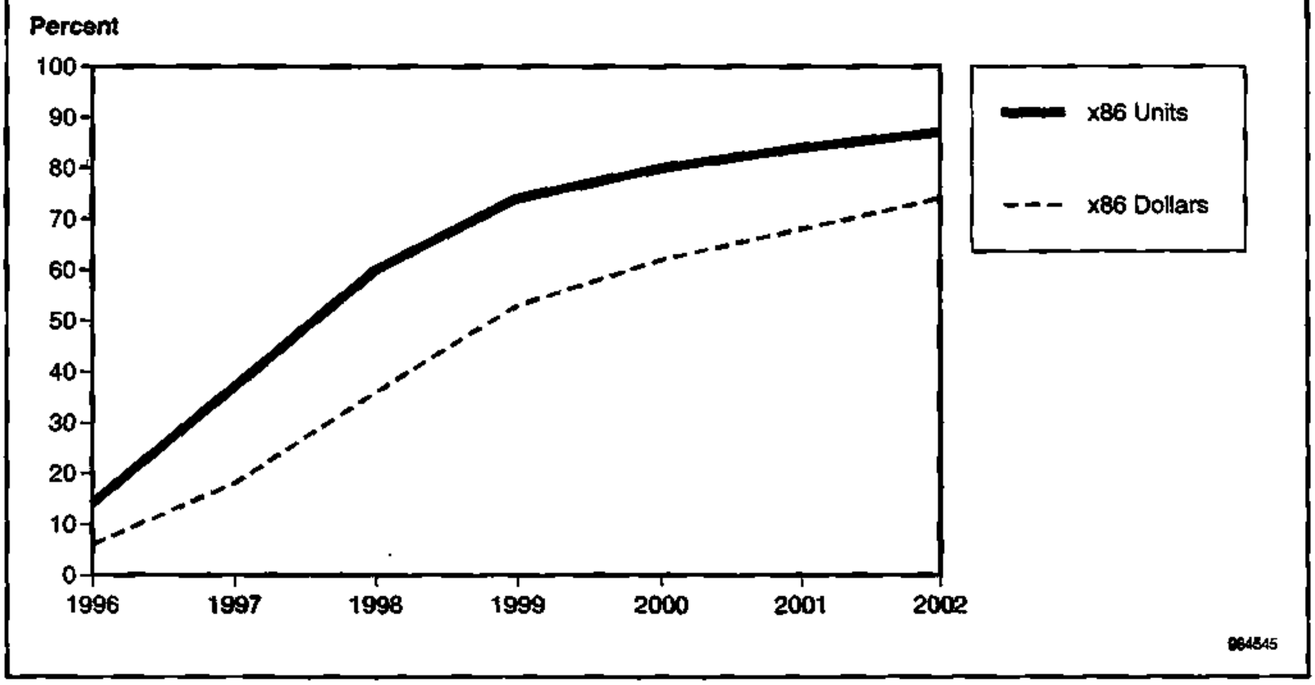
Source: Dataquest (November 1998)

Table 4-7
x86 Workstation Microprocessor Market Share, 1996-2002
(Percent)

	1996	1997	1998	1999	2000	2001	2002
x86 Units	14	37	60	74	80	84	87
x86 Dollars	6	18	36	53	62	68	74

Source: Dataquest (November 1998)

Figure 4-7
x86 Workstation Microprocessor Market Share, 1996-2002



Source: Dataquest (November 1998)

Chapter 5
Microprocessors for Servers

An Overview of the Server Market

Servers are the second-largest market for microprocessors (at least as measured by revenue) and one with enormous profit potential. The $10.7 billion in 1997 server microprocessor revenue falls short of the $16.7 billion recorded for personal computer processors. But the concentration of this revenue in a far smaller number of units causes the server processor's ASP ($1,690) to vastly exceed that of the PC ($173). Unlike the situation in the PC processor marketplace, where one vendor dominates, more than six vendors compete within the server processor market. Intel has the lion's share of the unit volume but captures less than one-third of the revenue. It clearly sees this market as a very juicy morsel.

Dataquest divides the server market by the size of the server and the size of the organization the server can service. Each has dramatically different characteristics:

- Workgroup servers support members of a workgroup. General-productivity applications and technical applications are often run on the same server. These systems are generally priced at less than $10,000.
- Departmental servers are dedicated to departmental-level uses. Mainframe, middle-level midrange, and PC servers are all found in this segment, with prices ranging from about $10,000 to $50,000.
- Enterprise servers include supercomputers, mainframes, high-end midrange systems, large-scale parallel database servers, and large-scale UNIX servers. Systems in this segment are generally fault tolerant and typically run company-critical applications. System prices typically exceed $50,000.

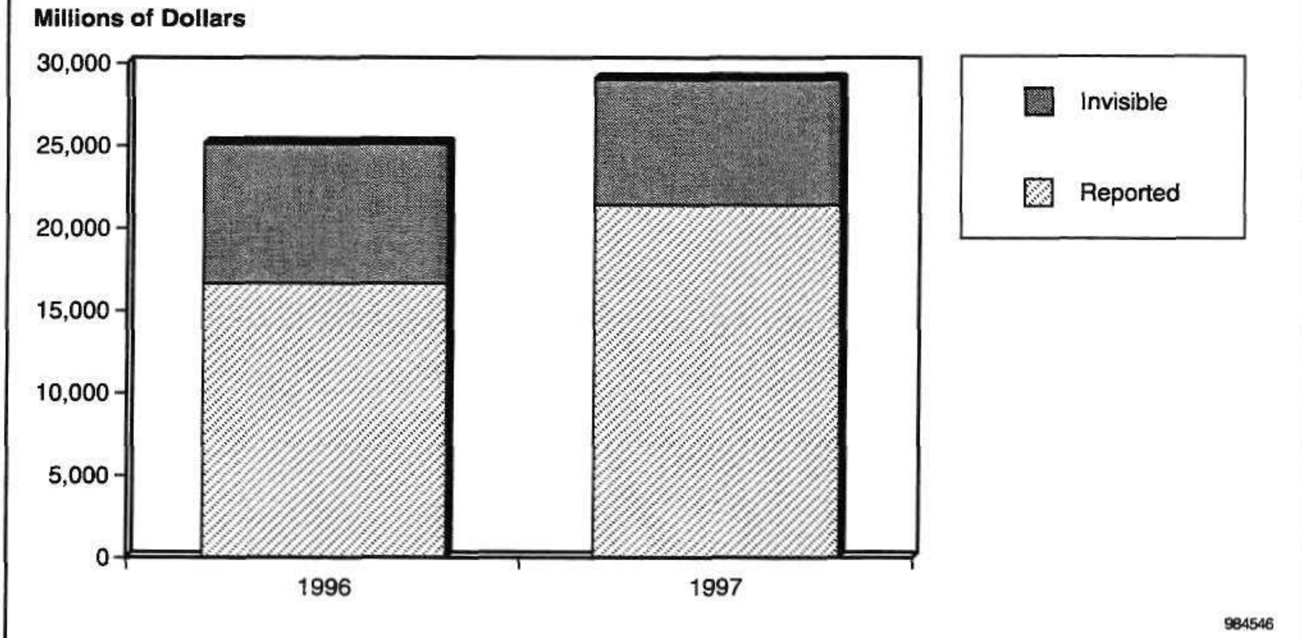
Many of the proprietary processors used in enterprise and departmental servers are manufactured by captive semiconductor operations inside their suppliers and never appear on the open market. Thus, they remain invisible to organizations like Dataquest or WSTS. In this report, Dataquest estimates the value of these components by comparing the results of our top-down processor consumption market model with the bottom-up statistics we collect from semiconductor vendors. The difference between these two correlates closely with our estimates for proprietary enterprise and departmental servers, as will be noted later. Table 5-1 outlines these calculations, and Figure 5-1 illustrates them.

Table 5-1
Top-Down and Bottom-Up Computational Microprocessor Market Estimates, 1996-1997

	Units (K) 1996	Revenue ($M) 1996	ASP ($) 1996	Units (K) 1997	Revenue ($M) 1997	ASP ($) 1997
Top Down	85,456	25,109	293.83	104,509	29,011	277
Reported	83,908	16,668	198.65	103,156	21,407	207
Invisible	1,548	8,441	5,454.31	1,353	7,604	5,618

Source: Dataquest (November 1998)

Figure 5-1
Reported and Invisible Computational Microprocessor Market Estimates, 1996-1997



Source: Dataquest (November 1998)

A Top-Level View of Server Microprocessors

Figure 5-2 lays out the overall market for server microprocessors by vendor revenue for each architecture and the percentage splits between those architectures. The solid line near the top of the chart, keyed to the scale on the right axis, displays overall server system revenue as tracked by Dataquest's Computer Systems and Servers program. The columns, keyed to the scale on the left, display the cumulative revenue contributions for each major architecture in the designated year. The architecture labeled "Power and PowerPC" includes servers based on the PowerPC 603 and 604 variants, as well as servers using IBM's proprietary Power series of processors used in a variety of high-end servers and workstations. The architecture labeled "proprietary and others" includes mainframe processors (manufactured but not sold on the open market by IBM, Fujitsu, NEC, and Hitachi) and MIPS microprocessors, sold on the open market by NEC and Toshiba and used in servers sold by Silicon Graphics, Tandem, and Siemens Nixdorf.

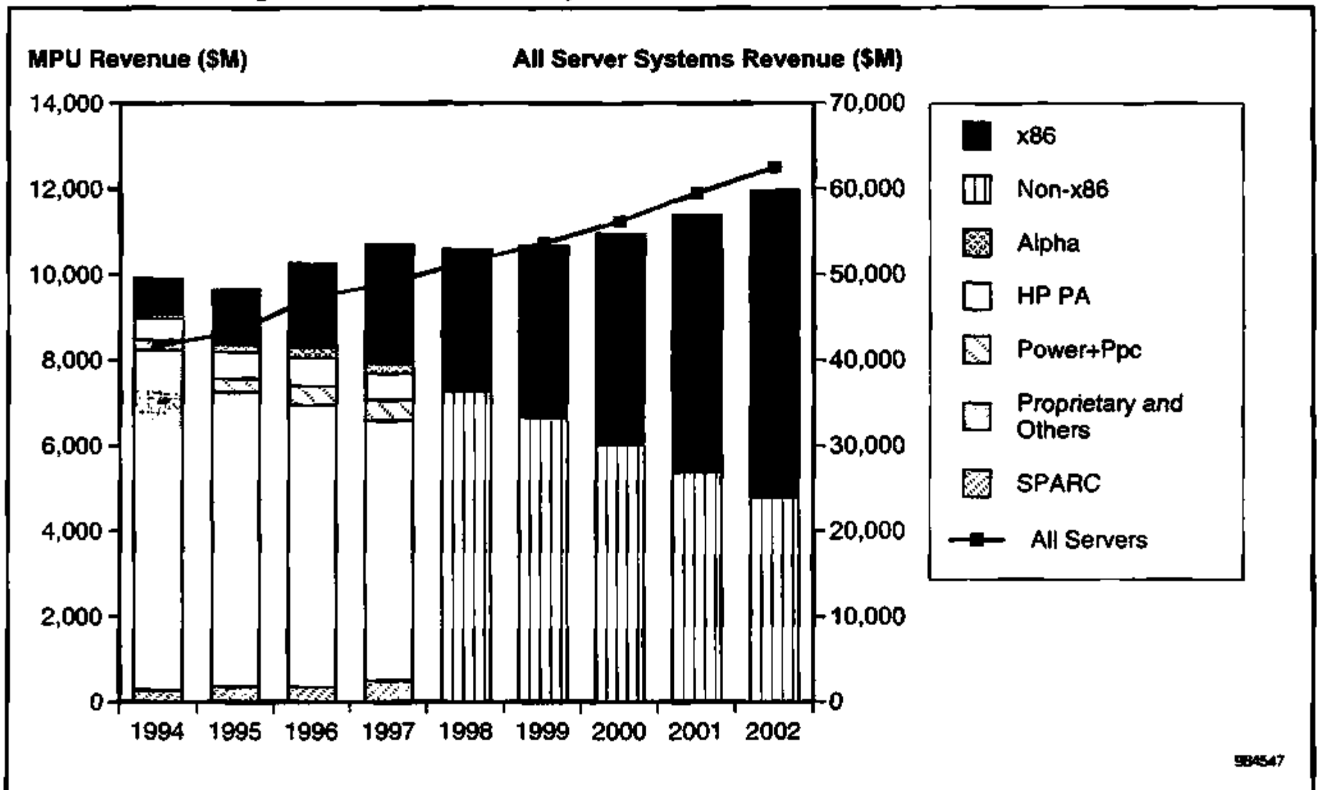
The overall message conveyed by Figure 5-2 is that server system revenue will grow relatively slowly, at a 5 percent CAGR, to $62.5 billion. Microprocessor revenue will grow even more slowly (a 2 percent CAGR), as expensive proprietary processors give way to less expensive commodity devices. Revenue of x86 processors grows at a rapid 21 percent CAGR, while revenue for non-x86 devices consumed in this market declines at a 10 percent CAGR. The price of processors used in all segments of the server market averaged $1,690 in 1997 but will decrease to $672 in 2002, as a vast number of low-end workgroup servers impact the calculations.

Figure 5-3 presents this information in terms of the market share for each architecture. This chart highlights the significant inroads the x86 will make in this market over the coming years.

Figures 5-4 and 5-5 illustrate the shipment volumes and market share for each of the major processor architectures used in the server market. It should come as little surprise that the combination of increasing revenue and relatively low ASP causes the x86 data to dominate this display.

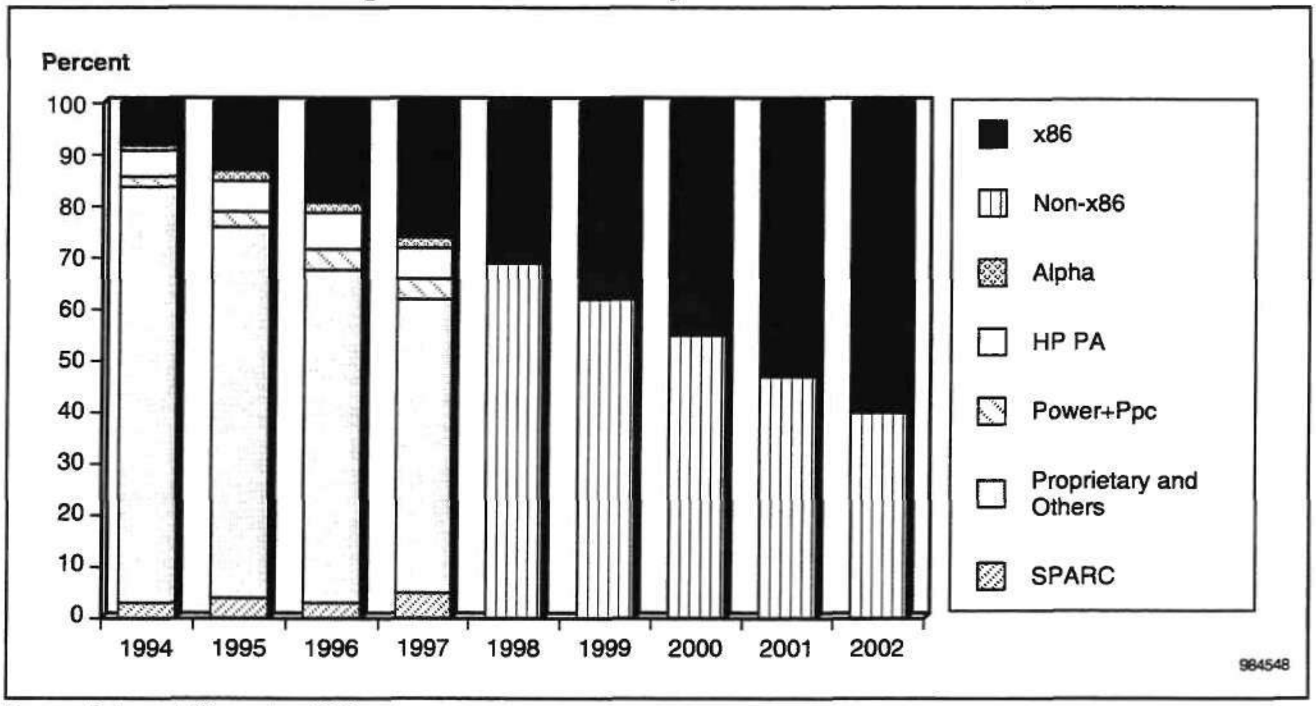
Table 5-2 provides in tabular form the data on server system revenue extracted from Dataquest's client/server database. Table 5-3 provides in tabular form Dataquest's estimate of the microprocessor revenue for devices used in these servers. In some cases, we have had to estimate these values to augment information obtained from suppliers. Table 5-4 provides in tabular form Dataquest's estimate of the microprocessor shipments corresponding to the revenue reported in Table 5-3.

Figure 5-2
All Server Microprocessor Revenue by Processor Architecture, 1994-2002



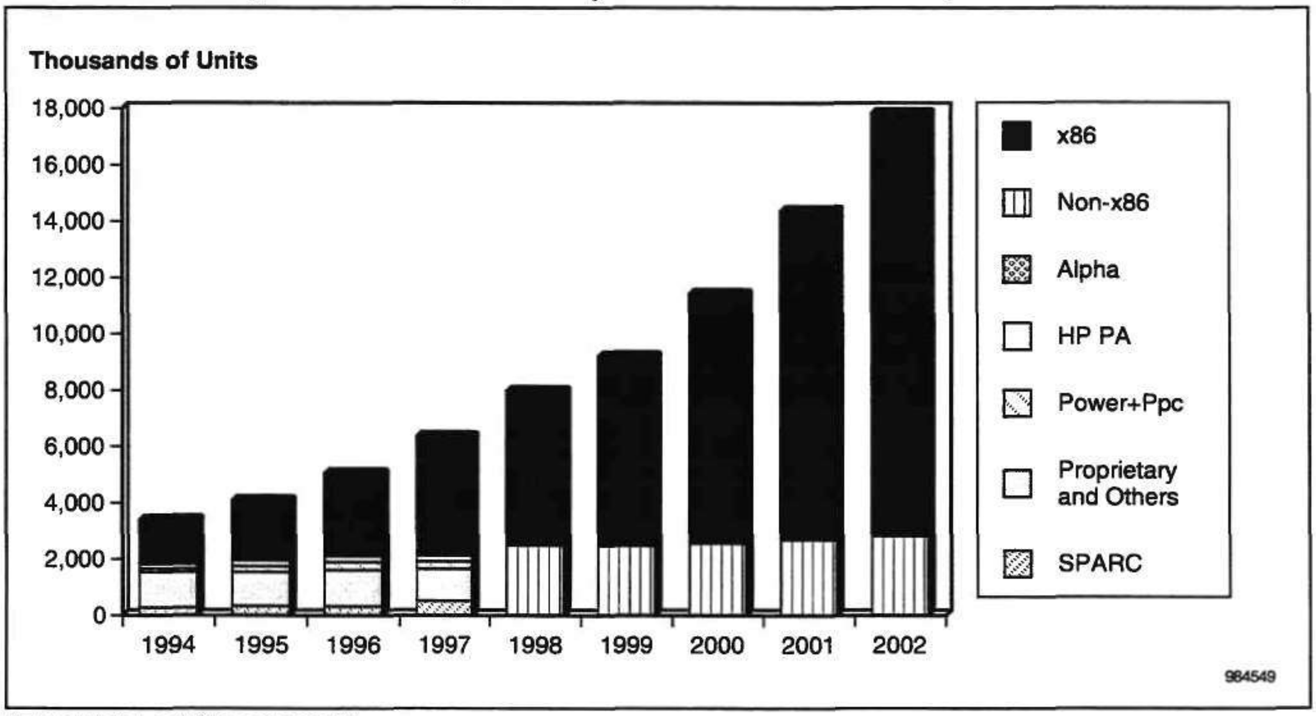
Source: Dataquest (November 1998)

Figure 5-3
Mix of All Server Microprocessor Revenue by Processor Architecture, 1994-2002



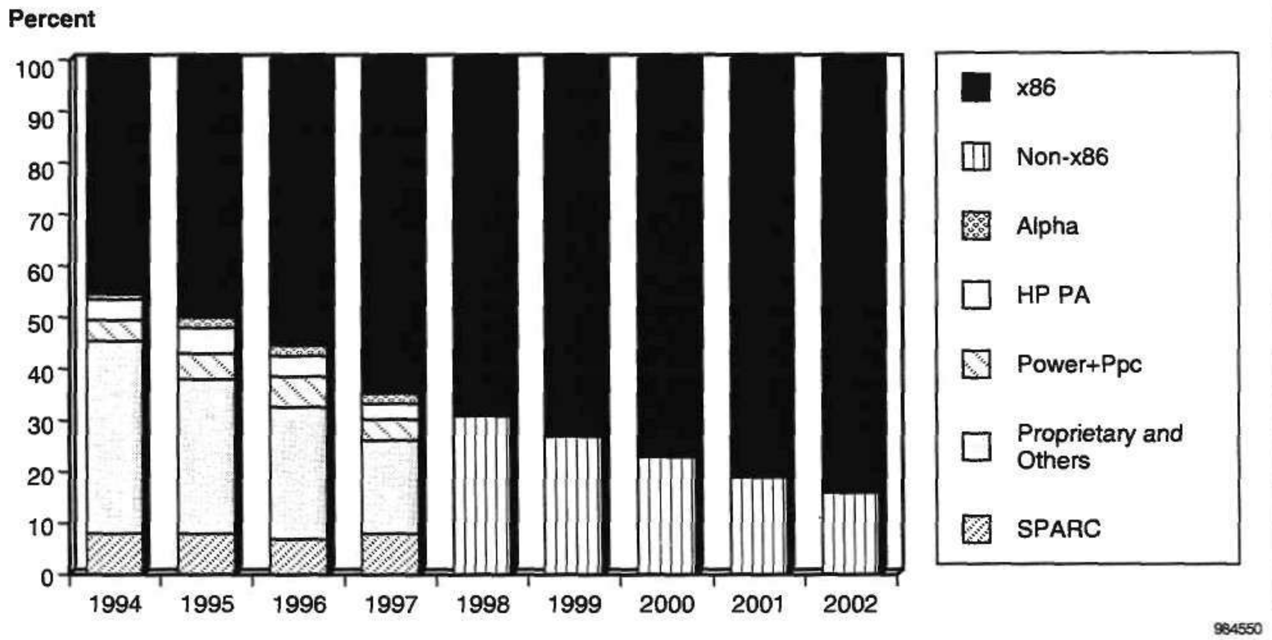
Source: Dataquest (November 1998)

Figure 5-4
All Server Microprocessor Shipments by Processor Architecture, 1994-2002



Source: Dataquest (November 1998)

Figure 5-5
All Server Microprocessor Shipment Market Share by Processor Architecture, 1994-2002



Source: Dataquest (November 1998)

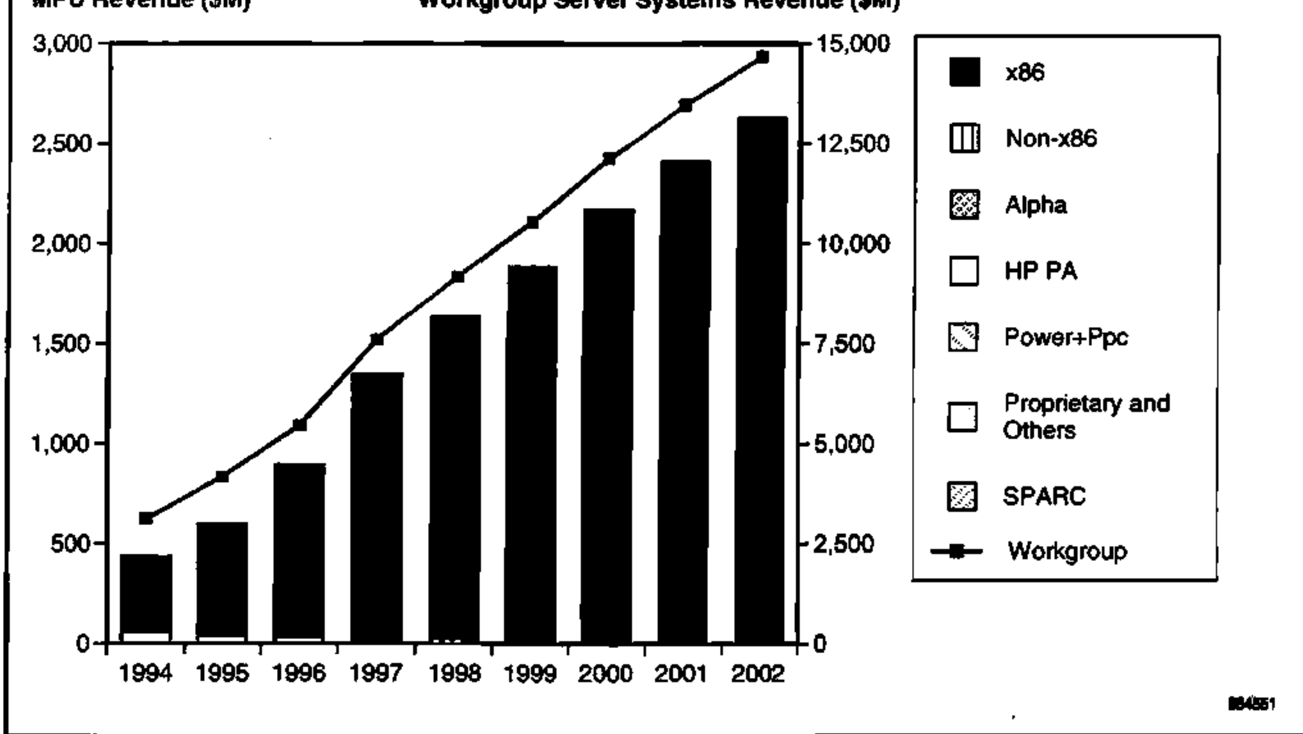
The Battle Has Ended for Workgroup Server Microprocessors

Figure 5-6 illustrates the size of the workgroup server market and the positions of the major architectures used within this segment. The percentage breakdown by architecture for this segment makes a boring picture and has been intentionally omitted. Most of these systems incorporate personal computer technology, and many are simply "personal computers on their side." (This expression stems from the time when most PCs were packaged only in desktop or horizontal enclosures, while servers came in tower cabinets.) Dataquest anticipates that this market will continue to use x86 processors intended for desktop applications, rather than the newer Xeon models intended for high-end use. Consequently, AMD and Cyrix could participate in this portion of the market, although Dataquest's current forecast aggregates all server x86 revenue in our forecast for Intel's revenue. The price of processors used in this market averaged $552 in 1997 and will decrease to $259 in 2002.

A Standoff in the Departmental Server Segment

Figure 5-7 and 5-8 display historical and forecast information for the departmental segment of the server market. Dataquest expects this area to be the most highly contested portion of the market. Much consolidation has already occurred, and the remaining participants seem highly committed to their technologies. The weakest player (Alpha) recently came under the control of a strong player (Compaq), and could stage a rally if Compaq chooses to promote it. ASPs differed little between x86 suppliers ($790) and non-x86 vendors ($956).

Figure 5-6
Workgroup Server Microprocessor Revenue by Processor Architecture, 1994-2002

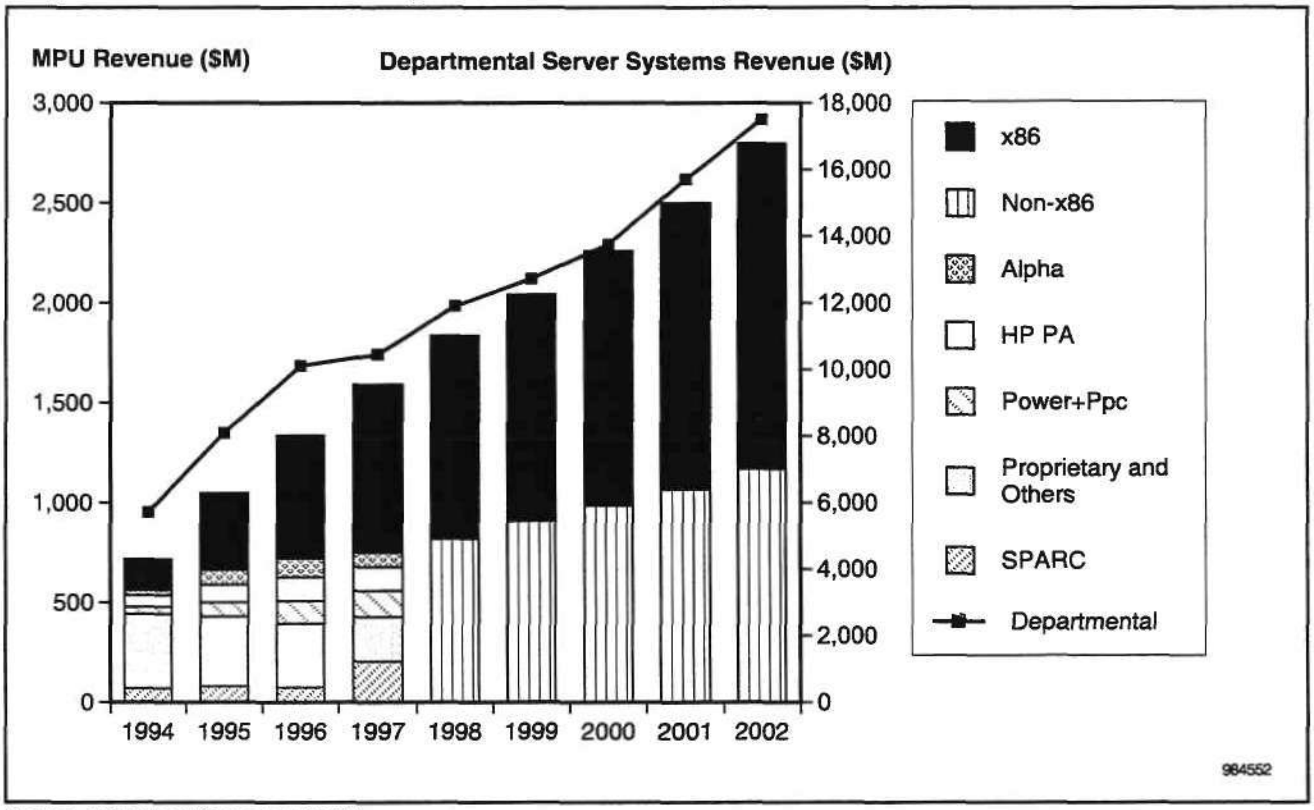


Source: Dataquest (November 1998)

The Holy Grail: Microprocessors for Enterprise Servers

The enterprise segment of the server market represents the Holy Grail for system vendors and their suppliers. Customers use such systems for many mission-critical tasks, and they quarrel less about price than they do about service and reliability. This segment accounts for almost two-thirds of all server revenue, although it has shown little overall growth for several years. As illustrated in Figure 5-9, Dataquest anticipates that revenue for x86-based systems will increase by almost a factor of five in this market, from $2.0 billion in 1997 to $9.8 billion in 2002. Some of this change results from Hewlett-Packard's decision in 1995 to migrate its proprietary Precision Architecture (HP PA) systems to the 64-bit Intel architecture (IA-64) scheduled to make its first appearance in the Merced processor in 2000. A bigger portion results from inroads into the mainframe market and shrinkage in IBM's System/390 revenue. x86 microprocessors have a powerful economic advantage in this market. Even at an ASP of $991 in 1997 (as shown in Table 5-5), they still cost only one-fifth as much as the non-x86 processors currently used in this segment. Even as x86 processors increase in price and performance while non-x86 processors decline in price, the x86 still enjoys a 2:1 cost advantage at the end of the period in 2002. Dataquest projects in Figure 5-10 that the x86 will increase its share of this segment from 8 percent of enterprise microprocessor revenue in 1997 to 45 percent in 2002. Intel must succeed in this segment if it is to continue the awesome growth it has experienced over the past five years.

Figure 5-7
Departmental Server Microprocessor Revenue by Processor Architecture, 1994-2002

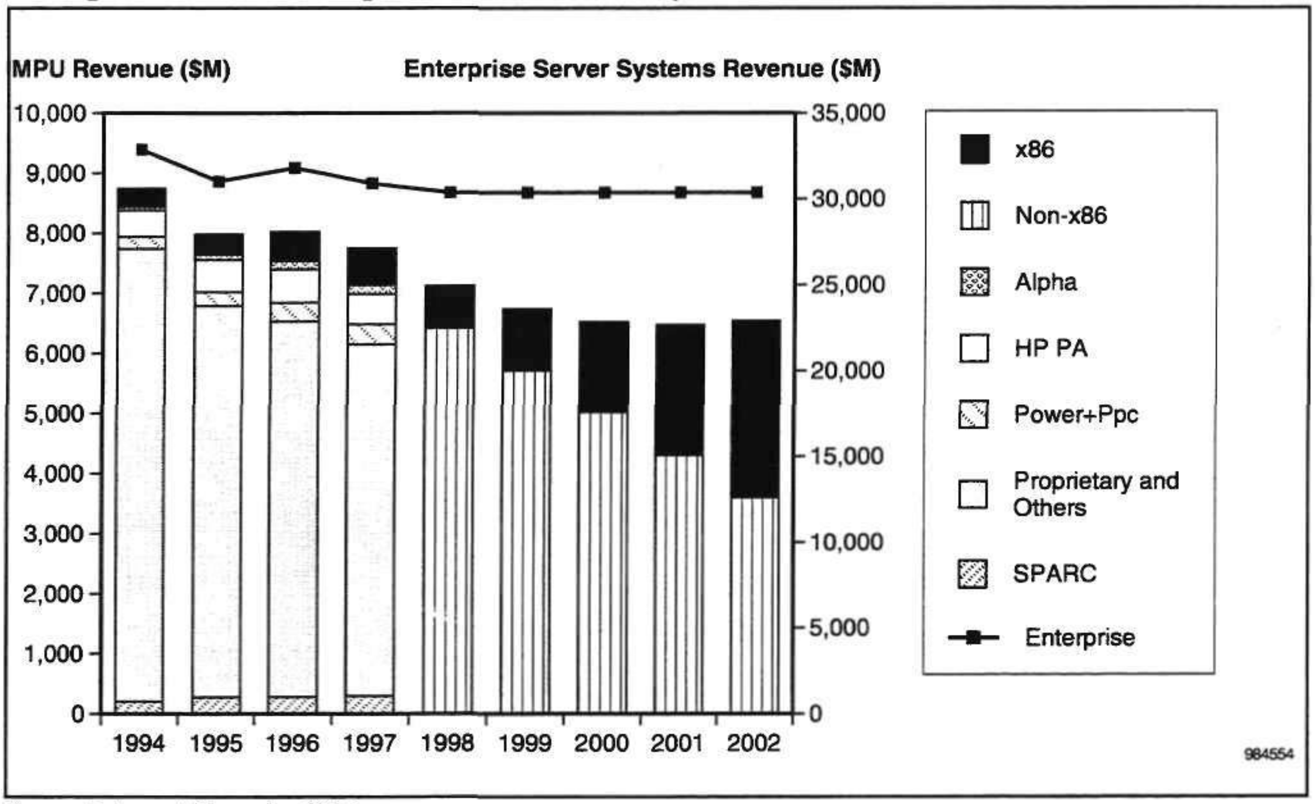


Source: Dataquest (November 1998)

Figure 5-8
Mix of Departmental Server Microprocessor Revenue by Processor Architecture, 1994-2002

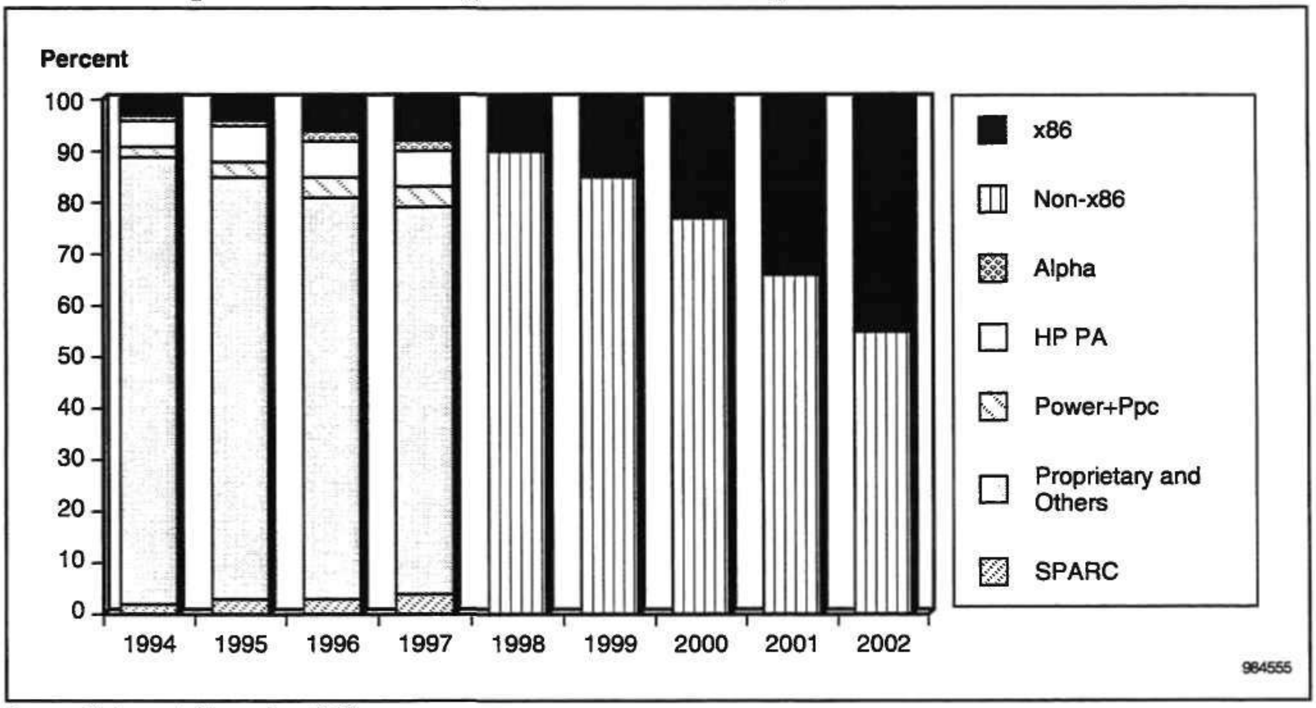
Source: Dataquest (November 1998)

Figure 5-9
Enterprise Server Microprocessor Revenue by Processor Architecture, 1994-2002



Source: Dataquest (November 1998)

Figure 5-10
Mix of Enterprise Server Microprocessor Revenue by Processor Architecture, 1994-2002



Source: Dataquest (November 1998)

Table 5-2
Server System Revenue by Server Segment and Processor Architecture, 1994-2002 (Millions of Dollars)

	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Enterprise	**32,872**	**31,012**	**31,810**	**30,908**	**30,365**	**30,365**	**30,365**	**30,365**	**30,365**	**0**
Non-x86	31,354	29,448	29,675	28,888	28,024	26,961	25,359	23,131	20,552	-7
x86	1,518	1,563	2,135	2,021	2,341	3,403	5,006	7,234	9,813	37
Alpha	403	571	919	1,012	-	-	-	-	-	-
HP PA	2,944	3,567	3,675	3,361	-	-	-	-	-	-
Power and PowerPC	1,536	1,771	2,389	3,046	-	-	-	-	-	-
Proprietary and Others	25,128	21,717	20,855	19,525	-	-	-	-	-	-
SPARC	1,343	1,822	1,837	1,943	-	-	-	-	-	-
Departmental	**5,711**	**8,086**	**10,106**	**10,447**	**11,903**	**12,717**	**13,749**	**15,707**	**17,501**	**11**
Non-x86	4,674	5,503	5,999	6,236	6,818	7,562	8,209	8,876	9,745	9
x86	1,037	2,583	4,107	4,211	5,084	5,156	5,540	6,831	7,756	13
Alpha	222	608	795	610	-	-	-	-	-	-
HP PA	478	745	994	982	-	-	-	-	-	-
Power and PowerPC	300	580	931	1,088	-	-	-	-	-	-
Proprietary and Others	3,101	2,907	2,668	1,854	-	-	-	-	-	-
SPARC	573	663	610	1,701	-	-	-	-	-	-
Workgroup	**3,117**	**4,175**	**5,454**	**7,600**	**9,167**	**10,542**	**12,123**	**13,457**	**14,668**	**14**
Non-x86	618	500	440	220	198	178	160	144	130	-10
x86	2,499	3,675	5,014	7,380	8,969	10,364	11,963	13,312	14,538	15
Alpha	0	2	8	29	-	-	-	-	-	-
HP PA	26	4	4	19	-	-	-	-	-	-
Power and PowerPC	38	136	140	99	-	-	-	-	-	-
Proprietary and Others	533	307	241	48	-	-	-	-	-	-
SPARC	21	51	46	24	-	-	-	-	-	-
All Servers	**41,700**	**43,273**	**47,369**	**48,956**	**51,434**	**53,624**	**56,236**	**59,528**	**62,533**	**5**
Non-x86	36,645	35,451	36,113	35,344	35,040	34,701	33,728	32,151	30,426	-3
x86	5,054	7,821	11,256	13,612	16,394	18,923	22,509	27,377	32,107	19
Alpha	625	1,181	1,722	1,652	-	-	-	-	-	-
HP PA	3,447	4,316	4,674	4,362	-	-	-	-	-	-
Power and PowerPC	1,874	2,488	3,460	4,234	-	-	-	-	-	-
Proprietary and Others	28,761	24,931	23,764	21,428	-	-	-	-	-	-
SPARC	1,937	2,536	2,493	3,668	-	-	-	-	-	-

Source: Dataquest (November 1998)

Table 5-3
Server Microprocessor Revenue by Server Segment and Processor Architecture, 1994-2002 (Millions of Dollars)

	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Enterprise	8,745	7,983	8,023	7,746	7,120	6,735	6,520	6,473	6,543	-3
x86	304	344	491	606	702	1,021	1,502	2,170	2,944	37
Non-x86	8,441	7,639	7,532	7,140	6,418	5,714	5,018	4,303	3,599	-13
Alpha	60	86	138	152	-	-	-	-	-	-
HP PA	442	535	551	504	-	-	-	-	-	-
Power and PowerPC	200	230	311	335	-	-	-	-	-	-
Proprietary and Others	7,538	6,515	6,257	5,858	-	-	-	-	-	-
SPARC	201	273	275	291	-	-	-	-	-	-
Departmental	716	1,048	1,336	1,591	1,835	2,042	2,259	2,500	2,798	12
x86	156	387	616	842	1,017	1,134	1,274	1,435	1,629	14
Non-x86	561	660	720	748	818	907	985	1,065	1,169	9
Alpha	27	73	95	73	-	-	-	-	-	-
HP PA	57	89	119	118	-	-	-	-	-	-
Power and PowerPC	36	70	112	131	-	-	-	-	-	-
Proprietary and Others	372	349	320	223	-	-	-	-	-	-
SPARC	69	80	73	204	-	-	-	-	-	-
Workgroup	437	601	896	1,350	1,634	1,883	2,169	2,411	2,630	14
x86	375	551	852	1,328	1,614	1,865	2,153	2,396	2,617	15
Non-x86	62	50	44	22	20	18	16	14	13	-10
Alpha	0	0	1	3	-	-	-	-	-	-
HP PA	3	0	0	2	-	-	-	-	-	-
Power and PowerPC	4	14	14	10	-	-	-	-	-	-
Proprietary and Others	53	31	24	5	-	-	-	-	-	-
SPARC	2	5	5	2	-	-	-	-	-	-
All Servers	9,898	9,632	10,255	10,687	10,589	10,660	10,949	11,384	11,971	2
x86	834	1,283	1,959	2,777	3,334	4,021	4,929	6,001	7,189	21
Non-x86	9,064	8,350	8,296	7,910	7,256	6,639	6,019	5,383	4,782	-10
Alpha	87	159	234	228	-	-	-	-	-	-
HP PA	501	625	671	624	-	-	-	-	-	-
Power and PowerPC	240	313	436	476	-	-	-	-	-	-
Proprietary and Others	7,964	6,895	6,601	6,085	-	-	-	-	-	-
SPARC	272	358	353	498	-	-	-	-	-	-

Source: Dataquest (November 1998)

Table 5-4
Server Microprocessor Shipments by Server Segment and Processor Architecture, 1994-2002 (Thousands of Units)

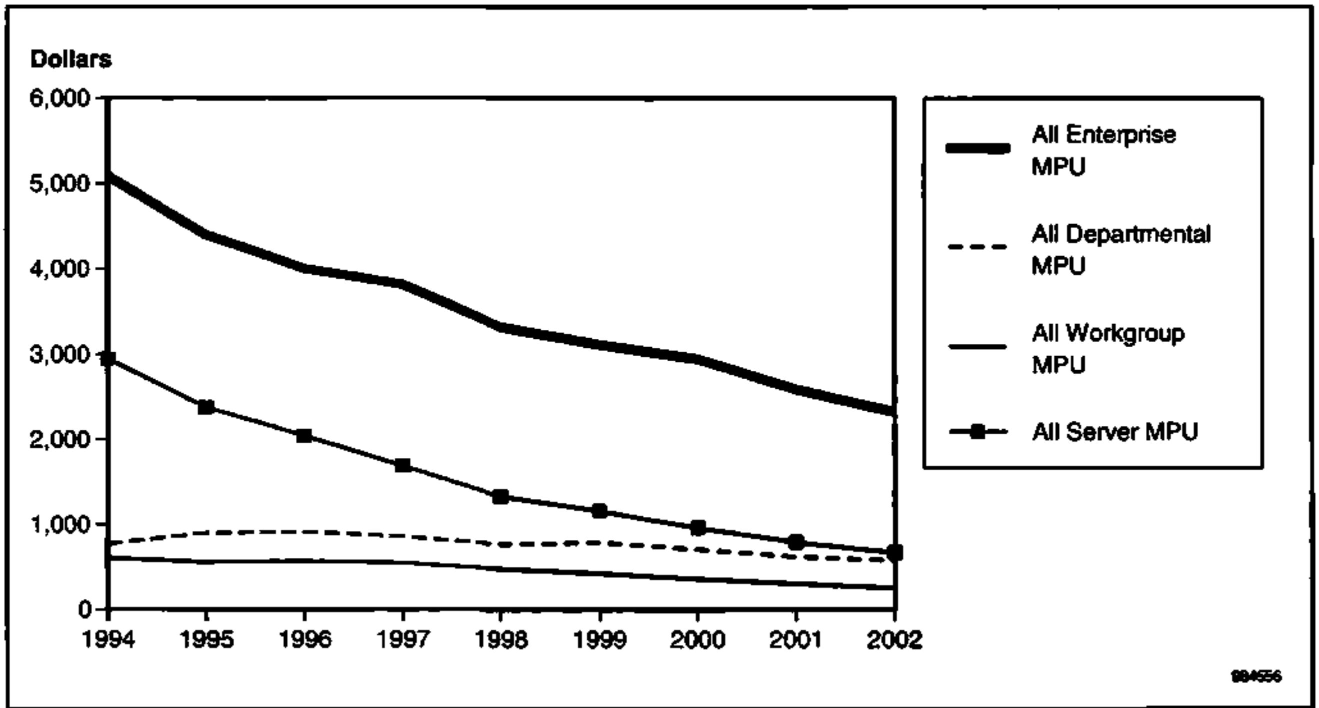
	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Enterprise	**1,718**	**1,814**	**2,003**	**2,028**	**2,142**	**2,163**	**2,213**	**2,503**	**2,816**	**7**
x86	501	505	560	611	658	788	968	1,375	1,840	25
Non-x86	1,218	1,309	1,442	1,417	1,485	1,375	1,245	1,128	976	-7
Alpha	16	28	56	65	-	-	-	-	-	-
HP PA	108	149	134	128	-	-	-	-	-	-
Power and PowerPC	86	95	126	125	-	-	-	-	-	-
Proprietary and Others	865	865	914	879	-	-	-	-	-	-
SPARC	142	172	213	220	-	-	-	-	-	-
Departmental	**925**	**1,162**	**1,454**	**1,849**	**2,395**	**2,592**	**3,187**	**3,998**	**4,820**	**21**
x86	404	545	775	1,067	1,445	1,543	1,941	2,505	3,044	23
Non-x86	521	617	679	783	951	1,049	1,246	1,492	1,776	18
Alpha	17	42	51	49	-	-	-	-	-	-
HP PA	37	57	91	83	-	-	-	-	-	-
Power and PowerPC	39	75	116	110	-	-	-	-	-	-
Proprietary and Others	290	278	311	242	-	-	-	-	-	-
SPARC	138	165	111	298	-	-	-	-	-	-
Workgroup	**717**	**1,078**	**1,562**	**2,445**	**3,407**	**4,422**	**5,983**	**7,832**	**10,166**	**33**
x86	598	976	1,454	2,388	3,340	4,348	5,905	7,749	10,080	33
Non-x86	119	102	108	57	67	74	79	83	86	9
Alpha	0	0	1	5	-	-	-	-	-	-
HP PA	3	1	1	3	-	-	-	-	-	-
Power and PowerPC	8	32	36	30	-	-	-	-	-	-
Proprietary and Others	105	63	63	15	-	-	-	-	-	-
SPARC	3	7	7	4	-	-	-	-	-	-
All Servers	**3,360**	**4,054**	**5,019**	**6,323**	**7,944**	**9,177**	**11,384**	**14,333**	**17,802**	**23**
x86	1,503	2,026	2,790	4,067	5,442	6,679	8,814	11,630	14,964	30
Non-x86	1,857	2,028	2,230	2,256	2,502	2,498	2,569	2,703	2,838	5
Alpha	33	70	108	119	-	-	-	-	-	-
HP PA	148	206	225	213	-	-	-	-	-	-
Power and PowerPC	133	202	277	265	-	-	-	-	-	-
Proprietary and Others	1,260	1,206	1,288	1,136	-	-	-	-	-	-
SPARC	284	344	332	523	-	-	-	-	-	-

Source: Dataquest (November 1998)

Processor ASPs Will Fall, Even for Servers

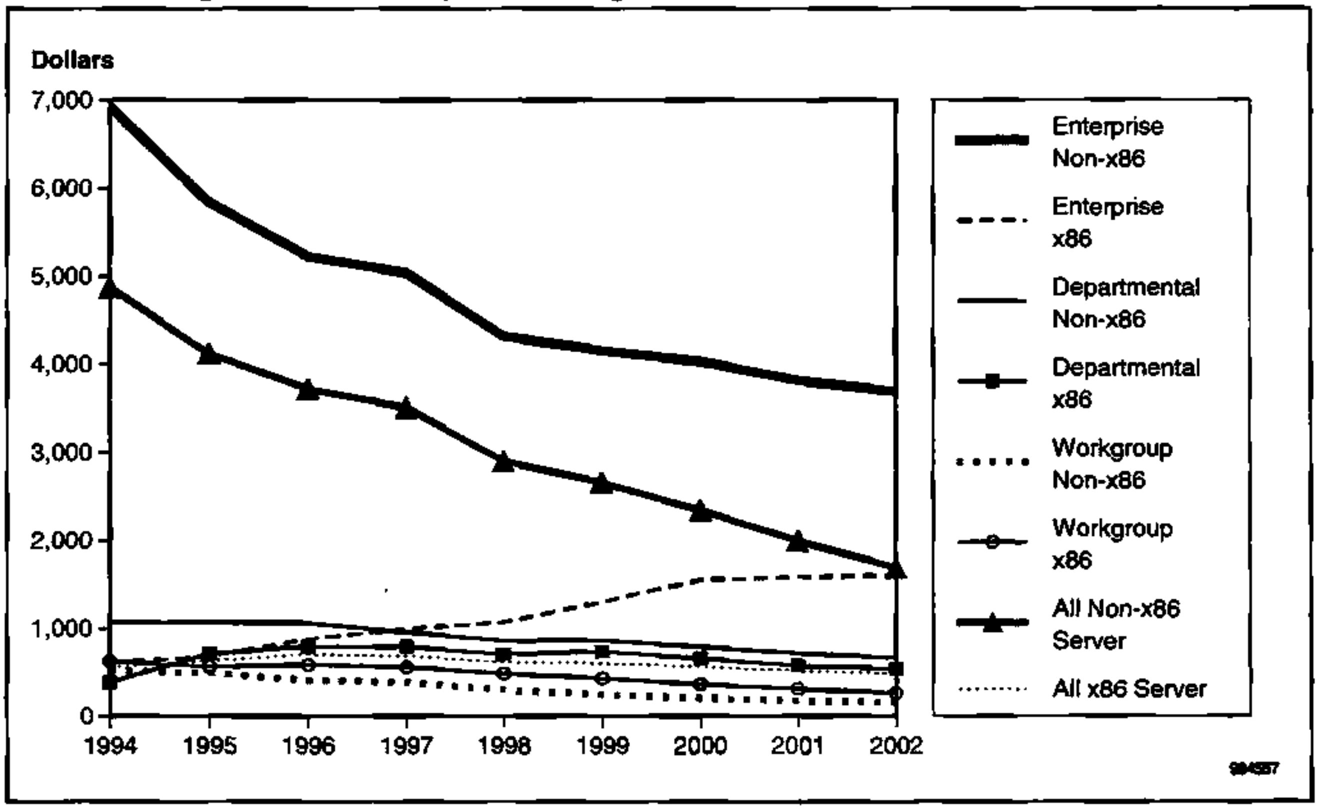
Although it will come as little consolation to vendors selling 64Mb DRAMs for less than $5, even vendors of $5,000 proprietary microprocessors for enterprise servers have no immunity from price pressures and eroding ASPs. As Figures 5-11 and 5-12, along with Table 5-5, illustrate, the processors used in servers will fall in price at a 17 percent rate between now and 2002. Table 5-5 also provides in tabular form Dataquest's estimate of the microprocessor ASPs for the units reported in Table 5-3. The radical shift in the mix from high-priced proprietary products to lower-priced commodity devices causes the overall rate of decline (17 percent) to exceed the rate of price erosion for non-x86 servers (14 percent CAGR) *and* the rate for x86 servers (7 percent). Processor ASPs will erode more quickly in the low-priced workgroup sector (where there is less microprocessor competition) than in the higher-priced departmental and enterprise segments. Dataquest believes that the shifting system mix toward fewer and less expensive workgroup servers has more to do with this phenomenon than any impulse toward generosity on Intel's part.

Figure 5-11
Server Microprocessor ASP by Server Class, 1994-2002



Source: Dataquest (November 1998)

Figure 5-12
Server Microprocessor ASP by Server Segment and Processor Architecture, 1994-2002



Source: Dataquest (November 1998)

Table 5-5
Server Microprocessor ASP by Server Segment and Processor Architecture, 1994-2002 (Dollars)

	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
All Enterprise MPU	**5,089**	**4,400**	**4,006**	**3,819**	**3,324**	**3,114**	**2,946**	**2,586**	**2,323**	**-9**
Enterprise Non-x86	6,932	5,836	5,222	5,039	4,323	4,155	4,031	3,816	3,687	-6
Enterprise x86	606	680	876	991	1,068	1,297	1,551	1,578	1,600	10
All Departmental MPU	**775**	**902**	**918**	**860**	**766**	**788**	**709**	**625**	**581**	**-8**
Departmental Non-x86	1,076	1,070	1,060	956	861	865	791	714	658	-7
Departmental x86	385	711	795	790	704	735	656	573	535	-7
All Workgroup MPU	**609**	**558**	**574**	**552**	**480**	**426**	**363**	**308**	**259**	**-14**
Workgroup Non-x86	521	491	406	388	296	242	204	175	151	-17
Workgroup x86	626	565	586	556	483	429	365	309	260	-14
All Server MPU	**2,946**	**2,376**	**2,043**	**1,690**	**1,333**	**1,162**	**962**	**794**	**672**	**-17**
All Non-x86 Server	4,880	4,118	3,720	3,506	2,900	2,658	2,343	1,992	1,685	-14
All x86 Server	555	633	702	683	613	602	559	516	480	-7

Source: Dataquest (November 1998)

Falling ASPs Drive an Increase in x86 Market Share

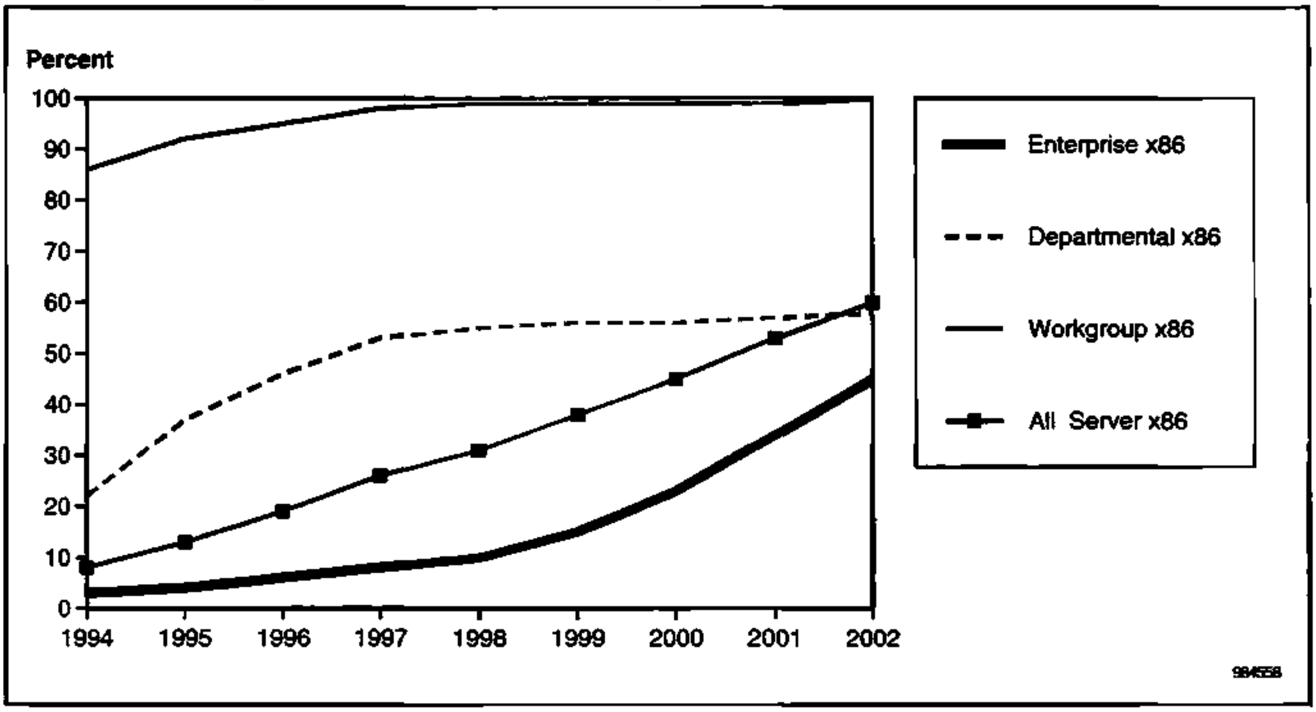
Dataquest projects that Intel's revenue share of the market for processors used in server configurations will increase by 20 points, from 64 percent in 1997 to 84 percent in 2002. In dollar terms, this translates into a revenue gain of $4.4 billion, and the margin for these products should exceed those Intel earns on desktop processors. To achieve this level of market share, Intel's revenue associated with server microprocessors must grow at a 21 percent CAGR, while the revenue of its competitors, principally the in-house suppliers of processors used in mainframes and supercomputers, will shrink at a 10 percent annual rate. Intel begins this battle with a five-to-one price advantage, but this will shrink to just two-to-one by the end of the period. A large difference in cost often is needed for a new technology to displace a mature one. Dataquest believes Intel possesses such a price advantage with regard to the proprietary processors used in today's mainframes. Table 5-6 summarizes Dataquest's estimates of the dollar market share x86 processors will attain in each segment of the server market over the forecast period. Figures 5-13 and 5-14 display the x86 dollar share and unit share in graphical form.

Table 5-6
Server x86 Microprocessor Revenue Share by Server Class, 1994-2002 (Percent)

	1994	1995	1996	1997	1998	1999	2000	2001	2002
Enterprise x86	3	4	6	8	10	15	23	34	45
Departmental x86	22	37	46	53	55	56	56	57	58
Workgroup x86	86	92	95	98	99	99	99	99	100
All Server x86	**8**	**13**	**19**	**26**	**31**	**38**	**45**	**53**	**60**

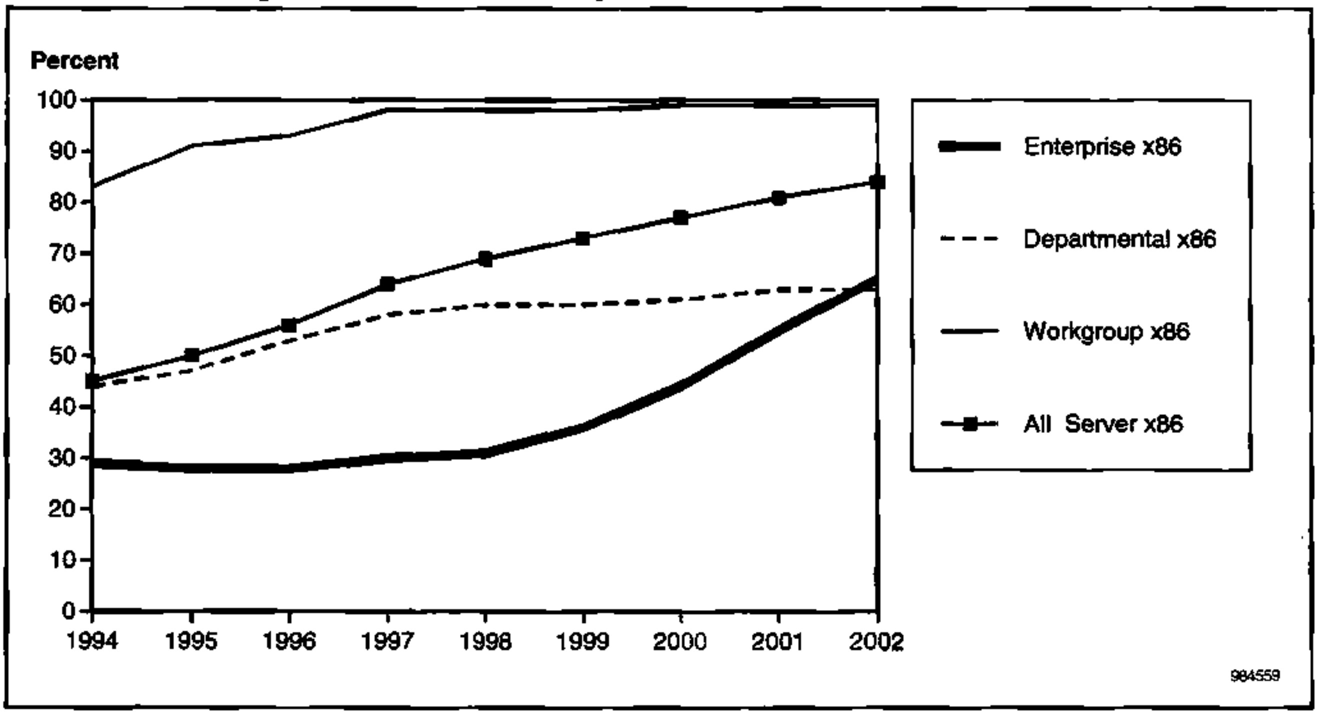
Source: Dataquest (November 1998)

Figure 5-13
Server x86 Microprocessor Revenue Share by Server Class, 1994-2002



Source: Dataquest (November 1998)

Figure 5-14
Server x86 Microprocessor Unit Share by Server Class, 1994-2002



Source: Dataquest (November 1998)

Chapter 6
A Recap of the Compute Microprocessor Forecast

In chapters 3, 4, and 5 of this report, Dataquest forecasts the computational microprocessors used in personal computers, workstations, and servers. In this chapter, we aggregate the data from those chapters into a cohesive view of the microprocessor market. Tables 6-1, 6-2, and 6-3 provide the forecasts for revenue, shipments, and ASP, respectively, in a manner consistent with the data provided in the prior chapters. These tables project a CAGR of 15 percent in units and 8 percent in revenue for the computational microprocessor market over the period 1997 to 2002. A price erosion of 6 percent CAGR accounts for the difference in revenue and shipment growth rates. x86-compatible processor revenue and shipments display strong growth throughout the period. Much of this growth comes at the expense of non-x86 processors, which decline in shipments and revenue during the period. As discussed in prior chapters, Dataquest cannot in practice measure much of the erosion in the non-x86 processor market segment, especially for high-end servers and workstations, because these processors are manufactured internally on a captive basis by system suppliers, and never appear on the merchant market.

Table 6-1
Forecast of Compute Microprocessor Revenue, 1997-2002 (Millions of Dollars)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Alpha	348	-	-	-	-	-	-
HPPA	848	-	-	-	-	-	-
Other (Proprietary+MIPS)	6,282	-	-	-	-	-	-
PowerPC	989	-	-	-	-	-	-
SPARC	978	-	-	-	-	-	-
Non-x86 Subtotal	9,445	9,089	8,241	7,432	6,626	5,861	-9
x86	19,565	22,842	25,747	28,976	32,354	36,876	14
Total MPU	**29,011**	**31,931**	**33,988**	**36,408**	**38,981**	**42,737**	**8**

Source: Dataquest (November 1998)

Table 6-2
Forecast of Compute Microprocessor Shipments, 1997-2002 (Thousands of Units)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Alpha	225,268	-	-	-	-	-	-
HPPA	374,581	-	-	-	-	-	-
Other (Proprietary+MIPS)	1,261,115	-	-	-	-	-	-
PowerPC	3,368,584	-	-	-	-	-	-
SPARC	1,022,253	-	-	-	-	-	-
Non-x86 Subtotal	6,251,802	6,469,637	6,014,289	5,698,756	5,489,985	5,321,621	-3
x86	98,261,673	114,082,658	132,679,249	154,048,990	179,064,486	213,444,816	17
Total MPU	**110,765,278**	**127,021,933**	**144,707,827**	**165,446,502**	**190,044,457**	**224,088,058**	**15**

Source: Dataquest (November 1998)

Table 6-3
Forecast of Compute Microprocessor Average Selling Prices, 1997-2002 (Dollars)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Alpha	1,543	-	-	-	-	-	-
HPPA	2,264	-	-	-	-	-	-
Other (Proprietary+MIPS)	4,982	-	-	-	-	-	-
PowerPC	294	-	-	-	-	-	-
SPARC	956	-	-	-	-	-	-
Overall Non-x86	1,511	1,405	1,370	1,304	1,207	1,101	-6
x86	199	200	194	188	181	173	-3
Overall MPU ASP ($)	**262**	**251**	**235**	**220**	**205**	**191**	**-6**

Source: Dataquest (November 1998)

Tables 6-4, 6-5, and 6-6 provide a view of microprocessor shipments that excludes the proprietary products produced in-house that Dataquest knows to be present in the market, but cannot count because of their nonmerchant nature. Because these tables exclude a shrinking part of the market, they suggest that microprocessor revenue will grow more rapidly (CAGR of 10 percent, versus 8 percent for the broader measure). These tables (Tables 6-4 and 6-5) also indicate that x86 microprocessor revenue and shipments will grow at a slightly slower pace than shown in Tables 6-1 and 6-2, but this phenomenon has little to do with the inclusion or exclusion of the proprietary processors. Modern microprocessors execute many instructions in an "out-of-order" manner, which means that instructions do not always exit a processor's pipeline in the same order they go in. Similarly, in the time needed to create and release this report, many other Dataquest reports entered and exited the Dataquest production pipeline. Some of those reports resulted in a reduction of the Dataquest estimate for x86 microprocessor shipments for 1998, as a consequence of the personal computer inventory overhang that plagued the PC market for much of 1998. System vendors cut back on production, and managed work-in-process inventories tighter than ever before, thus reducing processor shipments.

In the interest of providing Dataquest clients with our most current thoughts on the processor market, we chose to reflect this fine-tuning of our forecast, along with the proprietary adjustments discussed above. Tables 6-7 and 6-8 provide the detail needed to allow even the most diligent reader to understand the separate impacts the proprietary adjustment and the market-condition adjustment have had on our revenue and shipment forecast. Less diligent readers can use the data in Tables 6-4, 6-5, and 6-6 if they need the most current Dataquest view of the microprocessor market.

Table 6-4
Adjusted Forecast of Compute Microprocessor Revenue, 1997-2002 (Millions of Dollars)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Alpha	347	-	-	-	-	-	-
HPPA	0	-	-	-	-	-	-
MIPS	54	-	-	-	-	-	-
PowerPC	675	-	-	-	-	-	-
SPARC	591	-	-	-	-	-	-
Non-x86 Subtotal	1,667	2,378	2,404	2,420	2,413	2,425	8
x86	19,565	20,068	22,631	25,433	28,368	32,331	11
Total MPU	**21,232**	**22,446**	**25,034**	**27,853**	**30,781**	**34,757**	**10**

Source: Dataquest (November 1998)

Table 6-5
Adjusted Forecast of Compute Microprocessor Shipments, 1997-2002 (Thousands of Units)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Alpha	420,000	-	-	-	-	-	-
HPPA	393,000	-	-	-	-	-	-
MIPS	181,000	-	-	-	-	-	-
PowerPC	3,500,000	-	-	-	-	-	-
SPARC	1,217,000	-	-	-	-	-	-
Non-x86 Subtotal	5,711,000	5,197,042	4,820,280	4,528,527	4,302,040	4,124,890	-6
x86	98,261,673	103,203,398	121,021,239	141,663,550	165,923,996	199,263,329	15
Total MPU	**103,972,673**	**108,400,440**	**125,841,519**	**146,192,078**	**170,226,036**	**203,388,219**	**14**

Source: Dataquest (November 1998)

Table 6-6
Adjusted Forecast of Compute Microprocessor Average Selling Prices, 1997-2002 (Dollars)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Alpha	826	-	-	-	-	-	-
HPPA	0	-	-	-	-	-	-
MIPS	298	-	-	-	-	-	-
PowerPC	193	-	-	-	-	-	-
SPARC	486	-	-	-	-	-	-
Overall Non-x86	292	458	499	534	561	588	15
x86	199	194	187	180	171	162	-4
Overall Compute MPU	**204**	**207**	**199**	**191**	**181**	**171**	**-4**

Source: Dataquest (November 1998)

Table 6-7
Reconciliation of August and October Compute Microprocessor Revenue Forecasts, 1997-2002 (Millions of Dollars)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
August: x86Revenue	19,565	22,842	25,747	28,976	32,354	36,876	14
October: x86Revenue	19,565	20,068	22,631	25,433	28,368	32,331	11
Delta: x86 Revenue	**0**	**2,774**	**3,116**	**3,543**	**3,986**	**4,545**	-
August: Non-x86Revenue	9,445	9,089	8,241	7,432	6,626	5,861	-9
October: Nonx86 Revenue	1,667	2,378	2,404	2,420	2,413	2,425	8
Delta: Non-x86 Revenue	**7,778**	**6,711**	**5,837**	**5,012**	**4,213**	**3,436**	-
August: Compute MPU Revenue	29,011	31,931	33,988	36,408	38,981	42,737	8
October: Compute MPU Revenue	21,232	22,446	25,034	27,853	30,781	34,757	10
Delta: Compute MPU Revenue	**7,778**	**9,485**	**8,953**	**8,555**	**8,200**	**7,980**	-

Source: Dataquest (November 1998)

Table 6-8
Reconciliation of August and October Compute Microprocessor Shipment Forecasts, 1997-2002 (Thousands of Units)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
August: x86Units	98,261,673	114,082,658	132,679,249	154,048,990	179,064,486	213,444,816	17
October: x86 Units	98,261,673	103,203,398	121,021,239	141,663,550	165,923,996	199,263,329	15
Delta: x86 Units	**0**	**10,879,260**	**11,658,010**	**12,385,440**	**13,140,490**	**14,181,487**	-
August: Non-x86Units	6,251,802	6,469,637	6,014,289	5,698,756	5,489,985	5,321,621	-3
October: Non-x86 Units	5,711,000	5,197,042	4,820,280	4,528,527	4,302,040	4,124,890	-6
Delta: Non-x86 Units	**540,802**	**1,272,596**	**1,194,009**	**1,170,229**	**1,187,945**	**1,196,731**	-
August: Compute MPU Units	104,513,476	120,552,296	138,693,538	159,747,746	184,554,472	218,766,437	16
October: Compute MPU Units	103,972,673	108,400,440	125,841,519	146,192,078	170,226,036	203,388,219	14
Delta: Compute MPU Units	**540,802**	**12,151,856**	**12,852,019**	**13,555,669**	**14,328,435**	**15,378,218**	-

Source: Dataquest (November 1998)

Chapter 7
Vendors of Computational Microprocessors

Intel: A Processor in Every Segment

After several years of fast-paced growth, Intel's sales reached a plateau at the lofty rate of $25 billion per year in 1998. x86 ASPs actually declined in the first half of the year, a rarely observed phenomenon. Intel's response has been to segment the market and deliver products optimized for each segment. Intel's new world contains five segments: the basic PC, the performance/enthusiast PC, the mobile PC, and workstations and servers. It targeted a new brand, Celeron, at the basic PC market, and another new brand, Xeon, at the server and workstation segments. With these brands, along with distinctions in the performance, package, socket, and bus used within each segment, Intel hopes to achieve dramatically different prices for silicon devices that have only small variations in their basic manufacturing costs. Dataquest believes that as this strategy gains steam in the second half of 1998, it has a high probability of reviving revenue growth at the colossus of the semiconductor world.

Advanced Micro Devices: Snatching Defeat from the Jaws of Victory

AMD had another frustrating year in 1997. It launched its AMD-K6 processor to rave reviews in April, but a series of process-related manufacturing problems slowed its volume ramp and prolonged the company's period of losses. AMD did not correct these problems until almost a year after the initial launch of the K6, when it introduced an enhanced version it calls the AMD-K6-2. As 1998 progressed, AMD announced a series of impressive design wins: the Compaq Presario, the IBM Aptiva, and the Hewlett-Packard Pavilion, among others. Increased interest in low-priced systems worked to AMD's advantage, while Intel's initial Celeron offering proved a weak competitor and gave AMD a chance to catch its breath. If AMD can maintain its current momentum, the market may yet get to watch an interesting race.

Cyrix: Finally Some Customers with a Name You Can Recognize

For Cyrix, the road to x86 riches has been paved with potholes. Its M1 product, dubbed 6x86, was a long time coming, and finding a serious customer for the chip proved too big a task for Jerry Rogers, the founder who resigned late in 1996. Under the interim management of Jay Swent, Cyrix finally worked a deal, and Compaq's introduction of the $999 Presario 2100 in March 1997 altered the landscape forever. Later in the year, National Semiconductor acquired Cyrix and announced its plan to squeeze all the silicon needed for a standard PC onto a single chip. In parallel, Cyrix launched the new version of its 6x86, now rechristened M II, and also announced that Packard Bell, the No. 4 producer of personal computers in the United States, would recast its line around Cyrix processors. Now Cyrix, like AMD, faces the challenge of building on the momentum it finally gained in 1997 and 1998.

IBM Microelectronics: Winning the Copper Medal

IBM, always a powerhouse with regard to semiconductor technology, announced yet another breakthrough in 1997. Its new copper interconnect technology would make microprocessors run faster, especially as feature sizes shrink and device interconnect delays seriously limit overall performance. Unfortunately, just as it was basking in the copper glow, the processors that IBM might choose to build in copper hit a few snags. National Semiconductor acquired Cyrix and indicated that it will eventually pull the Cyrix manufacturing business in-house, rather than continuing with IBM as a foundry. Even if Cyrix continues to use IBM's manufacturing as a resource, it would appear unlikely the company will modify its M II design to exploit the advantages copper offers. At almost the same time, Apple Computer announced that it would abandon its Macintosh licensing program, thus cutting off the Macintosh clones and severely limiting the growth opportunities for the PowerPC on the desktop. In an ever-so-gentle fashion, IBM has redirected its PowerPC strategy toward the embedded market. The culmination of this redirection appeared in the spring of 1998, when IBM and Motorola parted ways on their development of desktop PowerPC processors at the jointly owned Somerset center in Austin, Texas. Motorola got custody of the engineers, while the two companies agreed to share custody of key specifications. Some advanced versions of the G3 and G4 microprocessors will spend alternate weekends (and some time during the summer) with IBM's engineers. IBM will continue to develop versions of the PowerPC to drive its AS400 line, along with a variety of workstation and server products that use proprietary PowerPC implementations. Given the changes at Somerset and Cyrix, it would not surprise Dataquest greatly if IBM were to exit the merchant market for computational processors within the next two years.

IDT Centaur: Lower than Low

Although shipments of the Integrated Device Technology Inc. WinChip C6 were too small to measure in 1997, IDT certainly bears watching in 1998. The company's in-house-developed x86 processor emphasized small die size over all other aspects and measures less than half the area of bigger alternatives. This allows IDT to market the device for prices under $50, which is inexpensive even by the standards of low-priced x86 clones. IDT markets the C6 primarily to Asian vendors for whom a few dollars in cost makes the difference between a wildly successful product and a loser. IDT has positioned itself in a part of the market that even AMD and Cyrix do not like to visit. If the company can achieve profitability there, it will find few challengers in the near term.

Sun Microelectronics: SPARCing Some Interest

Every year, Sun Microsystems defies predictions of the death of the UNIX market and announces increased sales of its SPARC-based products. The year 1997 proved no exception overall, but the company did lose a little ground in the workstation business, as noted earlier. It more than made up for this deficiency by increasing sales of its powerful SPARC-based servers targeted at departmental and enterprise applications. Sun's array of UltraSPARC II-based servers delivers a level of performance no ordinary x86-based server can match, and the growth in Sun's server business has more than offset the slight decline in its workstation business. Dataquest's estimates in the second table in Appendix A suggest that SPARC revenue took off in 1997 and grew to $550 million from $170 million in 1996.

Dataquest deserves at least as much credit (or blame) as Sun for this dramatic growth rate. In years past, we reported some SPARC shipments and revenue as originating at Texas Instruments Inc. TI actually served as a foundry source for Sun, and this revenue should have fallen under Sun's column. This year, we put these shipments in the right place, but we may have understated them by about $70 million. No vendor rankings were affected. Next year, Dataquest will try harder to get it right.

Digital's Alpha: Now Sold by the World's Largest PC Vendor and Manufactured by the World's Largest Semiconductor Vendor

Digital Equipment had to sue Intel to get the ball rolling, but it certainly managed to change the world over the past 12 months. Frustrated with its inability to find system vendors willing to incorporate its speedy Alpha processors into their product lines, in May 1997, Digital sued Intel, claiming the latter had used patented Digital technology to gain a performance advantage for its Pentium and Pentium Pro processors. After much gnashing of teeth, Digital settled its suit with Intel by agreeing to license the disputed technology to Intel, if Intel would agree to purchase Digital's semiconductor operation and agree to manufacture Alpha for Digital on a foundry basis. Shortly thereafter, Compaq announced its own plan to acquire Digital. Both deals were completed by the middle of 1998. As we enter the second half of the year, Compaq has indicated its intent to continue to offer Alpha-based products and to incorporate Alpha into its own successful ProLiant server line. With its Alpha-based offerings, Compaq joins the elite club of full-line computer manufacturers that can sell customers anything they need, from the lowliest PC to the biggest enterprise systems. Now, Compaq just needs to figure out how to digest its latest acquisition.

Motorola

Apple's decision to shut down Macintosh licensing impacted Motorola as well as IBM. Given that Motorola had actually created a subsidiary to market Macintosh clone systems, it may even have impacted Motorola more than IBM. In the near term, the company may benefit as IBM backs away from the merchant market for PowerPC devices, but in the longer run, as the Macintosh continues to fade slowly into the sunset, Motorola too will find itself focusing exclusively on embedded opportunities for the PowerPC.

Hewlett-Packard: Riding Two Horses

In 1994, HP was the first RISC vendor to announce its intention to throw its lot in with Intel's IA64. In exchange for this honor, it had the opportunity to work with Intel to ensure that the final version of IA-64 could execute Precision Architecture binaries at the fastest rate possible. As the HP/Intel relationship has evolved, HP must ride two horses simultaneously, as it enhances its PA RISC line while preparing for the transition to Merced. Once Merced appears, HP will be in a position to offer its customers a very clean path to IA-64, but meanwhile, it must do twice as much work. Fortunately, the company has an abundance of the engineering resources needed to accomplish such a feat.

MIPS/Silicon Graphics: SGI Eyes x86 White MIPS Plays Games

For years, Silicon Graphics funneled the royalties it earned by licensing its MIPS architecture to Nintendo and Sony into funding the development efforts it needed to keep its MIPS-based workstations competitive. Finally, in 1997, as x86-based workstations began to eat into Silicon Graphics' workstation business, the bubble burst. Along with a new management team, SGI announced its intent to base future "low-end" products on advanced versions of Intel's Pentium II architecture. It remains to be seen where SGI will draw the line between the "low-end" x86 products and higher performing proprietary offerings, but Dataquest will not be surprised if, in a few years, only SGI's Cray subsidiary continues with a non-x86 strategy.

Appendix A

x86 and Non-x86 Computational Microprocessor Statistics

Table A-1
x86 Computational Microprocessor Statistics

Company	Product Line	Units (K) 1996	Revenue ($M) 1996	Units (K) 1997	Revenue ($M) 1997	Unit Growth (%) 1997/1996	Revenue Growth (%) 1997/1996	Unit Share (%) 1997	Revenue Share (%) 1997
AMD	386	500	13	363	3	-27	-77	0	0
AMD	486	6,500	185	3,624	132	-44	-29	4	1
AMD	AMD-K5	1,802	112	1,467	101	-19	-10	2	1
AMD	AMD-K6			2,654	446	NA	NA	3	2
Subtotal	AMD x86	8,802	310	8,108	682	-8	120	8	3
Cyrix	486	660	30	-	-	-	-	0	0
Cyrix	6x86	1,260	130	1,400	67	11	-48	1	0
Cyrix	6x86MX	-	-	1,000	145	NA	NA	1	1
Cyrix	MediaGX	-	-	1,300	98	NA	NA	1	0
Subtotal	Cyrix x86	1,920	160	3,700	310	93	94	4	2
IBM	486	421	38	-	-	-100	-100	0	0
IBM	6x86	1,300	136	700	31	-46	-77	1	0
IBM	6x86MX	-	-	1,000	120	NA	NA	1	1
Subtotal	IBM x86	1,721	174	1,700	151	-1	-13	2	1
Intel	486	3,000	400	-	-	-100	-100	0	0
Intel	Pentium	60,000	13,549	71,741	10,367	20	-23	74	53
Intel	Pentium Pro	2,000	726	6,800	4,715	240	549	7	24
Intel	Pentium II	-	-	5,250	3,477	NA	NA	5	18
Subtotal	Intelx86	65,000	14,675	83,791	18,559	29	26	86	94
SGS-Thomson	6x86	75	8	26	26	-65	225	0	0
Texas Instruments	486	820	18	-	-	-100	-100	0	0
Total	**All x86**	**78,338**	**15,345**	**97,325**	**19,728**	**24**	**29**	**100**	**100**

NA = Not available
Source: Dataquest (November 1998)

Table A-2
Non-x86 Computational Microprocessor Statistics

Company	Subarchitecture	Units (K) 1996	Revenue ($M) 1996	Units (K) 1997	Revenue ($M) 1997	Unit Growth (%) 1997/1996	Revenue Growth (%) 1997/1996	Unit Share (%) 1997	Revenue Share (%) 1997
Digital	Alpha	301	235	420	347	40	48	7	21
Subtotal	Alpha	301	235	420	347	40	48	7	21
Integrated Device Technology	MIPS	10	3	11	3	10	0	0	0
NEC	MIPS	100	40	100	42	0	5	2	3
Toshiba	MIPS	40	32	70	9	75	-72	1	1
Subtotal	MIPS	150	75	181	54	21	-28	3	3
TCS	Proprietary	-	-	120	12	NA	NA	2	1
Subtotal	Proprietary	-	-	120	12	NA	NA	2	1
Hewlett-Packard	PA-RISC	298	0	393	0	32	NA	7	0
Subtotal	PA-RISC	298	0	393	0	32	NA	7	0
IBM	PowerPC	2,510	439	1,800	329	-28	-25	31	20
Motorola	PowerPC	1,507	209	1,700	346	13	66	29	21
Subtotal	PowerPC	4,017	648	3,500	675	-13	4	60	40
Fujitsu	SPARC			117	41	NA	NA	2	2
Sun Microsystems	SPARC	525	170	1,100	550	110	224	19	33
Texas Instruments	SPARC	279	195			-100	-100	0	0
Subtotal	SPARC	804	365	1,217	591	51	62	21	35
Total	**Other Architectures**	**5,570**	**1,323**	**5,831**	**1,679**	**5**	**2**	**100**	**100**

NA = Not available
Source: Dataquest (November 1998)

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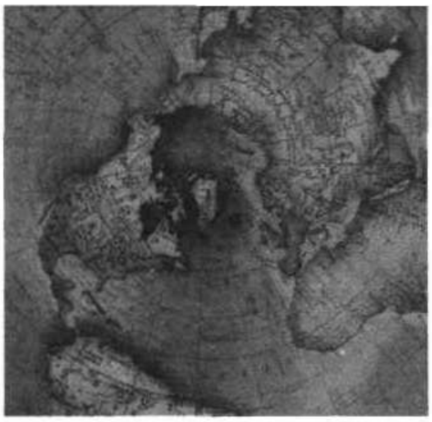

Dataquest

Dynamics of the PC and PC Semiconductor Markets

Market Trends

Program: Personal Computer Semiconductors and Applications Worldwide
Product Code: PSAM-WW-MT-9802
Publication Date: September 7, 1998
Filing: Market Trends

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Chapter 1
Executive Summary

PCs are the largest single application for semiconductors and as such consume acres of chips every year. This relationship is traditionally a boon for both markets, but over the last year, the dependence of the semiconductor market on the PC market has exacted a stiff toll.

The PC market, counting motherboards and handheld PCs, is forecast to grow at a cumulative annual growth rate of 8.6 percent on a revenue basis from 1997 to 2002, with Asia/Pacific exhibiting higher growth than other regions. The semiconductor revenue per PC will decline driven by oversupply for semiconductors in general and a slowdown in the demand for faster MPUs. Dataquest expects PC semiconductor revenue to grow 10.4 percent over the same period, giving semiconductor vendors a slightly larger slice of the PC market pie.

This level of growth will create opportunity for semiconductor vendors to sell a variety of chips into the PC market, but the growth is rocky at best for the next 12 months. Microprocessors and memory products top the list for sheer magnitude of revenue, but graphics and communication products offer opportunity as well. Overall semiconductor content in PCs will grow to $72.8 billion in 2002, up from the $44.4 billion mark in 1997.

This document provides detailed information about the PC and workstation markets and the semiconductor content of their products. Market sizes and forecasts for the PC market are presented by form factor and microprocessor. Semiconductor revenue detail includes major product segments and memory configuration assumptions by PC form factor and by microprocessor generation.

Project Analyst: Geoff Ballew

Chapter 2

Introduction and Methodology

This document is the second in a series of three that provide reference information and analysis about the markets for semiconductor devices in personal computers. The three books are graphics and audio controllers (PSAM-WW-MT-9701), microprocessors and core logic chipsets (PSAM-WW-MT-9703), and this volume which includes a model of total semiconductor content for PCs. Specific areas of information include the following:

- PC system market size (in production terms) in revenue, units, and average selling price
- PC system market and product feature trends
- Hardware architecture trends and semiconductor device opportunities
- Semiconductor content and market forecast
- Listings of key OEMs

The information in this report is gathered from both primary and secondary sources. Primary sources include surveys and interviews of industry vendors and customers, as well as analyst knowledge and opinions. Secondary sources include governmental and trade sources on sales, prodution, trade, and public spending. Semiconductor content assumptions are based on both surveys of producing OEMs and physical teardown evaluations by Dataquest analysts of representative personal computers.

The forecast methodology is based on various methods and assumptions, depending upon the specific market. To form a solid basis for projecting system demand, capital, government, and consumer spending, assumptions are made for various regions of the world. For specific markets, saturation and displacement dynamics are considered as well. Key exogenous factors such as new software introductions, exchange rate changes, and government policies are also considered. Semiconductor content forecasts are based upon interviews of system marketers and designers (including makers of enabling semiconductor technology) along with an analysis of historical trends.

Chapter 3
Personal Computer and Workstation Markets

Market and Production Trends

Personal Computers

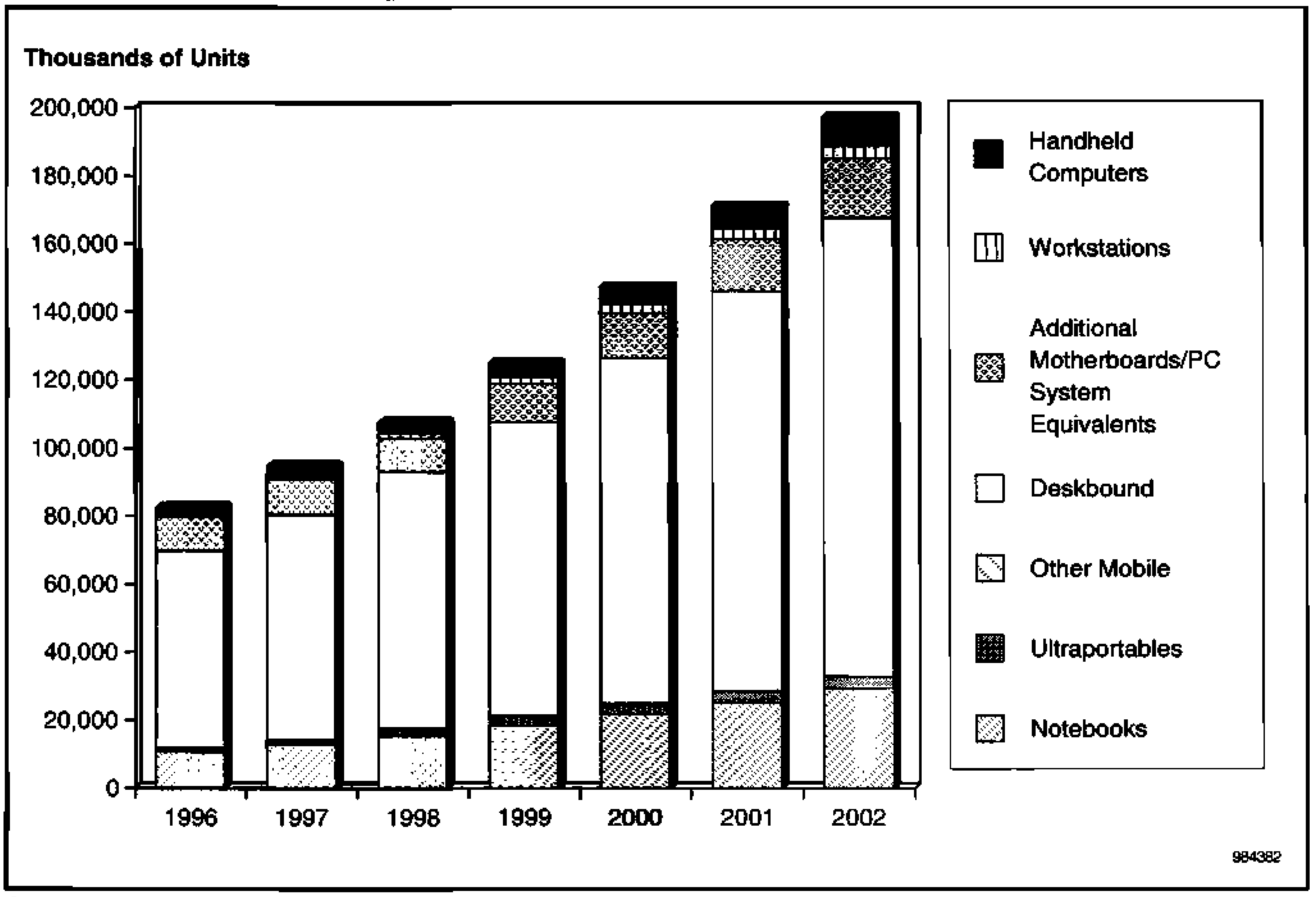
Market and production trends in PCs and workstations are as follows:

- The PC unit shipments are forecast to grow at a 15.8 percent compound annual growth rate (CAGR) over the next five years. PC market revenue should post a much lower 8.6 percent CAGR.
- Regional growth for PCs highlights these important dynamics:
  - The United States is dominated by a replace-and-upgrade cycle but has strongly embraced the sub-$1,000 PC. Lower PC prices have prompted more consumers to purchase their first home PC, boosting the penetration rate to over 40 percent.
  - Europe has shown surprising strength over the past year and offset some of the sluggishness caused by the Asian financial crisis.
  - Asia/Pacific is bolstered by China, but continued economic troubles throughout much of Asia/Pacific temper the overall expectations.
  - Japan is suffering a protracted recession that has slowed the sales of consumer PCs. Strong growth in home PC sales is predicated on progress toward economic recovery.
- Mobile PC shipments will grow faster than the overall market, but deskbound systems will continue to dominate the computing platform because of their lower manufacturing costs, the ability to handle robust configurations with large amounts of storage, and their role in offering the fastest and latest computing technologies.
- Notebooks have enjoyed solid unit growth because of their ability to replicate desktop environments, and growth for 1997 should top 18 percent on a unit base. Larger LCDs, bigger hard disks, integrated CD-ROM drives, and new CPU modules continue to narrow the performance gap between desktop and notebook PCs. Revenue growth will come under pressure as declines in average selling prices (ASPs) offset the unit shipment gains for this year.
- Ultraportable and notepad shipments continue to grow but may be surpassed by handheld PCs as the second largest mobile category, behind notebooks, in 1999. Ultraportable ASPs, like those of traditional notebooks, are expected to decline this year, limiting revenue growth to just a few percentage points despite a forecast of almost 20 percent unit growth.
- Shipments of larger portable PCs are rising after a decline in 1997. This resurgence in sales of transportable PCs will continue through 2002 when shipments will reach nearly 200,000 units.

- In the world of mobile computing, handheld devices continue to promise function and mobility, but face size, weight, and cost issues. Dataquest has defined two categories for these handheld devices:
  - Expandable organizers: These are computers that typically measure 3.0 x 6.0 x 0.75 inches and weigh less than a pound. They are distinguished by the capability to have the user add applications and memory, and the fact that expansion is proprietary to a particular device or family. The operating systems typically are proprietary. The market for these devices is expected to peak at more than 0.5 million unit shipments in 1995 and then slowly shrink to fewer than 0.4 million by 1999.
  - Handheld computers: These devices typically measure 4 x 7 x 1 inches and weigh about a pound. They are distinguished from expandable organizers by their adherence to hardware and software compatibility standards. The operating systems are open and licensed, and application development and memory expansion are open to third-party developers and may be distributed in a standard format (such as PCMCIA). PDAs fall into this category and, specifically, U.S. Robotics' Pilot products are included.
- Growth in the worldwide home PC market will continue across all regions of the world but is affected by economic turmoil through most of Asia. The home PC market will grow slightly faster than the business PC market. The CAGR for these two market segments are 16.4 percent and 15.6 percent, respectively.
- Price elasticity is an important factor in the home PC market. Sub-$1,000 PCs from major OEMs bolstered sales in the United States last fall. The segment zero price segment is here to stay.
- Asia/Pacific is the fastest-growing region and Europe is the slowest-growing region for PC unit shipments.
- Major PC manufacturers will continue to place a strong emphasis on the branding of PCs.
- Manufacturing strategies are dictated by economies of scale with strong influence from free trade zones, the availability of components, and the quality and price of labor. For desktop PCs, the trend is toward final configuration (adding CPU and main memory) of units close to the end market. Most top-tier OEMs have adopted build-to-order (BTO) strategies or some type of channel assembly (CA) strategy for some product lines. For mobile PCs, production is largely focused on Japan and other Asian countries. A rising tide of OEM notebooks from Taiwanese vendors will continue Asia/Pacific region's growing influence on the mobile PC market.
- Motherboard production will depend more heavily on the Asia/Pacific region as suppliers continue to regain some of the market share they lost because of Intel's rapid growth in the motherboard business in 1994 and 1995.

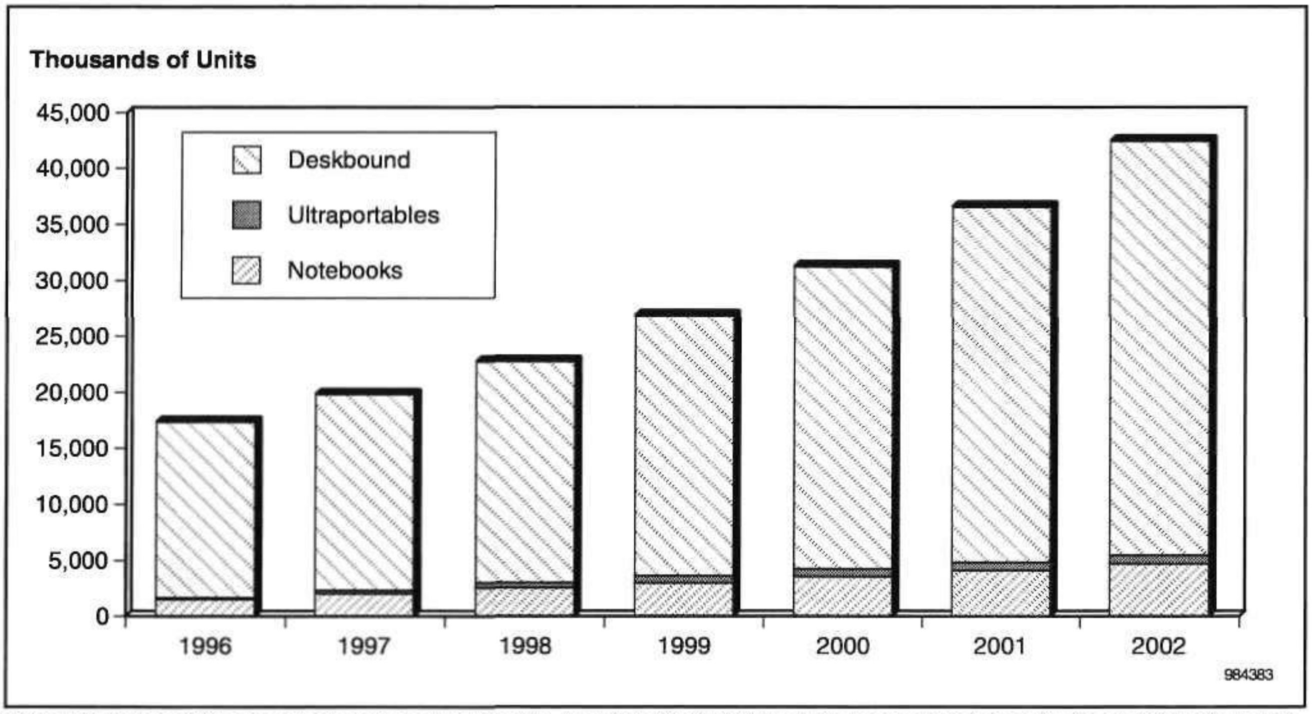
Figures 3-1 through 3-3 and Tables 3-1 through 3-7 present Dataquest's worldwide PC market forecasts. Figures 3-4 and 3-5 show the regional variation in markets and production from 1996 to 2002. Tables 3-8 through 3-10 show worldwide shipments. Tables 3-11 through 3-13 show worldwide revenue. Figure 3-6 and Table 3-14 show the regional PC and motherboard production for 1997.

Figure 3-1
Worldwide Personal Computer Shipments by Product Type (Thousands of Units)



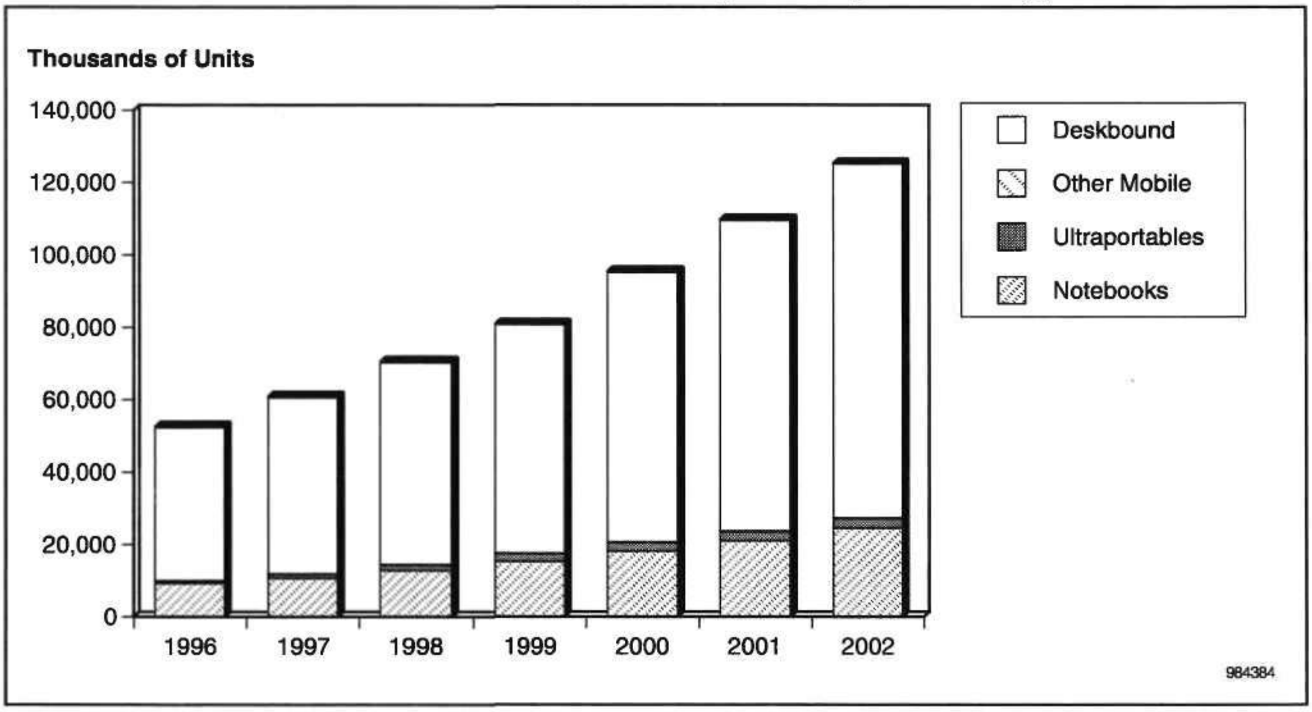
Source: Dataquest (August 1998)

Figure 3-2
Worldwide Private Personal Computer Shipments by Product Type (Thousands of Units)



Notes: Excludes additional motherboards and handhelds. All shipments for "other mobile" are counted as professional shipments for this book.
Source: Dataquest (August 1998)

Figure 3-3
Worldwide Professional Personal Computer Shipments by Product Type



Notes: Excludes additional motherboards and handhelds. All PCs in "other mobile" category of the Dataquest PC forecast are considered professional PC shipments for this figure.
Source: Dataquest (August 1998)

Table 3-1
Worldwide Personal Computer Market by Product Type

Product Type	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Deskbound								
Units (K)	58,061	66,285	75,561	86,393	101,486	117,599	134,758	15.2
ASP ($K)	1.92	1.76	1.65	1.58	1.47	1.37	1.29	-5.9
Factory Revenue ($M)	111,590	116,403	124,430	136,470	149,345	160,765	174,312	8.4
Notebook								
Units (K)	10,931	12,942	15,547	18,481	21,826	25,239	29,337	17.8
ASP ($K)	2.87	2.78	2.42	2.20	2.09	1.97	1.88	-7.5
Factory Revenue ($M)	31,386	35,965	37,640	40,612	45,607	49,799	55,227	9.0
Ultraportable								
Units (K)	823	1,323	1,983	2,693	3,071	3,177	3,395	20.7
ASP ($K)	2.58	2.24	1.65	1.56	1.57	1.48	1.41	-8.9
Factory Revenue ($M)	2,126	2,970	3,277	4,194	4,810	4,715	4,786	10.0
Other Mobile								
Units (K)	54	39	54	91	141	169	194	37.8
ASP ($K)	4.11	5.23	4.67	3.66	3.01	2.71	2.46	-14.0
Factory Revenue ($M)	222	204	252	333	424	458	477	18.5
Subtotal of Above PC Categories								
Units (K)	69,869	80,589	93,145	107,658	126,524	146,184	167,684	15.8
ASP ($K)	2.08	1.93	1.78	1.69	1.58	1.48	1.40	-6.2
Factory Revenue ($M)	145,324	155,542	165,599	181,609	200,186	215,737	234,802	8.6
Additional Motherboards/PC System Equivalents								
Units (K)	10,045	10,407	9,823	11,231	13,193	15,288	17,519	11.0
ASP ($K)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0
Factory Revenue ($M)	1,004	1,041	982	1,123	1,319	1,529	1,752	11.0
Handheld								
Units (K)	1,499	2,471	3,008	3,692	4,624	6,053	8,033	26.6
ASP ($K)	391.59	373.94	372.67	364.57	340.18	296.55	287.69	-5.1
Factory Revenue ($M)	587	924	1,121	1,346	1,573	1,795	2,311	20.1
Workstation								
Units (K)	854	991	1,390	2,021	2,718	3,180	3,754	30.5
ASP ($K)	14.39	12.38	10.43	8.87	7.71	7.11	6.58	-11.9
Factory Revenue ($M)	12,291	12,268	14,495	17,928	20,950	22,595	24,683	15.0
Grand Total								
Units (K)	82,267	94,458	107,366	124,603	147,059	170,705	196,989	15.8
ASP ($K)	1.94	1.80	1.70	1.62	1.52	1.42	1.34	-5.7
Factory Revenue ($M)	159,207	169,775	182,197	202,006	224,029	241,656	263,547	9.2

Note: ASP and factory revenue include standard peripherals and memory upgrades installed by the factory or PC assembler.
Columns may not add to totals shown because of rounding.
Source: Dataquest (August 1998)

Table 3-2
Worldwide Personal Computer Unit Shipments by Microprocessor Clock Speed (Thousands of Units)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
<90 MHz	11,661	667	20	10	0	0	0	-100.0
90-100 MHz	23,566	3,197	112	0	0	0	0	-100.0
120-133 MHz	23,514	23,097	3,116	17	0	0	0	-100.0
150-166 MHz	8,851	29,084	14,507	1,488	0	0	0	-100.0
180-200 MHz	2,278	18,102	30,282	10,740	1,375	60	0	-100.0
233-266 MHz	0	5,901	32,536	57,928	50,668	27,425	8,265	7.0
300/+ MHz	0	541	12,571	37,474	74,482	118,699	159,420	211.8
Total	**69,870**	**80,589**	**93,145**	**107,657**	**126,525**	**146,185**	**167,685**	**15.8**

Notes: Excludes additional motherboards and handhelds; Includes only branded PCs, no additional motherboards, no handhelds.
Source: Dataquest (August 1998)

Table 3-3
Worldwide Deskbound Personal Computer Shipments by Microprocessor Clock Speed (Thousands of Units)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
<90 MHz	9,482	446	16	10	0	0	0	-100.0
90-100 MHz	17,978	2,176	55	0	0	0	0	-100.0
120-133 MHz	19,807	15,429	1,354	0	0	0	0	-100.0
150-166 MHz	8,518	24,250	8,303	391	0	0	0	-100.0
180-200 MHz	2,277	17,716	24,507	5,500	158	0	0	-100.0
233-266 MHz	0	5,726	28,884	46,885	37,556	16,370	1,386	-24.7
300/+ MHz	0	541	12,441	33,606	63,773	101,230	133,374	200.9
Total	**58,062**	**66,284**	**75,560**	**86,392**	**101,487**	**117,600**	**134,760**	**15.2**

Notes: Excludes additional motherboards and handhelds; Includes only branded PCs, no additional motherboards, no handhelds.
Columns may not add to totals shown because of rounding.
Source: Dataquest (August 1998)

Table 3-4
Worldwide Mobile Personal Computer Shipments by Microprocessor Clock Speed (Thousands of Units)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
<90 MHz	2,179	222	4	0	0	0	0	-100.0
90-100 MHz	5,589	1,021	56	0	0	0	0	-100.0
120-133 MHz	3,706	7,668	1,762	17	0	0	0	-100.0
150-166 MHz	333	4,834	6,203	1,096	0	0	0	-100.0
180-200 MHz	1	385	5,775	5,239	1,217	60	0	-100.0
233-266 MHz	0	175	3,653	11,044	13,112	11,055	6,879	108.4
300/+ MHz	0	0	130	3,869	10,710	17,468	26,047	-
Total	**11,808**	**14,305**	**17,583**	**21,265**	**25,039**	**28,583**	**32,926**	**18.1**

Notes: Excludes additional motherboards and handhelds; Includes only branded PCs, no additional motherboards, no handhelds.
Source: Dataquest (August 1998)

Table 3-5
Worldwide Personal Computer Revenue by Microprocessor Clock Speed (Millions of Dollars)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
<90 MHz	18,655	943	24	10	0	0	0	-100.0
90-100 MHz	43,707	4,744	167	0	0	0	0	-100.0
120-133 MHz	53,809	41,644	5,057	19	0	0	0	-100.0
150-166 MHz	22,537	55,983	23,175	2,072	0	0	0	-100.0
180-200 MHz	6,613	37,665	48,992	14,487	1,663	75	0	-100.0
233-266 MHz	0	13,144	56,816	83,109	62,298	30,195	10,121	-5.1
300/+ MHz	0	1,419	31,366	81,913	136,225	185,467	224,680	175.4
Total	**145,321**	**155,542**	**165,597**	**181,610**	**200,186**	**215,737**	**234,801**	**8.6**

Notes: Excludes additional motherboards and handhelds. Includes only branded PCs, no additional motherboards, no handhelds. Factory revenue include standard peripherals and memory installed by the OEM.
Source: Dataquest (August 1998)

Table 3-6
Worldwide Deskbound Personal Computer Revenue by Microprocessor Clock Speed (Millions of Dollars)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
<90 MHz	13,523	614	15	10	0	0	0	-100.0
90-100 MHz	29,906	2,827	61	0	0	0	0	-100.0
120-133 MHz	40,322	22,371	1,554	0	0	0	0	-100.0
150-166 MHz	21,229	40,460	9,872	374	0	0	0	-100.0
180-200 MHz	6,608	36,305	35,175	5,912	138	0	0	-100.0
233-266 MHz	0	12,407	46,913	60,599	40,521	14,609	1,199	-37.3
300/+ MHz	0	1,419	30,839	69,575	108,686	146,156	173,111	161.4
Total	**111,588**	**116,403**	**124,429**	**136,470**	**149,345**	**160,765**	**174,310**	**8.4**

Notes: Excludes additional motherboards and handhelds. Includes only branded PCs, no additional motherboards, no handhelds.
Source: Dataquest (August 1998)

Table 3-7
Worldwide Mobile Personal Computer Revenue by Microprocessor Clock Speed (Millions of Dollars)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
<90 MHz	5,132	329	9	0	0	0	0	-100.0
90-100 MHz	13,801	1,917	106	0	0	0	0	-100.0
120-133 MHz	13,487	19,273	3,503	19	0	0	0	-100.0
150-166 MHz	1,308	15,523	13,303	1,698	0	0	0	-100.0
180-200 MHz	5	1,360	13,817	8,575	1,525	75	0	-100.0
233-266 MHz	0	737	9,903	22,510	21,777	15,586	8,922	64.7
300/+ MHz	0	0	527	12,338	27,539	39,311	51,569	-
Total	**33,733**	**39,139**	**41,168**	**45,140**	**50,841**	**54,972**	**60,491**	**9.1**

Notes: Excludes additional motherboards and handhelds. Includes only branded PCs, no additional motherboards, no handhelds.
Source: Dataquest (August 1998)

Table 3-8
Worldwide Personal Computer Shipments by Target Buyer (Thousands of Units)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Private	17,401	19,851	22,767	26,854	31,265	36,587	42,492	16.4
Professional	52,468	60,738	70,378	80,804	95,259	109,597	125,192	15.6

Notes: Excludes additional motherboards and handhelds. Includes only branded PCs, no additional motherboards, no handhelds. Factory revenue include standard peripherals and memory installed by the OEM.
Source: Dataquest (August 1998)

Table 3-9
Worldwide Private Personal Computer Shipments by Product Type (Thousands of Units)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Notebooks	1,559	2,065	2,590	3,017	3,578	4,125	4,716	18.0
Ultraportables	122	274	449	622	706	721	760	22.6
Other Mobile	23	7	8	15	16	18	19	22.1
Deskbound	15,697	17,505	19,720	23,200	26,965	31,723	36,997	16.1

Notes: Excludes additional motherboards and handhelds. Includes only branded PCs, no additional motherboards, no handhelds.
Source: Dataquest (August 1998)

Table 3-10
Worldwide Professional Personal Computer Shipments by Product Type (Thousands of Units)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Notebooks	9,372	10,877	12,957	15,464	18,248	21,114	24,621	17.7
Ultraportables	701	1,049	1,534	2,071	2,365	2,456	2,635	20.2
Other Mobile	31	32	46	76	125	151	175	40.5
Deskbound	42,364	48,780	55,841	63,193	74,521	85,876	97,761	14.9

Notes: Excludes additional motherboards and handhelds. Includes only branded PCs, no additional motherboards, no handhelds.
Source: Dataquest (August 1998)

Table 3-11
Worldwide Personal Computer Revenue by Target Buyer (Millions of Dollars)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Notebooks	4,257	5,360	5,872	6,225	6,569	7,508	8,207	8.9
Ultraportables	298	561	688	884	1,024	983	981	11.8
Other Mobile	59	21	37	50	44	46	45	16.5
Deskbound	30,283	31,052	32,528	35,574	38,109	41,475	45,145	7.8

Notes: Excludes additional motherboards and handhelds. Includes only branded PCs, no additional motherboards, no handhelds. Factory revenue include standard peripherals and memory installed by the OEM.
Source: Dataquest (August 1998)

Table 3-12
Worldwide Private Personal Computer Revenue by Product Type (Millions of Dollars)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Notebooks	4,257	5,360	5,872	6,225	6,569	7,508	8,207	8.9
Ultraportables	298	561	688	884	1,024	983	981	11.8
Other Mobile	59	21	37	50	44	46	45	16.5
Deskbound	30,283	31,052	32,528	35,574	38,109	41,475	45,145	7.8

Notes: Excludes additional motherboards and handhelds. Includes only branded PCs, no additional motherboards, no handhelds.
Source: Dataquest (August 1998)

Table 3-13
Worldwide Professional Personal Computer Revenue by Product Type (Millions of Dollars)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Notebooks	27,129	30,605	31,768	34,387	39,038	42,291	47,020	9.0
Ultraportables	1,828	2,409	2,589	3,310	3,786	3,732	3,805	9.6
Other Mobile	163	183	215	283	380	412	432	18.7
Deskbound	81,307	85,351	91,902	100,896	111,236	119,290	129,167	8.6

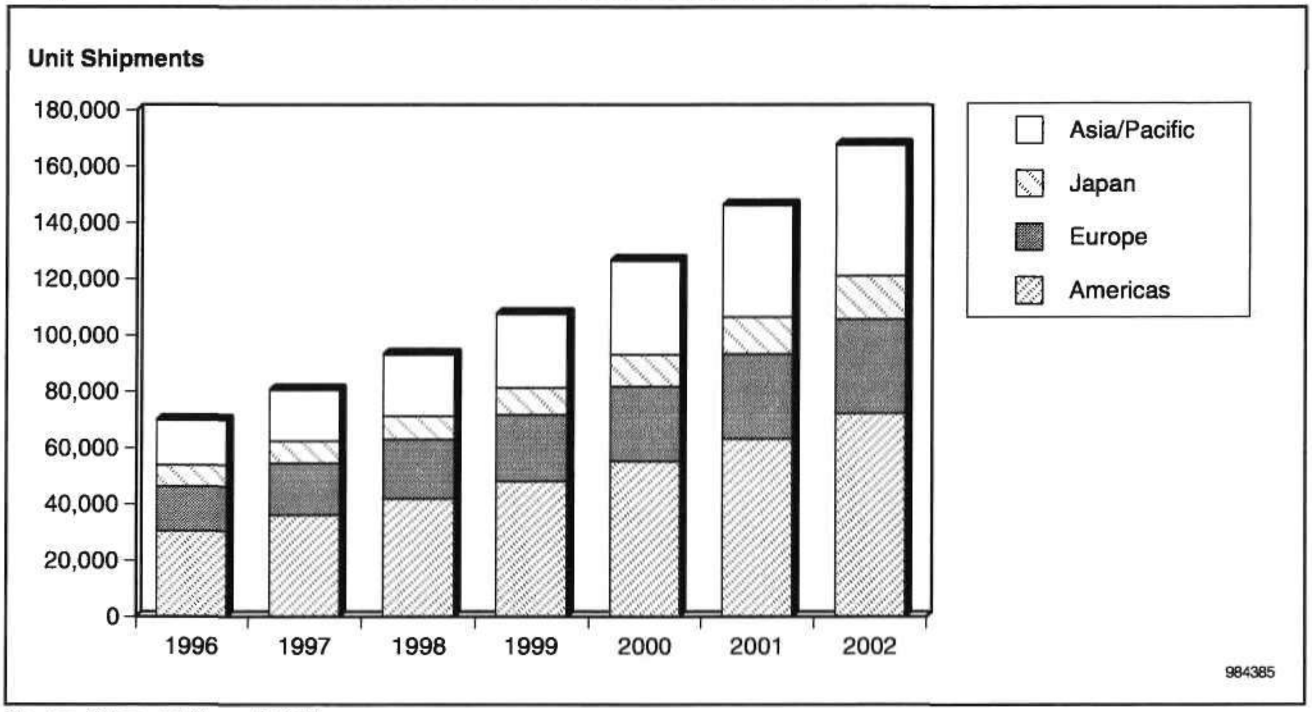
Notes: Excludes additional motherboards and handhelds. Includes only branded PCs, no additional motherboards, no handhelds.
Source: Dataquest (August 1998)

Table 3-14
Regional PC and Motherboard Production (Millions of Dollars)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Americas	46,012	50,913	56,339	62,790	70,228	78,200	79,321	9.3
Europe	24,522	31,064	34,235	37,850	41,415	46,671	52,081	10.9
Japan	20,487	20,324	21,454	22,849	23,680	24,315	25,575	4.7
Asia/Pacific	16,287	15,955	18,413	21,796	25,506	29,006	33,300	15.9
Total	**107,308**	**118,256**	**130,440**	**145,285**	**160,828**	**178,192**	**190,277**	**10.0**
Year-to-Year Growth (%)		10.2	10.3	11.4	10.7	10.8	6.8	-

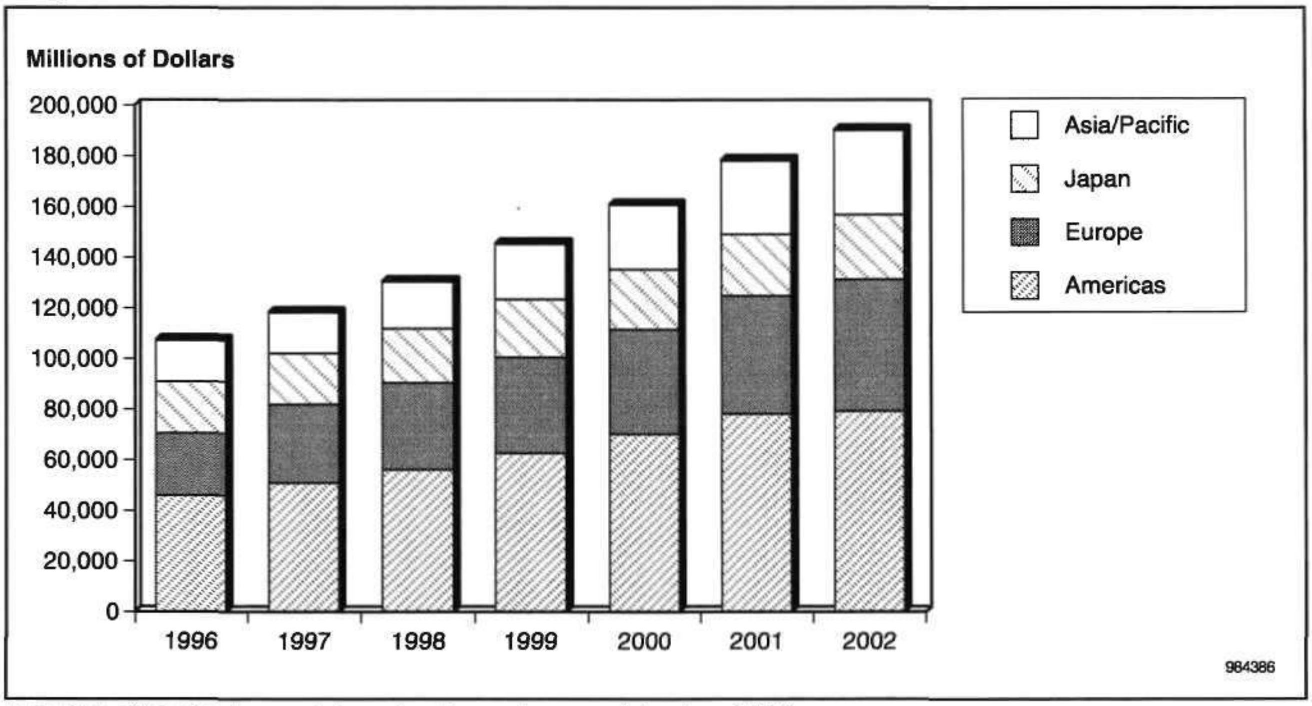
Note: Excludes handhelds
Source: Dataquest (August 1998)

Figure 3-4
Regional Personal Computer Markets (Unit Shipments)



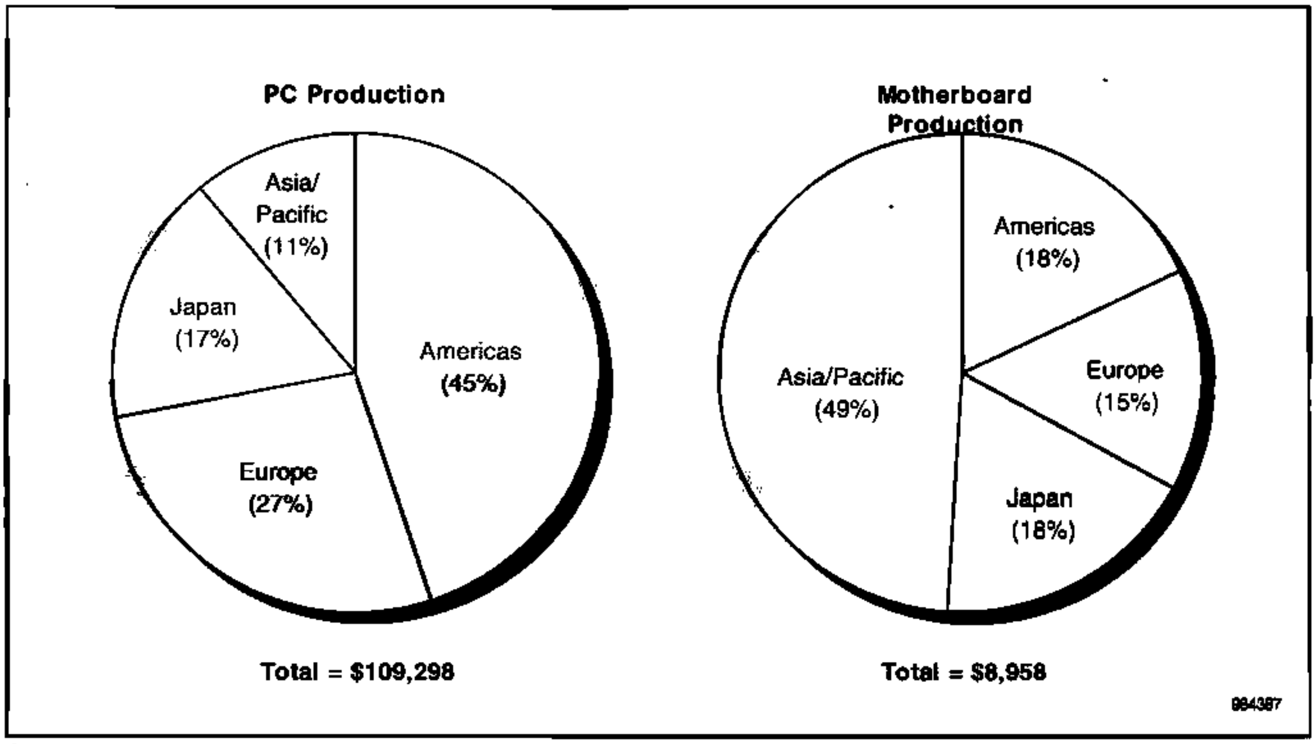
Source: Dataquest (August 1998)

Figure 3-5
Regional PC and Motherboard Production (Millions of Dollars)



Note: Production value here excludes value of mass storage peripherals and CRTs.
Source: Dataquest (August 1998)

Figure 3-6
Regional PC and Motherboard Production for 1997



Source: Dataquest (August 1998)

OEMs

Tables 3-15 and 3-16 list the key OEMs ranked by revenue and unit shipment market share. The trend in personal computer market share is for the strong to get stronger as top-tier vendors continue to gain share at the expense of second- and third-tier players. In 1997, the top five vendors captured 40.4 percent of the revenue and 37.2 percent of the unit shipments. Both numbers are up sharply from 1996 when the top five represented only 34.4 percent of revenue and 31.6 percent of unit shipments. Dataquest forecasts consolidation to continue in the PC market as the biggest vendors sell PCs as part of a total computing solution.

Systems Technology and Architecture Trends

The technology road maps of PCs and workstations are principally driven by the twin factors of economy and improved end-user features. PC makers typically try to give the buyer more features with each new product generation while maintaining price points. The recent popularity of the sub-$1,000 PC has introduced some new price points that historically have not existed in the PC market before, but the strategy of introducing products at "magic" price points continues. Products at a given price point are refreshed with new technology and the price point is maintained because of the added functions or features. Workstation vendors have always differentiated their products on hardware/software integration and high-end applications, but continue to face severe competition from PC workstations at the low end of the market. PC workstations benefit from the economy of scale of the PC industry and the continued development of Windows NT and professional-grade applications for NT. Some specific trends are listed in the following sections.

Table 3-15
Personal Computers Worldwide Revenue Market Share (Percent)

	1996	1997
Compaq Computer Corp.	10.76	12.66
IBM	9.52	10.70
Dell Computer Corp.	4.79	6.41
Hewlett-Packard	4.06	5.64
Toshiba	4.62	5.04
Packard Bell NEC	0	4.82
Acer	2.90	3.66
Apple Computer	4.69	3.60
Gateway 2000	3.26	3.60
Fujitsu	3.35	3.39
Others	52.04	40.48
Total	**100.00**	**100.00**

Notes: Does not include motherboard upgrade revenue.
Columns may not add to totals shown because of rounding.
Source: Dataquest (August 1998)

Table 3-16
Personal Computers Worldwide Unit Market Share (Percent)

	1996	1997
Compaq Computer Corp.	10.04	12.32
IBM	8.59	8.79
Dell Computer Corp.	3.98	5.56
Hewlett-Packard	4.11	5.55
Packard Bell NEC	0	5.01
Toshiba	3.63	3.91
Acer	3.02	3.76
Fujitsu	3.29	3.58
Apple Computer	5.25	3.23
Gateway 2000	2.80	3.23
Others	55.10	45.07
Total	**100.00**	**100 .00**

Notes: Does not include additional motherboards or handheld PCs.
Columns may not add to totals shown because of rounding.
Source: Dataquest (August 1998)

Personal Computers

Trends in PCs are as follows:

- Desktop power demand will come from servicing graphical user interface (GUI) and WYSIWYG-oriented applications including processing (compressing and decompressing) both store-forward-and-read multimedia (OLE-enabled) and real-time multimedia such as desktop videoconferencing. New user interfaces, such as Microsoft's Chrome product, will require more MIPS and better graphics accelerators. Networking support increasingly will require faster servicing as transfer rates climb (for example, toward 100 Mbps over Ethernet) and the size and frequency of transferred files and e-mail increase as well.
- Pentium-class microprocessors continue to thrive in the low end of the computing spectrum, but will fade as clock speeds climb to 300 MHz for entry-level systems. Pentium II-class processors will dominate as Intel pushes Pentium II architecture through its entire line from Celeron at the low end to Pentium II for mainstream PCs and Xeon at the server/ workstation level.
- The Power PC alliance suffered a devastating blow over a year ago when Microsoft announced it would stop supporting Windows NT on the Power PC microprocessors. IBM subsequently announced that it would not participate in further development of PowerPC products for compute applications. IBM will continue developing the PowerPC architecture for embedded applications.
- PCI and ISA combinations are the overwhelming standard for backplane buses. Accelerated graphics port (AGP) is the dominant bus for PCs using a Slot 1 microprocessor interface and should dominate Socket-7 PCs by the end of 1999. ISA will continue to exist for a few years for compatibility with the vast bulk of legacy add-in cards but faces eventual extinction as Microsoft pushes for the elimination of ISA in its yearly certification standards such as PC98 and PC99.
- Plug-and-play PCs, with support from major players such as Microsoft, Intel, Compaq, AMD, and others, will be a significant feature in the drive to make PCs more user-friendly. Universal serial bus (USB) and 1394 will be the standards for external plug-and-play devices, with USB already shipping on virtually every new PC. 1394 is gaining ground but is still two years away from widespread adoption, unless Intel changes its mind and integrates the link layer into a core logic chipset in 1999.
- The "green" PC, as stimulated by the Energy Star program a few years ago and similar requirements coming out of Europe, has been recycled with new emphasis on desktop PC power management. Advanced configuration power interface (ACPI) and Microsoft's OnNow are critical elements of the renewed efforts to make desktop PCs more efficient.
- EIDE will remain the dominant interface to mass storage, with parallel SCSI the choice for connecting external mass storage devices for the next several years. Parallel SCSI will face increasing pressure from serial SCSI standards (predominantly 1394, with fibre channel arbitrated loop making inroads in the workstation market).

- Serial and parallel I/O have remained constant, but technologies such as 1394 and USBs are vying to displace those trusted standbys. Watch for traditional serial and parallel ports to fade gradually over the next five years.
- USB got a much-needed boost from Windows 98, which simplifies many of the software issues that plagued Windows 95. This local bus for the PC will provide a common standard for communicating among PCs, modems, scanners, joysticks, keyboards, mice, monitors, and printers. Peripheral manufacturers are rolling out USB peripherals on a slow and steady basis.
- Desktop management interface (DMI) will enhance the remote monitoring capabilities of networked computers, allowing system administrators to check a variety of operational and environmental parameters over a network.
- Mobile computers will be increasingly enhanced with 32-bit CardBus slots rather than the standard PCMCIA slots, but the average number of slots per mobile PC may decline as modems and network controllers become standard equipment on more notebook designs.
- Other key trends in mobile computing will include commercialized low-power consuming components, standardization of operating voltage for circuits and components at 3V/3.3V, continued increases in sophistication of battery management, improved battery technology, and effective handwriting/voice recognition.

Table 3-17 highlights projected trends in PC technology. Figure 3-7 shows areas that offer opportunities for enhancement.

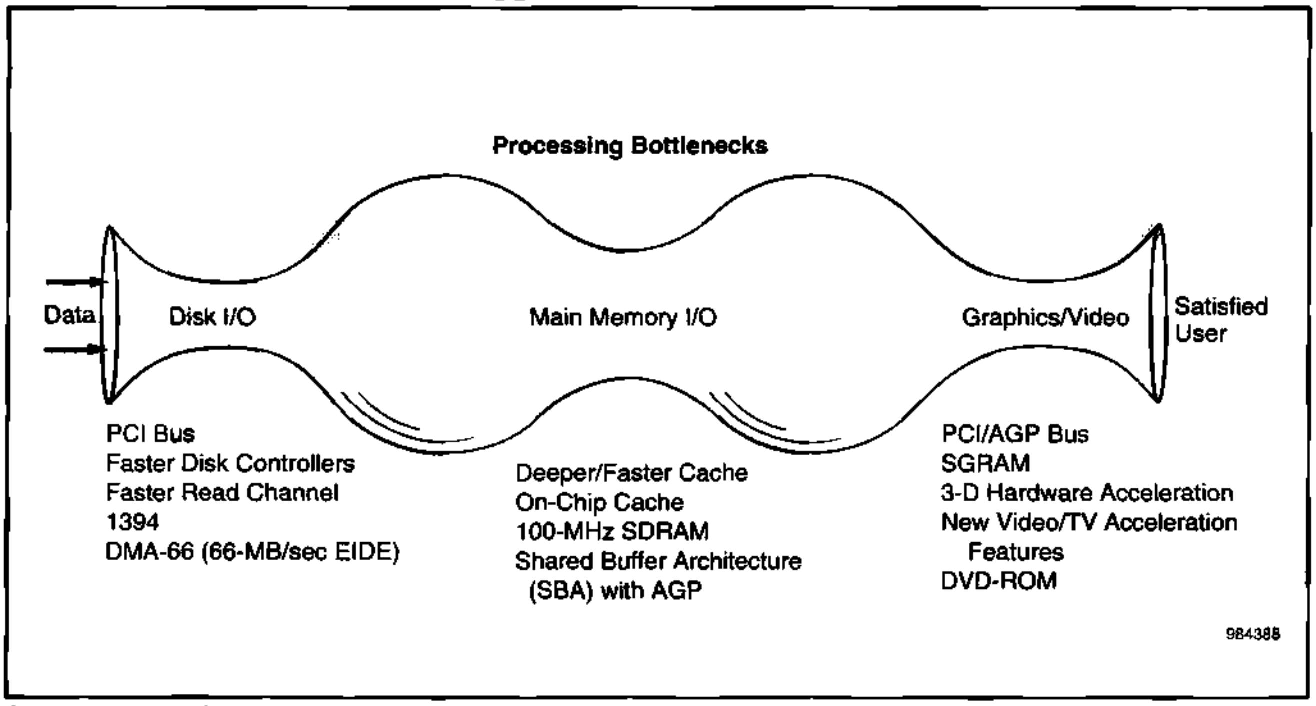
Tables 3-18 through 3-21 provide forecasts for key PC and workstation technologies.

Table 3-17
The Evolving PC

	1996	1998	2000	2002	Trend
Main Memory (Factory Installed)	14MB to 16MB EDO DRAM	32MB to 64MB SDRAM	96MB to 128MB ADRAM*	192MB ADRAM*	Toward synchronous types of DRAM
CPU	Pentium 100 MHz to 133 MHz	200-MHz Pentium with MMX; 266-MHz Pentium II	600-MHz Pentium II	1-GHz Pentium II	Rapid adoption of MMX; shift from Pentium to Pentium II
Cache (KB) (Factory Configured)	0/256	512	512/1,024	1,024	Secondary cache included in Pentium II module
Peripheral Buses	PCI/ISA	PCI/AGP/ISA	PCI/AGP	PCI/AGP	Rise of AGP for graphics; ISA will fade by 2000
Graphics and Video	64-bit, 2-D, and Video Accel, 2MB buffer	64-bit, 2-D, 3-D, and Video Accel, 4MB buffer	128-bit, 2-D, 3-D, and Video Accel, 6MB buffer	128-bit, 2-D, 3-D, and Video Accel, 8MB buffer	Rapid growth of 3-D as graphics vendors strive to continue to add value
Storage	EIDE (13 MB/sec)/ SCSI-2	EIDE (33 MB/sec)/ SCSI-2/3/1394	EIDE (66 MB/sec)/ SCSI-2/3/1394	EIDE (66 MB/sec)/ 1394	EIDE likely to remain in-box interface; rise of 1394
Local I/O	RS-232/422, beginning of shift to USB	USB, RS-232/422	USB/1394	USB/1394	USB will become primary interface; RS-232/422 will fade by 2000

*And corresponding core logic
Source: Dataquest (August 1998)

Figure 3-7
PC Performance Enhancement Opportunities



Source: Dataquest (August 1998)

Table 3-18
Worldwide PC Bus Requirements (Percentage of Total or Category)

	1996	1997	1998	1999	2000	2001	2002
VL/ISA	15.6	0.6	0	0	0	0	0
PCI/ISA	81.4	88.1	49.7	5.0	0	0	0
PCI/AGP/ISA	0	10	50	95	100	100	100
Others	3.0	1.3	0.3	0	0	0	0

Source: Dataquest (August 1998)

Table 3-19
Worldwide PC Storage Interface Requirement, Host (Percentage of Category)

	1994	1995	1996	1997	1998	1999	2000	2001
All PCs								
EIDE/ATA	85	86	88	87	85	65	16	5
SCSI (I/II/III)	15	14	12	12	12	10	9	5
1394/SSA/FC-AL	0	0	0	1	3	25	75	90
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Source: Dataquest (August 1998)

Table 3-20
Worldwide PC Graphics Standard Penetration

	1995	1996	1997	1998	1999	2000	2001	2002
Std. VGA	9.4	0.8	0	0	0	0	0	0
2-D Accel	66.2	28.9	4.1	0	0	0	0	0
2-D Accel with Video Accel	24.3	66.9	73.0	44.9	14.9	1.6	0	0
2-D, 3-D, and Video Accel	0.1	3.4	22.9	55.1	85.1	98.4	100.0	100.0

Note: Motherboard-based or add-in.
Source: Dataquest (August 1998)

Table 3-21
Worldwide Embedded Communications and Multimedia in PCs (Percentage of Total)

	1996	1997	1998	1999	2000	2001	2002
Overall PC							
Analog Modem	1.5	1.6	7.0	10.6	15.4	18.2	20.2
LAN	8.3	16.4	15.5	15.6	19.0	22.8	25.9
USB	0	0	75.0	88.4	97.3	100.0	100.0
Sound I/O	3.2	33.9	50.0	63.6	73.6	74.4	75.3
Graphics	43.8	57.9	58.5	63.0	63.1	63.0	63.0
MPEG Decoder	0	0.6	1.7	2.2	2.0	2.0	2.0
General-Purpose DSP	0.1	0.5	1.0	1.7	2.2	3.0	3.6
Desktop/Deskside PC							
Analog Modem	1.4	1.5	1.7	2.0	2.4	2.7	3.0
LAN	9.8	19.3	18.2	17.4	20.1	22.3	25.0
USB	0	0	90.0	100.0	100.0	100.0	100.0
Sound I/O	1.2	35.0	50.0	60.0	70.0	70.0	70.0
Graphics	34.0	50 .0	50.0	55.0	55.0	55.0	55.0
MPEG Decoder	0	0.5	1.0	2.0	2.0	2.0	2.0
General-Purpose DSP	0.1	0.4	0.8	1.6	2.3	3.2	4.0
Mobile PC (Excluding Handhelds)							
Analog Modem	2.0	2.0	33.0	50.0	75.0	90.0	100.0
LAN	0.8	2.9	4.0	8.4	14.6	25.0	29.8
USB	0	0	2.0	35.0	85.0	100.0	100.0
Sound I/O	15.0	28.3	50.0	80.0	90.0	95.0	100.0
Graphics	100.0	100.0	100.0	100.0	100.0	100.0	100.0
MPEG Decoder	0	1.0	5.0	3.0	2.0	2.0	2.0
General-Purpose DSP	0	1.0	2.0	2.0	2.0	2.0	2.0

Source: Dataquest (August 1998)

Chapter 4

Semiconductor Market Trends for PCs and Workstations

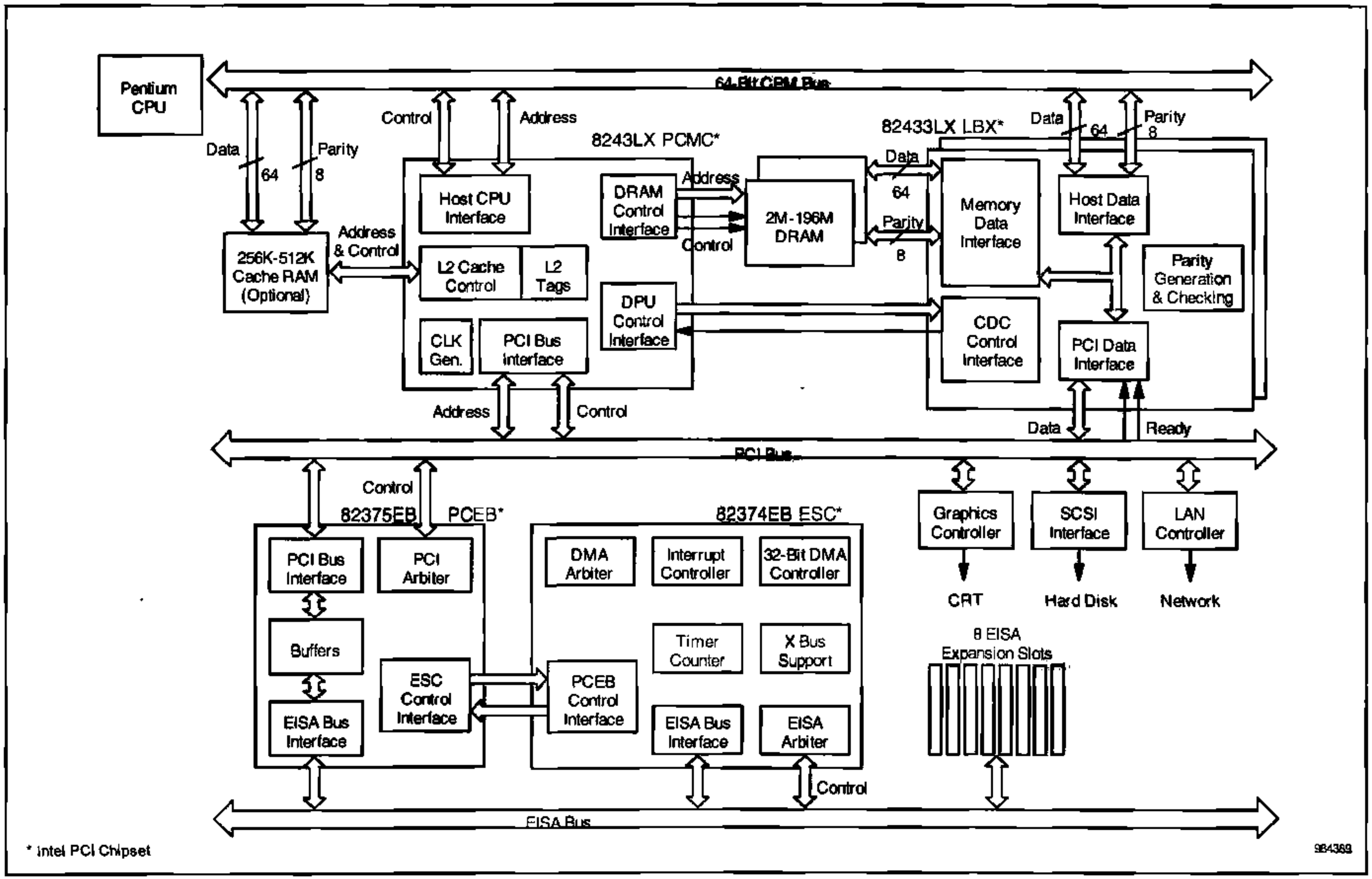
Semiconductor Market Opportunities and Technology Trends

Semiconductor market opportunities and technology trends are as follows:

- New generations of Pentium II, IA-64, SPARC, and MIPS processors will drive future PCs, workstations, and servers. Future trends include internal frequencies climbing past the current 400-MHz offerings for PCs and 600 MHz for workstations. Multiprocessing features will also be available in many workstations and high-end PCs using Pentium II and Xeon microprocessors.
- Processors such as ARM, MIPs, and Hitachi's SH products will continue to be used in palmtop devices and other communications-centric applications.
- PC main memory size will triple from 1996 to 1998, reaching 48MB for the average factory-installed memory size in 1998.
- SDRAM replaced EDO for main memory applications in late 1997. RDRAM will replace SDRAM, starting in 1999 when Intel releases an RDRAM-compatible core logic chipset.
- SGRAM replaced EDO for graphics memory applications early this year. Double data rate (DDR) SGRAM will provide an interim step before RDRAM gets widespread adoption in the graphics subsystem.
- Embedded secondary caches will grow in popularity as Intel's Celeron product line will quickly gain on-chip secondary caches. Leading-edge products from AMD and Cyrix already include on-chip secondary cache to compensate for performance issues with the Socket 7 interface.
- New chipsets to support MPUs and the new buses (USB and the AGP enhancement to PCI) will continue to emerge. Watch for more third-party core logic vendors to add AGP to their Pentium-bus products for use with K6 and 6x86 microprocessors.
- 3-D acceleration should be considered a standard feature for new graphics chips. Competition will be fierce through 1997 and 1998 with emphasis on performance as measured by the Ziff Davis 3-D benchmark, 3-D Winbench 98. TV features and MPEG-2 motion compensation engines are other value-add features for desktop PC graphics controllers. TV features will become increasingly important, while MPEG-2 motion compensation will fade as CPU clock speeds spiral upward from 350 MHz. Integrated memory is the biggest value-added feature for mobile graphics controllers.
- Mixed-signal I/O chips will support high-speed storage and peripherals communications (EIDE, SCSI, 1394).

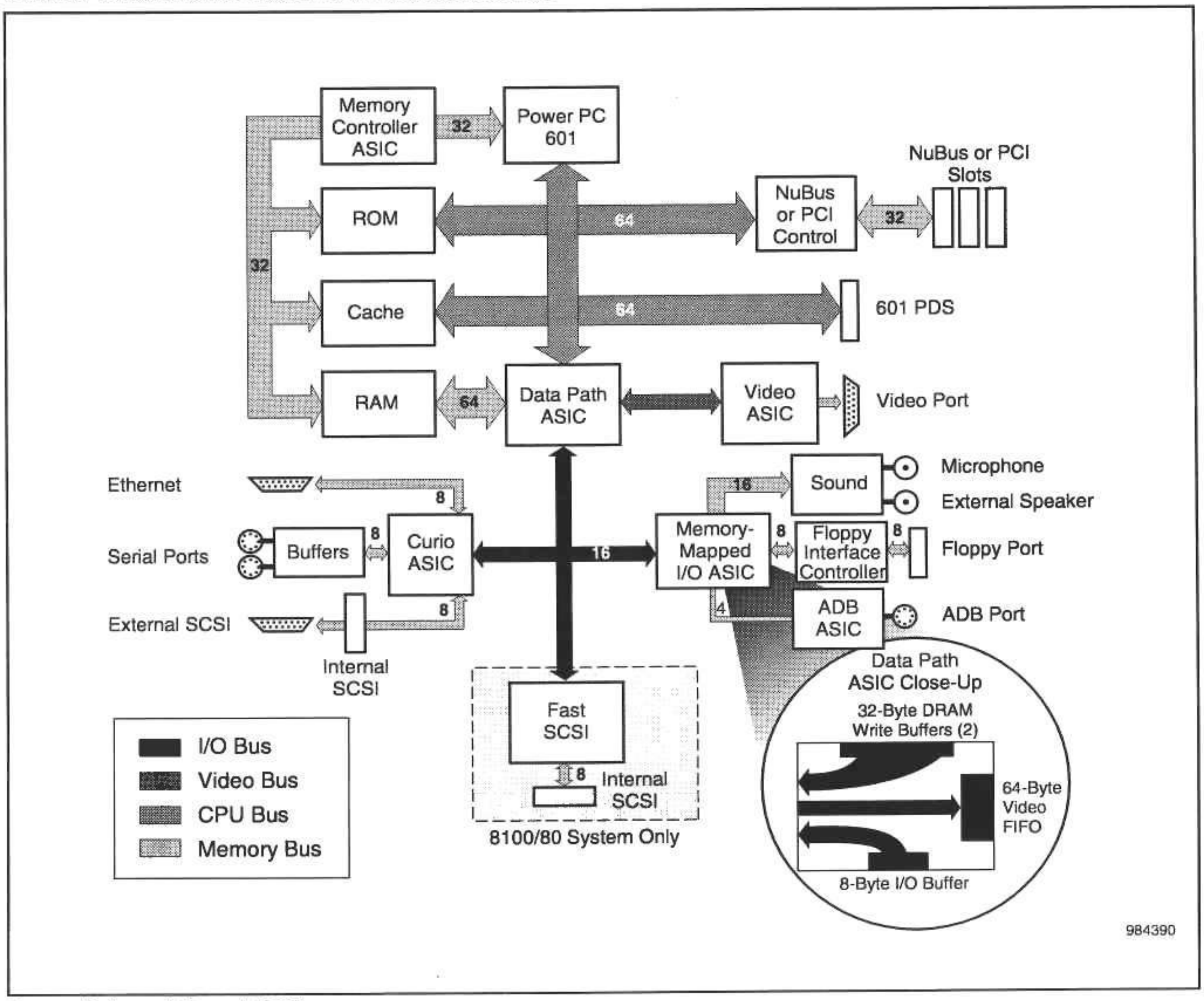
Figures 4-1 through 4-3 provide block diagrams for generic Pentium desktop, Power Macintosh, and generic notebook systems.

Figure 4-1
Generic Pentium-Based Desktop PC Using PCI Bus



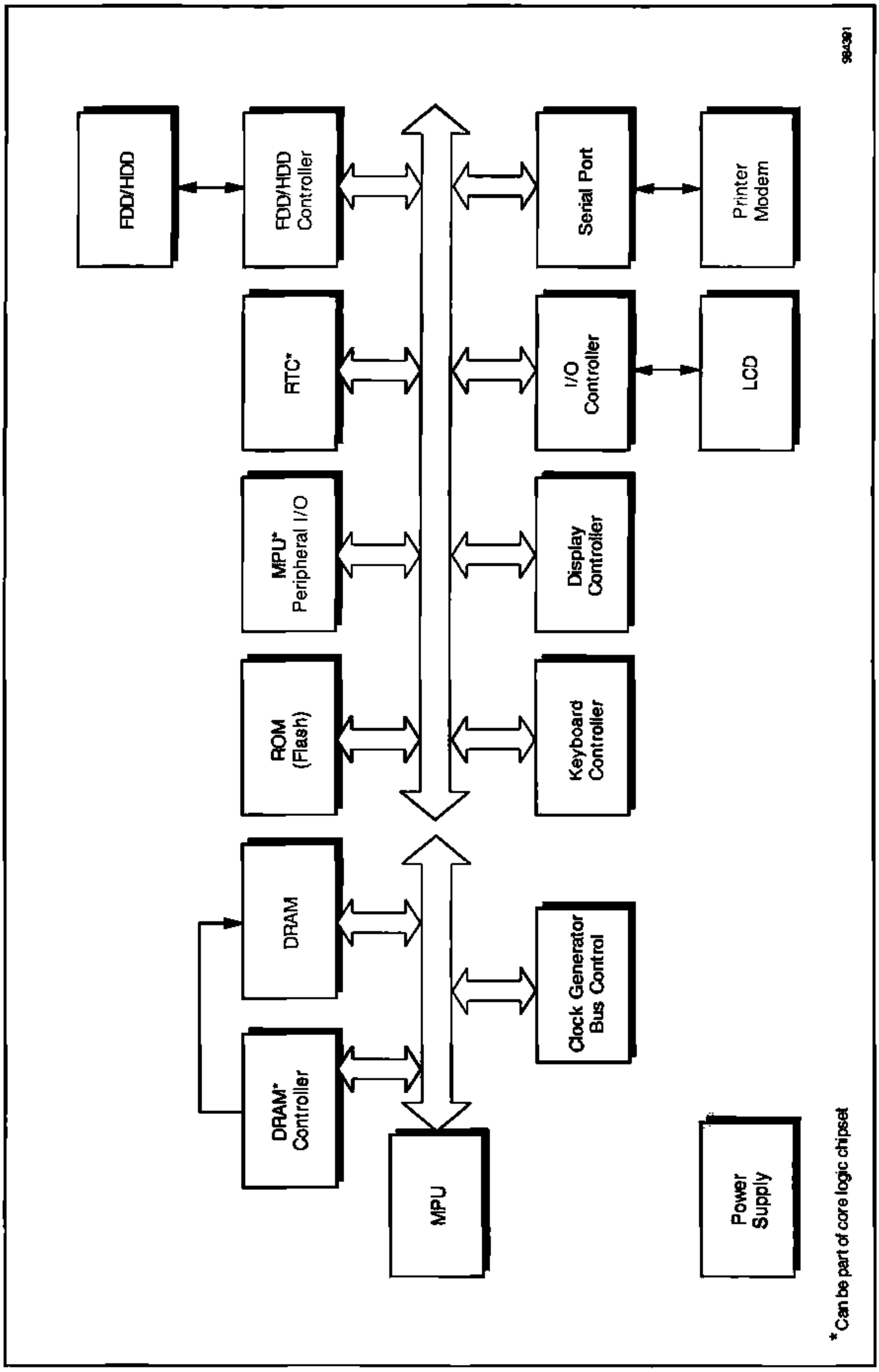
Source: Intel

Figure 4-2
Power Macintosh Hardware Architecture



Source: Dataquest (August 1998)

Figure 4-3
Generic Notebook Block Diagram



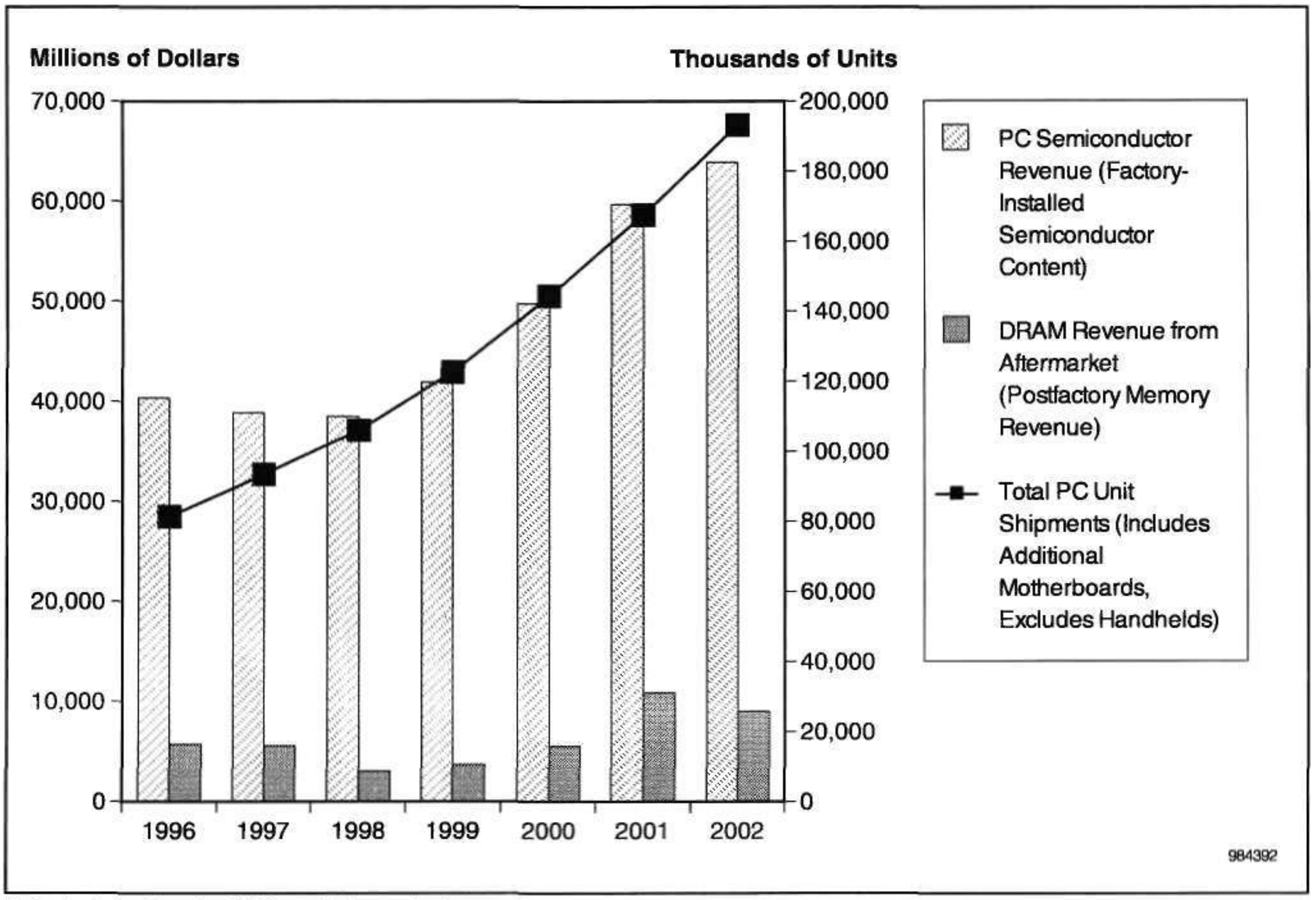
* Can be part of core logic chipset

Source: Dataquest (August 1998)

Chapter 5
Market Size and Forecast for PC and Workstation Semiconductors

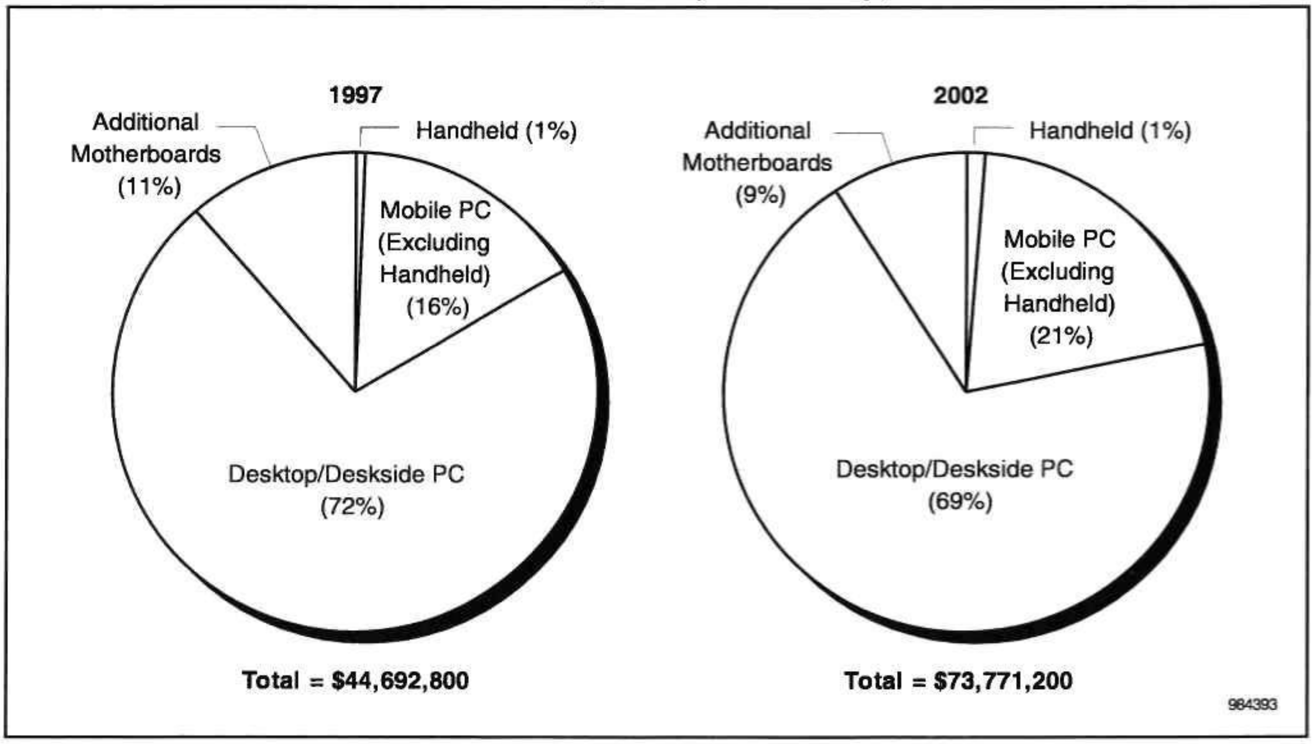
Figures 5-1 and 5-2 and Table 5-1 provide forecasts and illustrations of semiconductor opportunities in the PC and workstation markets, including a focus on opportunities by region, system type, and semiconductor device type.

Figure 5-1
Worldwide PC Semiconductor Market



Note: Includes handheld PCs and aftermarket memory.
Source: Dataquest (August 1998)

Figure 5-2
Worldwide PC Semiconductor Consumption by Product Type (Percent)



Note: Includes aftermarket memory.
Source: Dataquest (August 1998)

Semiconductor Opportunities by System

Figures 5-3 through 5-9 and Table 5-2 detail semiconductor opportunities by system.

Semiconductor Opportunities by Device Type

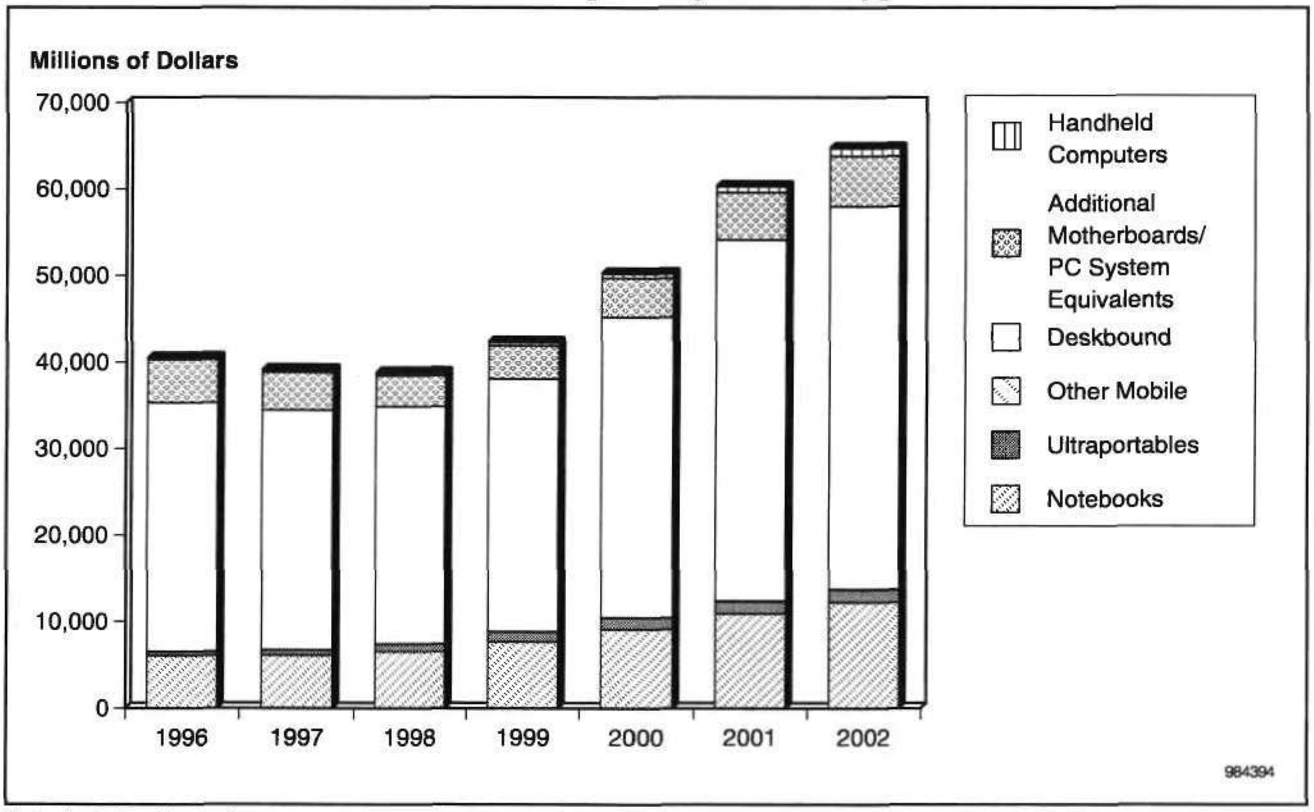
Figures 5-10 through 5-15 and Tables 5-3 through 5-13 detail semiconductor opportunities by device type. Tables 5-14 through 5-15 detail semiconductor opportunities by system. Figure 5-16 shows worldwide microprocessor opportunities by product type. Figure 5-17 details DRAM demand in PCs by device type and Figure 5-18 details a breakdown of main memory configured by OEMs versus aftermarket in PCs by device type.

Table 5-1
Worldwide PC and PC Semiconductor Market

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Complete PC Systems								
Units (K)	69,869	80,589	93,145	107,658	126,524	146,184	167,684	15.8
Factory ASP ($K)	2.08	1.93	1.78	1.69	1.58	1.48	1.40	-6.2
Factory Revenue ($M)	145,324	155,542	165,599	181,609	200,186	215,737	234,802	8.6
Semiconductor Content per System ($)	576	488	404	384	396	438	395	-4.2
Semiconductor TAM ($M)	40,232	39,326	37,597	41,394	50,162	63,977	66,179	11.0
Desktop/Deskside PC Systems								
Units (K)	58,061	66,285	75,561	86,393	101,486	117,599	134,758	15.2
Factory ASP ($K)	1.92	1.76	1.65	1.58	1.47	1.37	1.29	-5.9
Factory Revenue ($M)	111,590	116,403	124,430	136,470	149,345	160,765	174,312	8.4
Semiconductor Content per System ($)	571	486	396	372	383	425	378	-4.9
Semiconductor TAM ($M)	33,159	32,201	29,899	32,113	38,915	49,977	50,997	9.6
Mobile PC Systems								
Units (K)	11,808	14,304	17,584	21,265	25,038	28,585	32,926	18.1
Factory ASP ($K)	2.86	2.74	2.34	2.12	2.03	1.92	1.84	-7.7
Factory Revenue ($M)	33,734	39,139	41,169	45,139	50,841	54,972	60,490	9.1
Semiconductor Content per System ($)	599.0	498.1	437.8	436.5	449.2	489.8	461.1	-1.5
Semiconductor TAM ($M)	7,073	7,125	7,698	9,282	11,247	14,000	15,182	16.3
Additional Motherboards								
Units (K)	10,045	10,407	9,823	11,231	13,193	15,288	17,519	11.0
Factory ASP ($K)	0	0	0	0	0	0	0	0
Factory Revenue ($M)	1,004	1,041	982	1,123	1,319	1,529	1,752	11 .0
Semiconductor Content per System ($)	571	486	396	372	383	425	378	-4.9
Semiconductor TAM ($M)	5,736	5,056	3,887	4,175	5,059	6,497	6,630	5.6
Total PC Market								
Units (K)	79,914	90,996	102,968	118,889	139,717	161,472	185,203	15.3
Factory ASP ($K)	1.83	1.72	1.62	1.54	1.44	1.35	1.28	-5.8
Factory Revenue ($M)	146,328	156,583	166,581	182,732	201,505	217,266	236,554	8.6
Semiconductor Content per System ($)	576	488	403	384	396	437	394	-4.2
Semiconductor TAM ($M)	46,047	44,441	41,518	45,608	55,279	70,567	72,893	10.4
Workstation Market								
Units (K)	854	991	1,390	2,021	2,718	3,180	3,754	30.5
Factory ASP ($K)	14	12	10	9	8	7	7	-11.9
Factory Revenue ($M)	12,291	12,268	14,495	17,928	20,950	22,595	24,683	15.0
Semiconductor Content per System ($)	2,183	1,359	831	725	717	782	675	-13.1
Semiconductor TAM ($M)	1,865	1,347	1,155	1,465	1,948	2,487	2,533	13.5

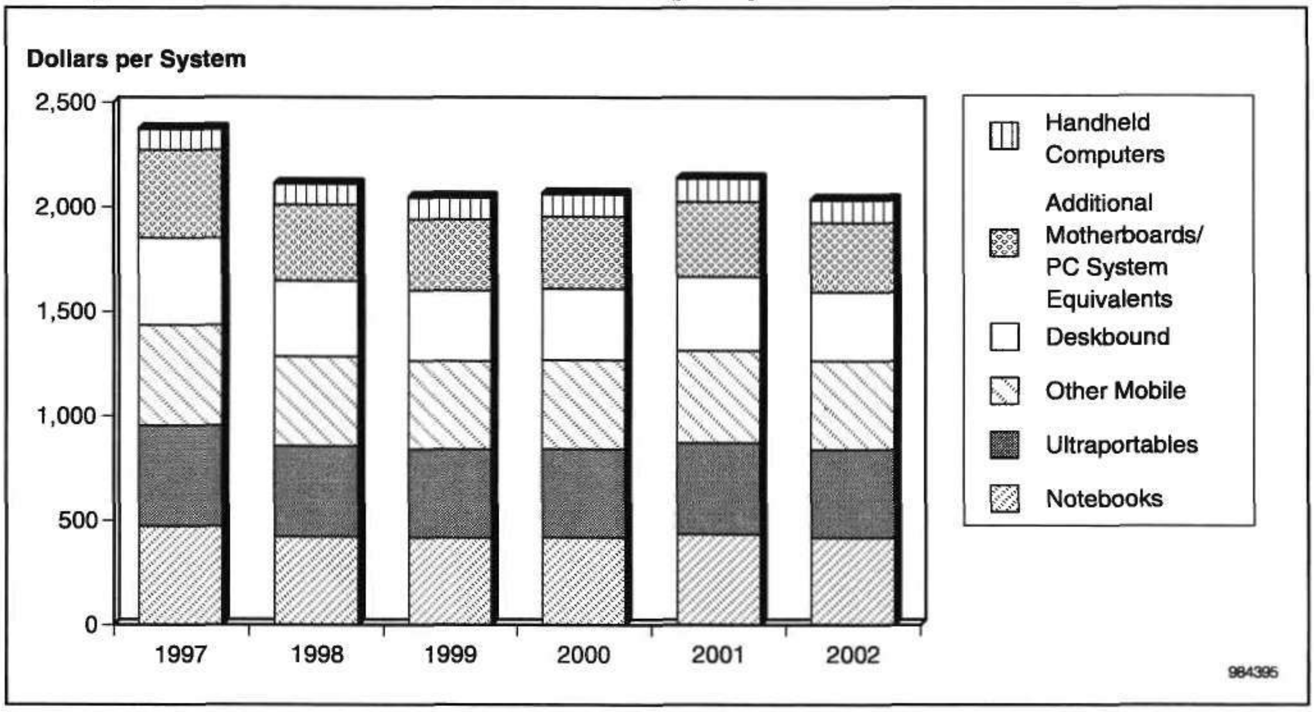
Note: Includes handheld PCs.
Source: Dataquest (August 1998)

Figure 5-3
Worldwide PC Semiconductor Consumption by Product Type (Millions of Dollars)



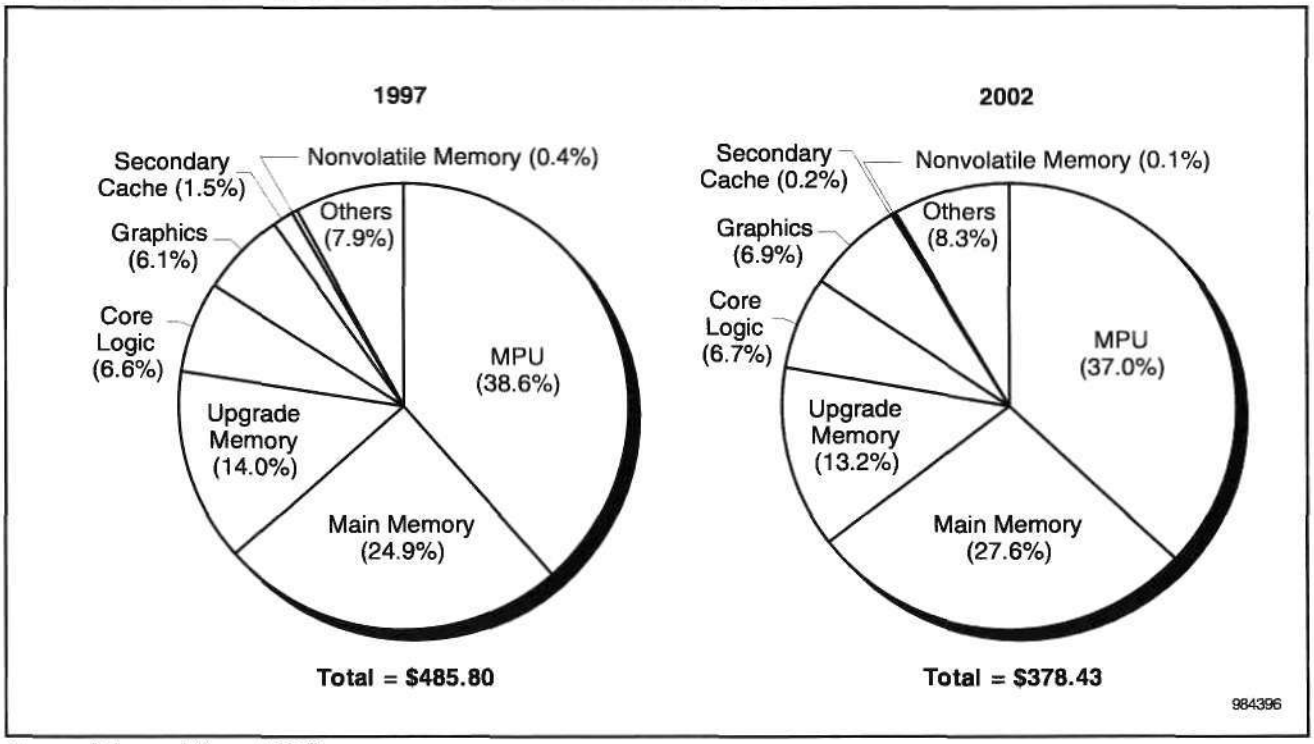
Note: Includes aftermarket memory.
Source: Dataquest (August 1998)

Figure 5-4
Average PC Semiconductor Content (Dollars per System)



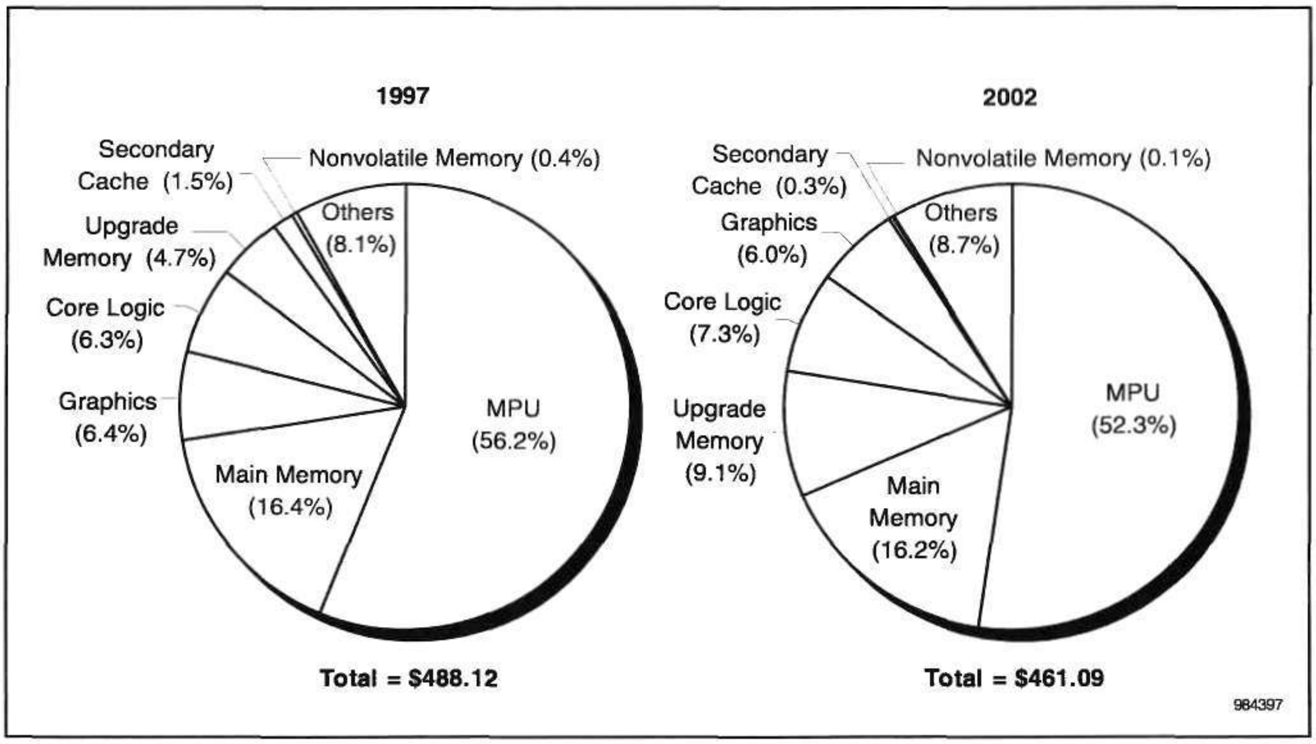
Note: Includes aftermarket memory.
Source: Dataquest (August 1998)

Figure 5-5
Overall Deskbound PC Semiconductor Content Trend



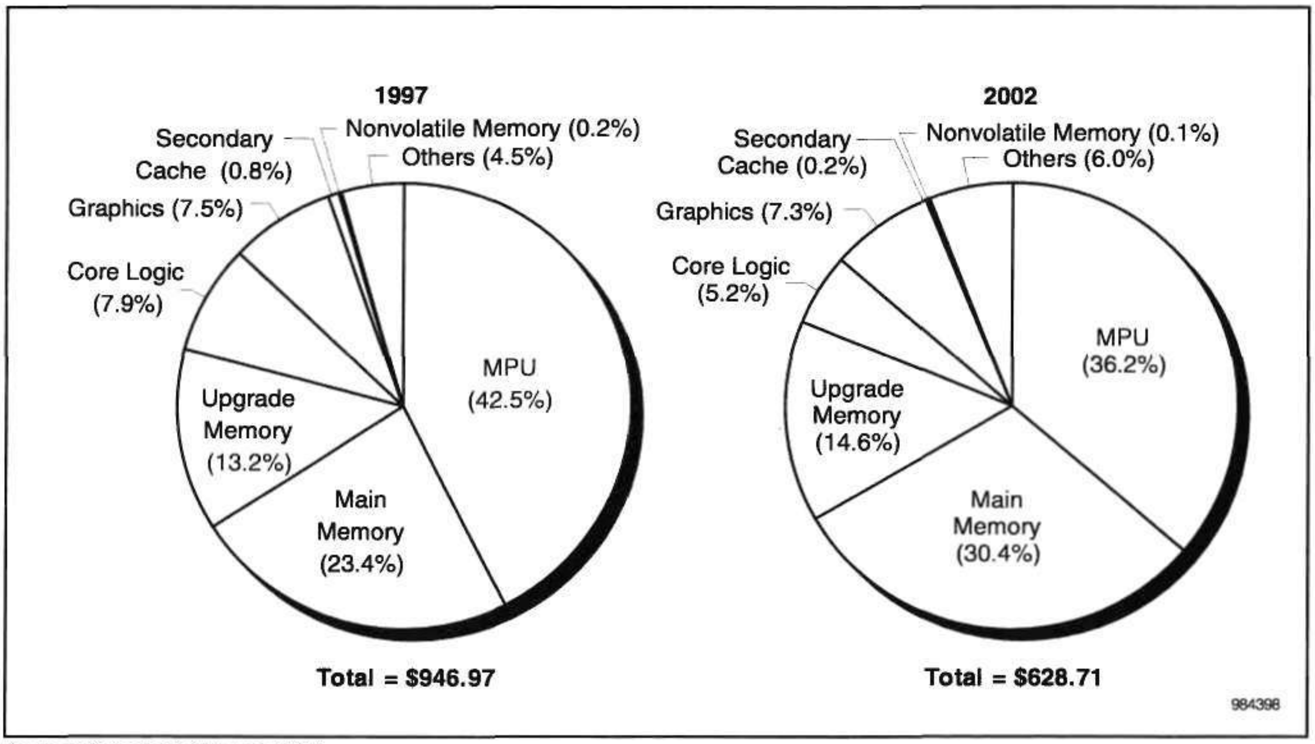
Source: Dataquest (August 1998)

Figure 5-6
Overall Mobile PC Semiconductor Content Trend



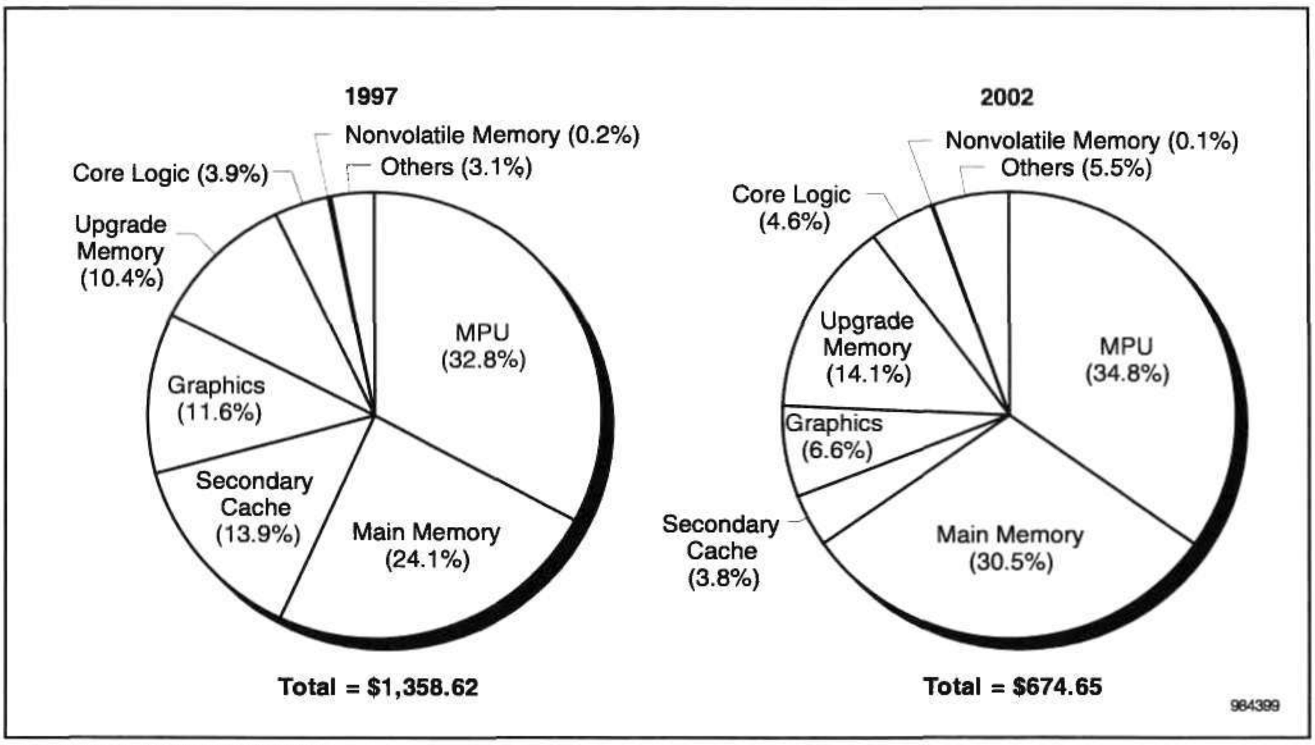
Note: Excludes handhelds.
Source: Dataquest (August 1998)

Figure 5-7
Overall PC Workstation Semiconductor Content Trend



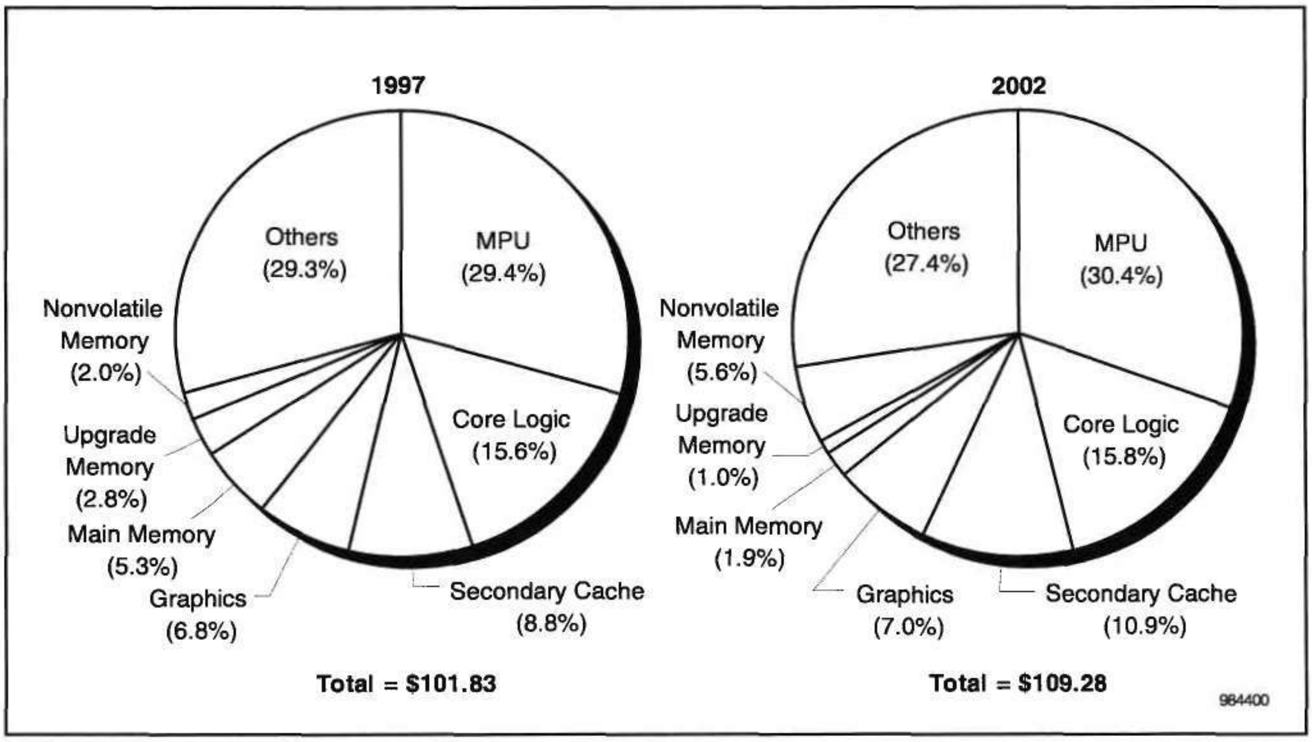
Source: Dataquest (August 1998)

Figure 5-8
Overall Workstation Semiconductor Content Trend



Source: Dataquest (August 1998)

Figure 5-9
Overall Handheld PC Semiconductor Content Trend



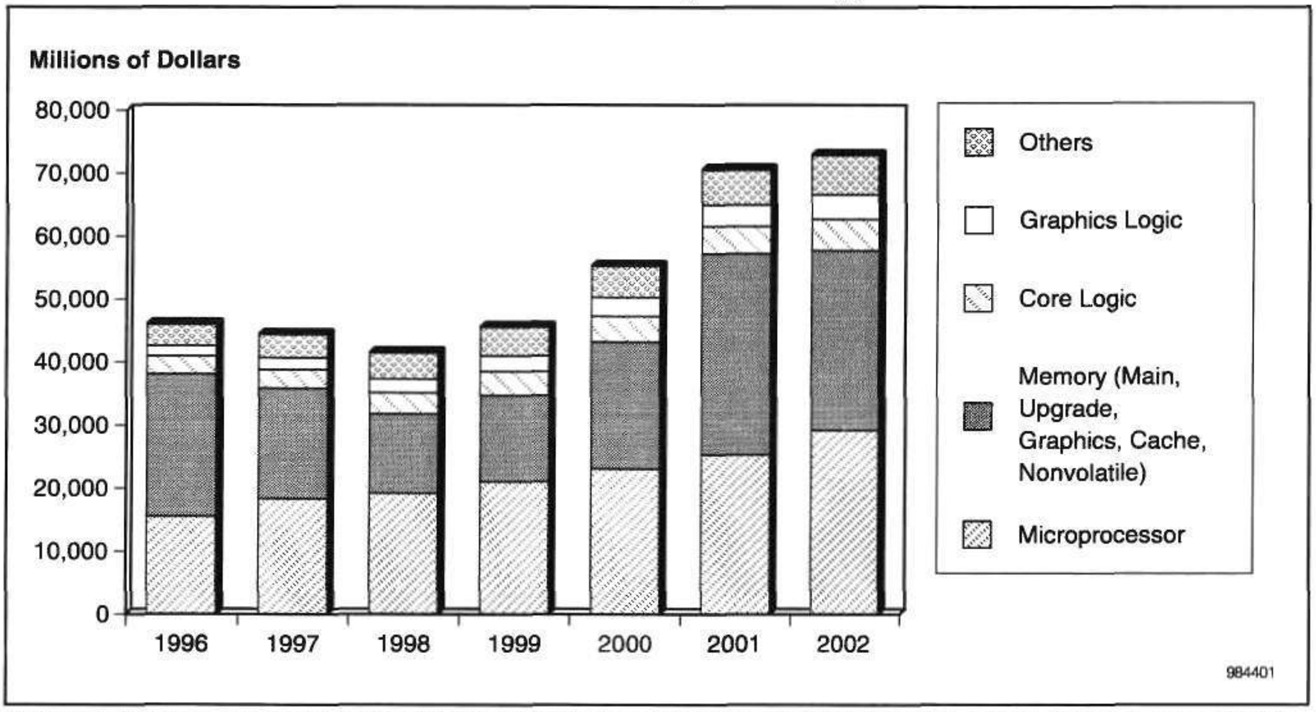
Source: Dataquest (August 1998)

Table 5-2
Worldwide PC and Workstation Semiconductor Market by System

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Notebooks	6,547	6,438	6,790	8,052	9,793	12,350	13,515	16.0
Ultraportables	494	668	884	1,190	1,390	1,566	1,577	18.8
Other Mobile	32	20	24	40	64	84	90	35.8
Deskbound	33,159	32,201	29,899	32,113	38,915	49,977	50,997	9.6
Additional Motherboards	5,815	5,115	3,922	4,213	5,116	6,591	6,715	5.6
Workstation	1,865	1,347	1,155	1,465	1,948	2,487	2,533	13.5
Handhelds	157	252	300	385	496	672	878	28.4
Total	**48,069**	**46,039**	**42,973**	**47,458**	**57,722**	**73,726**	**76,304**	**10.6**
Year-to-Year Growth (%)		-4.2	-6.7	10.4	21.6	27.7	3.5	-

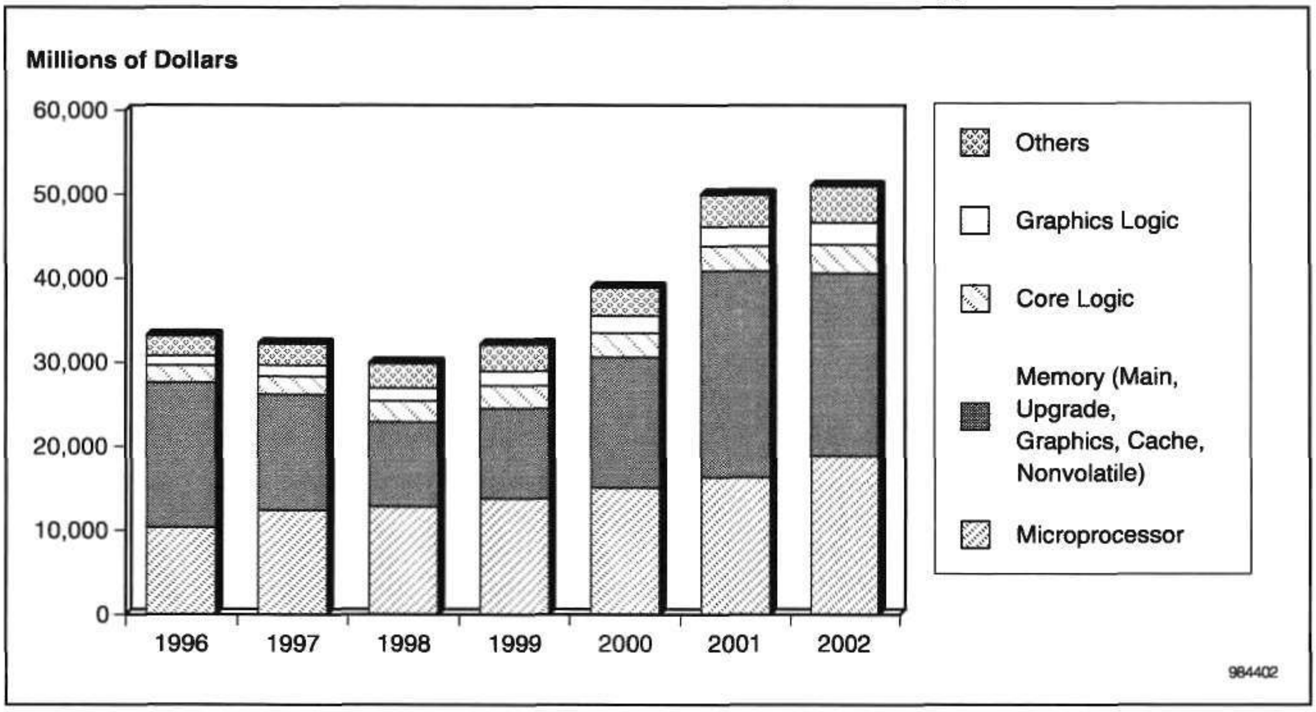
Source: Dataquest (August 1998)

Figure 5-10
Worldwide Total PC Semiconductor Market by Device Type (Millions of Dollars)



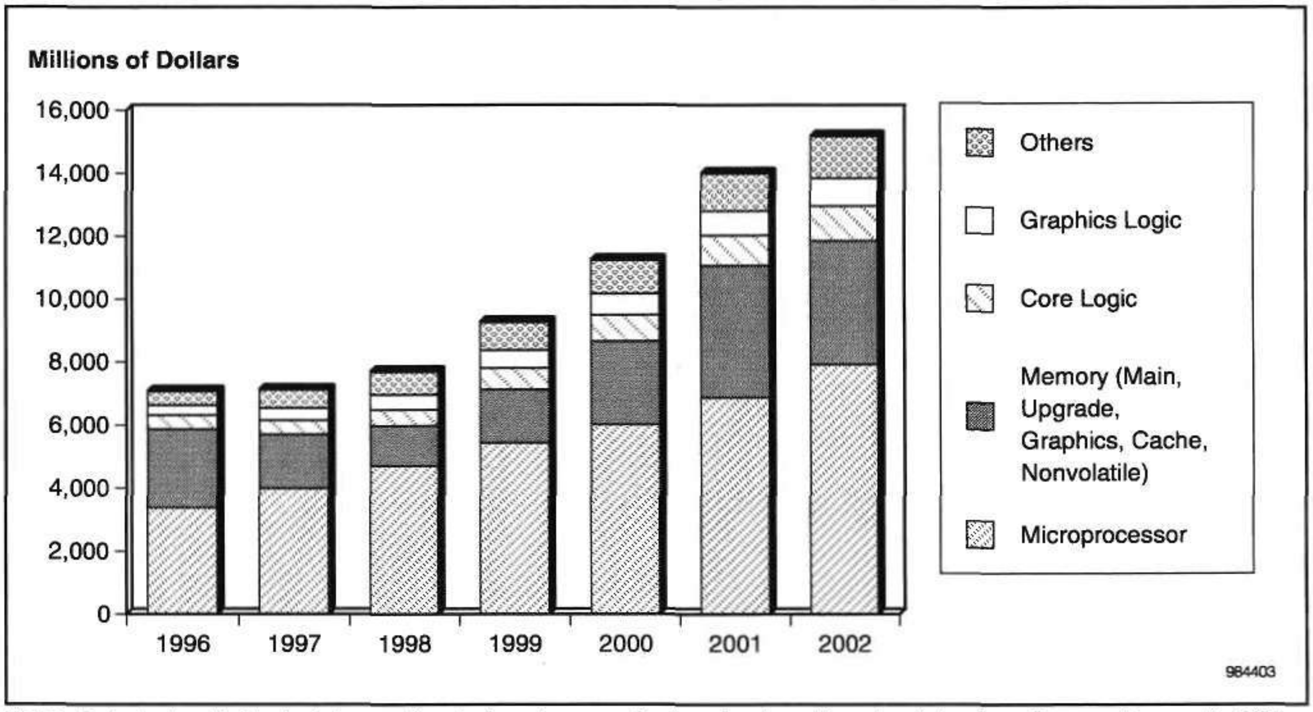
Notes: Includes semiconductor value on motherboard and card-based peripherals such as graphics, audio, LAN, WAN, etc.; excludes semiconductor value on mass storage peripherals.
Source: Dataquest (August 1998)

Figure 5-11
Worldwide Deskbound PC Semiconductor Market by Device Type (Millions of Dollars)



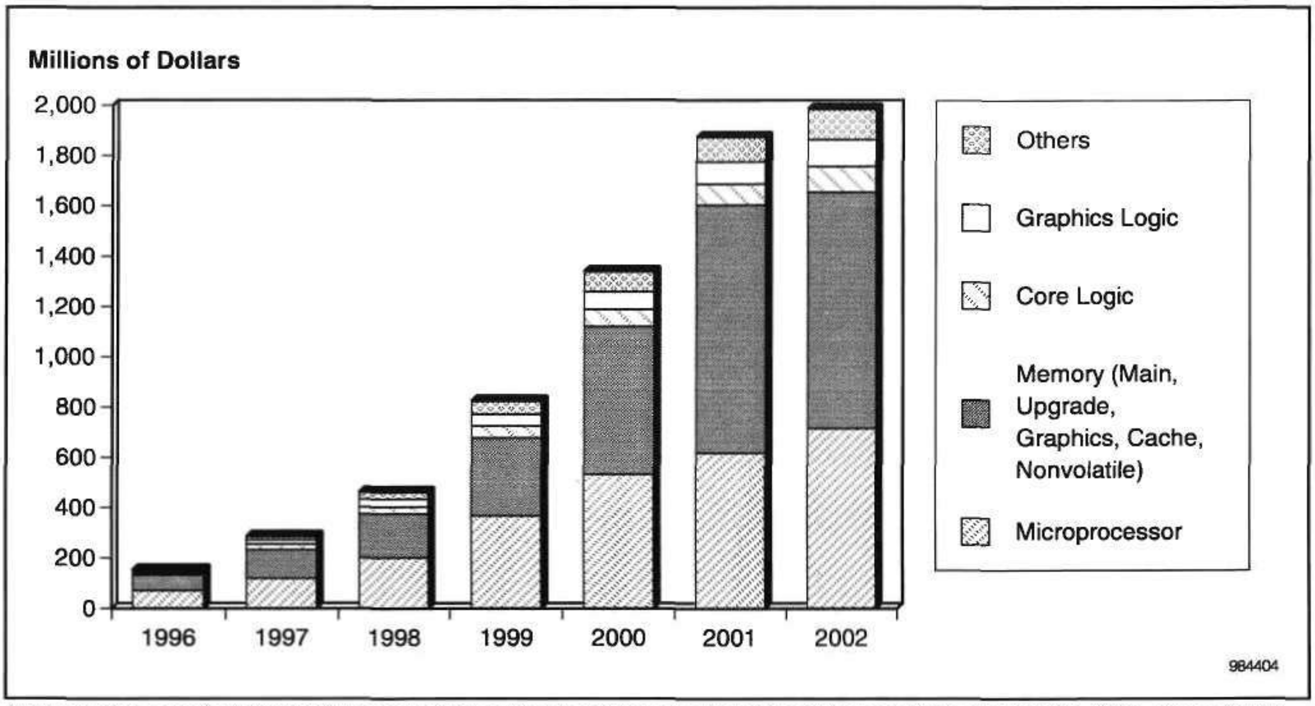
Notes: Includes semiconductor value on motherboard and card-based peripherals such as graphics, audio, LAN, WAN, etc.; excludes semiconductor value on mass storage peripherals.
Source: Dataquest (August 1998)

Figure 5-12
Worldwide Mobile PC Semiconductor Market by Device Type (Millions of Dollars)



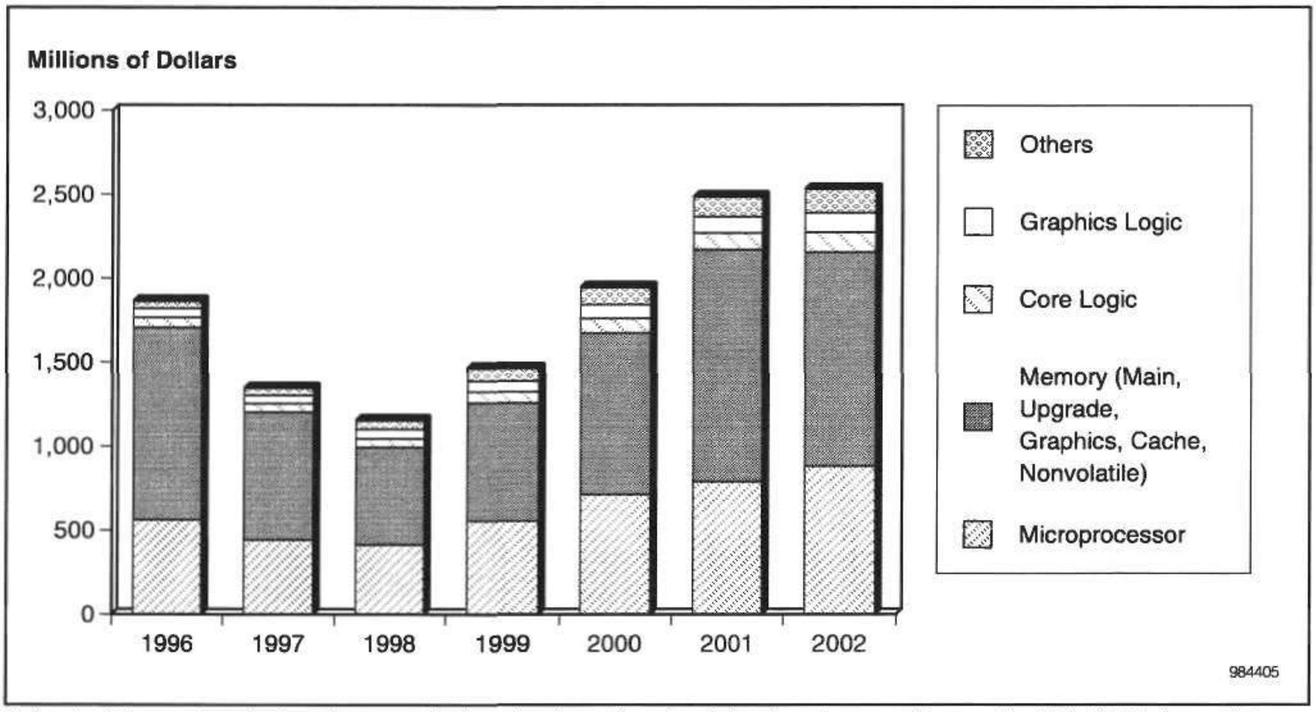
Notes: Excludes handhelds. Includes semiconductor value on motherboard and card-based peripherals such as graphics, audio, LAN, WAN, etc.; excludes semiconductor value on mass storage peripherals.
Source: Dataquest (August 1998)

Figure 5-13
Worldwide PC Workstation Semiconductor Market by Device Type (Millions of Dollars)



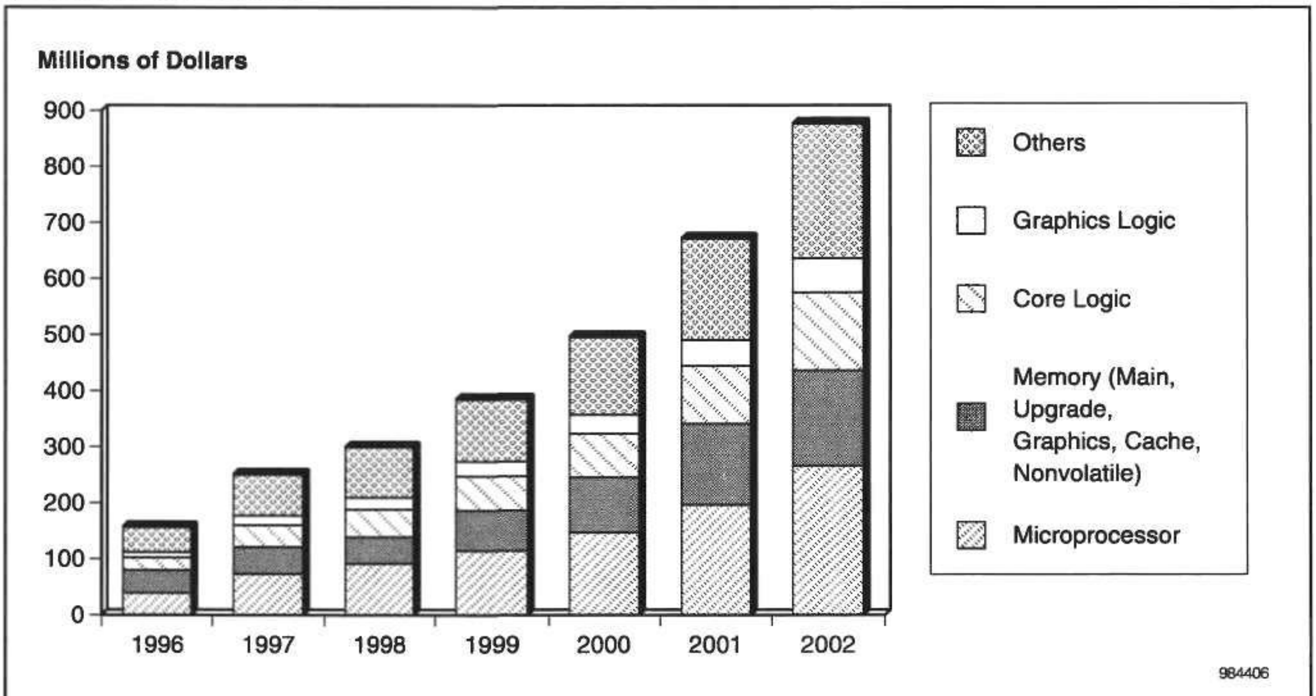
Notes: Includes semiconductor value on motherboard and card-based peripherals such as graphics, audio, LAN, WAN, etc.; excludes semiconductor value on mass storage peripherals.
Source: Dataquest (August 1998)

Figure 5-14
Worldwide Overall Workstation Semiconductor Market by Device Type (Millions of Dollars)



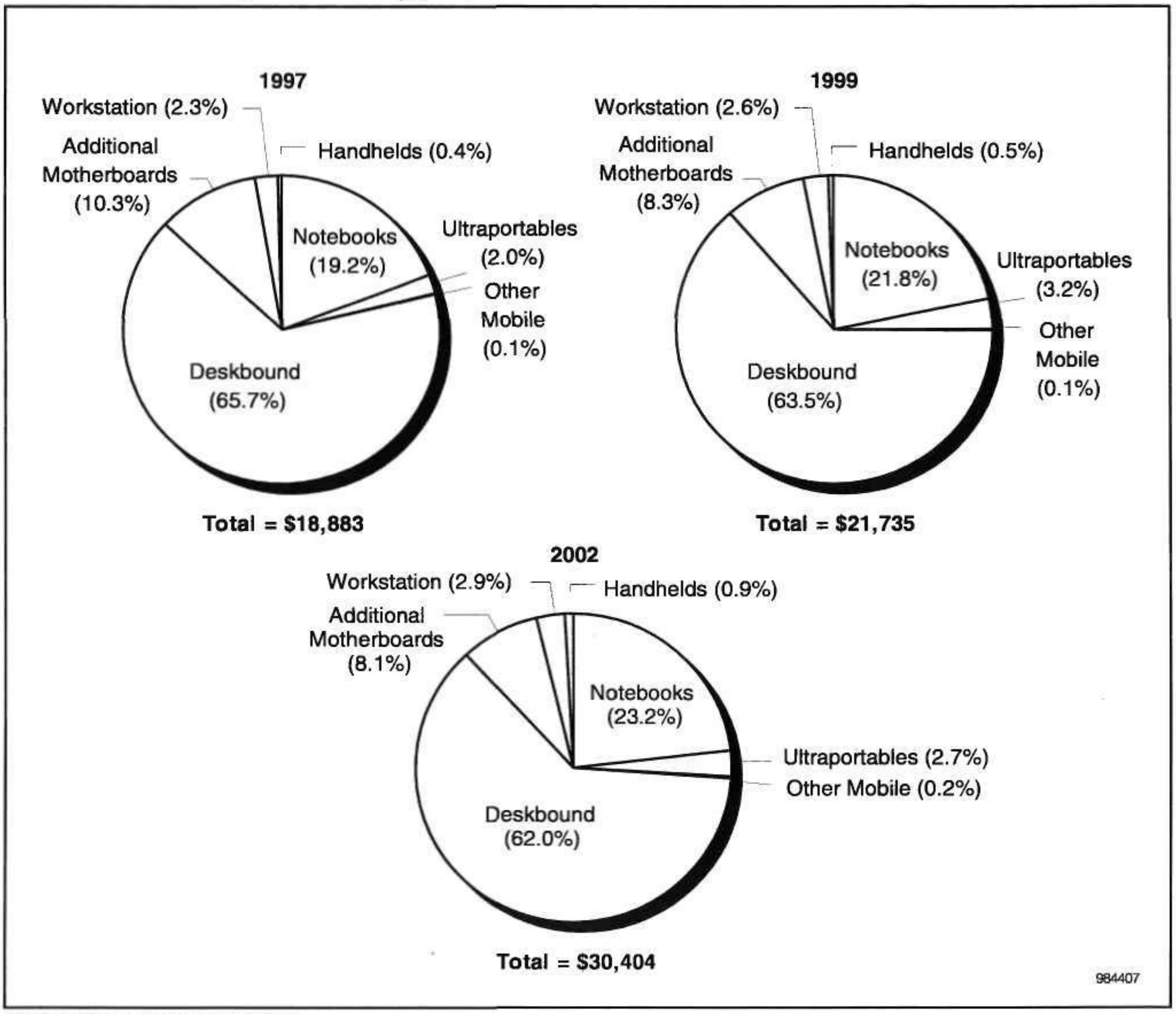
Notes: Includes semiconductor value on motherboard and card-based peripherals such as graphics, audio, LAN, WAN, etc.; excludes semiconductor value on mass storage peripherals.
Source: Dataquest (August 1998)

Figure 5-15
Worldwide Overall Handheld PC Semiconductor Market by Device Type (Millions of Dollars)



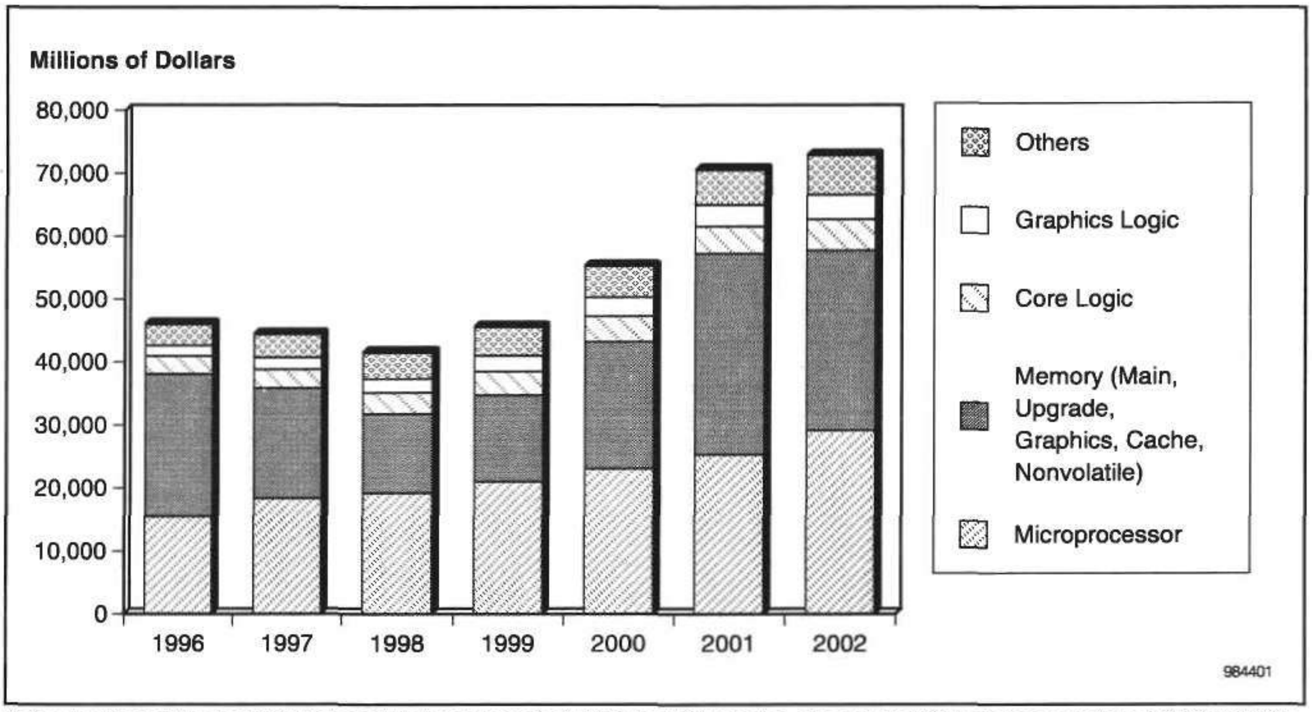
Notes: Includes semiconductor value on motherboard and card-based peripherals such as graphics, audio, LAN, WAN, etc.; excludes semiconductor value on mass storage peripherals.
Source: Dataquest (August 1998)

Figure 5-16
Worldwide Microprocessor Opportunities in PCs



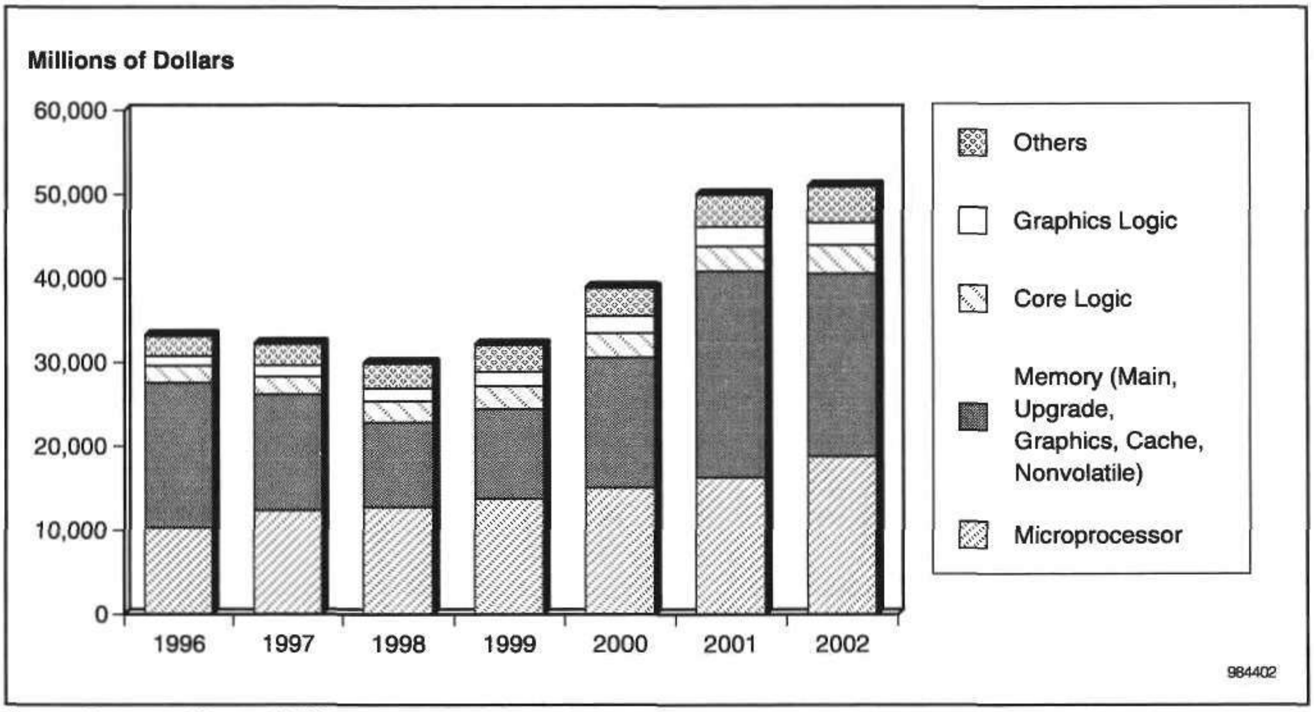
Source: Dataquest (August 1998)

Figure 5-17
Worldwide Aftermarket DRAM Demand in PCs



Notes: Includes all memory upgrades following shipment of PC from OEM to sales channel. Includes memory purchased for installation in PCs after PC system point of sale.
Source: Dataquest (August 1998)

Figure 5-18
Breakdown of Main Memory Configured by OEMs versus Aftermarket in PCs (Millions of Dollars)



Source: Dataquest (August 1998)

Table 5-3
Worldwide Total PC Semiconductor Market by Device Type (Millions of Dollars)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Microprocessor	15,543	18,367	19,228	21,064	23,121	25,360	29,254	9.8
Memory (Main, Upgrade, Graphics, Cache, Nonvolatile)	22,609	17,555	12,574	13,722	20,155	31,945	28,541	10.2
Core Logic	2,822	2,908	3,365	3,754	4,098	4,307	4,940	11.2
Graphics Logic	1,681	1,920	2,183	2,522	2,959	3,411	3,905	15.3
Others	3,392	3,692	4,169	4,547	4,946	5,545	6,253	11.1
Total Semiconductor	**46,047**	**44,441**	**41,518**	**45,608**	**55,279**	**70,567**	**72,893**	**10.4**
Year-to-Year Growth (%)		-3.5	-6.6	9.9	21.2	27.7	3.3	-

Notes: Includes semiconductor value on motherboard and card-based peripherals such as graphics, audio, LAN, WAN, etc.; excludes semiconductor value on mass storage peripherals.
Source: Dataquest (August 1998)

Table 5-4
Worldwide Deskbound PC Semiconductor Market by Device Type (Millions of Dollars)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Microprocessor	10,362	12,413	12,845	13,823	15,121	16,346	18,866	8.7
Memory (Main, Upgrade, Graphics, Cache, Nonvolatile)	17,248	13,809	10,076	10,696	15,527	24,552	21,767	9.5
Core Logic	2,025	2,124	2,528	2,722	2,890	2,964	3,397	9.8
Graphics Logic	1,161	1,326	1,511	1,724	2,020	2,334	2,668	15.0

Table 5-6
Worldwide PC Workstation Semiconductor Market by Device Type (Millions of Dollars)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Microprocessor	72	121	202	368	534	619	717	42.7
Memory (Main, Upgrade, Graphics, Cache, Nonvolatile)	61	113	174	311	587	985	938	52.7
Core Logic	9	23	28	47	69	85	104	35.8
Graphics Logic	6	16	31	46	70	87	106	46.9
Others	5	13	27	52	79	98	120	56.1
Total Semiconductor	**153**	**285**	**463**	**824**	**1,340**	**1,873**	**1,985**	**47.4**
Year-to-Year Growth (%)		86.1	62.4	78	62.6	39.8	6	-

Notes: Includes semiconductor value on motherboard and card-based peripherals such as graphics, audio, LAN, WAN, etc.; excludes semiconductor value on mass storage peripherals.
Source: Dataquest (August 1998)

Table 5-7
Worldwide Overall Workstation Semiconductor Market by Device Type (Millions of Dollars)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Microprocessor	562	443	416	556	715	791	883	14.8
Memory (Main, Upgrade, Graphics, Cache, Nonvolatile)	1,148	761	579	703	963	1,380	1,274	10.9
Core Logic	59	52	53	67	86	100	118	17.8
Graphics Logic	54	49	54	63	82	98	117	18.8
Others	41	41	53	75	101	118	140	27.8
Total Semiconductor	**1,865**	**1,347**	**1,155**	**1,465**	**1,948**	**2,487**	**2,533**	**13.5**
Year-to-Year Growth (%)	0	-27.8	-14.2	26.8	33	27.7	1.8	-

Notes: Includes semiconductor value on motherboard and card-based peripherals such as graphics, audio, LAN, WAN, etc.; excludes semiconductor value on mass storage peripherals.
Source: Dataquest (August 1998)

Table 5-8
Worldwide Handheld PC Semiconductor Market by Device Type (Millions of Dollars)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Microprocessor	40	74	92	115	148	197	267	29.4
Memory (Main, Upgrade, Graphics, Cache, Nonvolatile)	41	48	48	72	98	145	170	28.8
Core Logic	22	39	49	61	78	103	139	28.7
Graphics Logic	10	17	21	27	34	46	61	29
Others	44	73	90	110	138	181	240	26.7
Total Semiconductor	**157**	**252**	**300**	**385**	**496**	**672**	**878**	**28.4**
Year-to-Year Growth (%)		59.9	19.2	28.6	28.6	35.6	30.7	-

Notes: Includes semiconductor value on motherboard and card-based peripherals such as graphics, audio, LAN, WAN, etc.; excludes semiconductor value on mass storage peripherals.
Source: Dataquest (August 1998)

Table 5-9
Worldwide Semiconductor Memory Demand in PCs and Workstations by Device (Millions of Dollars)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
DRAM/SDRAM/etc.	22,257	17,480	12,537	13,945	20,836	33,099	29,607	11.1
SRAM	1,535	876	659	547	375	336	328	-17.8
Nonvolatile	195	195	132	107	94	116	124	-8.7
Total	**23,987**	**18,552**	**13,328**	**14,599**	**21,305**	**33,551**	**30,059**	**10.1**

Note: Includes aftermarket memory.
Source: Dataquest (August 1998)

Table 5-10
Worldwide Semiconductor Memory Demand in Deskbound PCs by Device (Millions of Dollars)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
DRAM/SDRAM/etc.	16,124	13,186	9,594	10,379	15,351	24,399	21,629	10.4
SRAM	989	485	389	242	112	94	84	-29.6
Nonvolatile	135	137	93	74	65	58	54	-17.1
Total	**17,248**	**13,809**	**10,076**	**10,696**	**15,527**	**24,552**	**21,767**	**9.5**

Note: Includes aftermarket memory.
Source: Dataquest (August 1998)

Table 5-11
Worldwide Semiconductor Memory Demand in Mobile PCs by Device (Millions of Dollars)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
DRAM/SDRAM/etc.	2,355	1,573	1,197	1,596	2,570	4,129	3,878	19.8
SRAM	101	105	61	85	55	46	41	-17
Nonvolatile	31	30	22	18	16	14	13	-15
Total	**2,487**	**1,707**	**1,280**	**1,699**	**2,641**	**4,189**	**3,933**	**18.2**

Note: Includes aftermarket memory.
Source: Dataquest (August 1998)

Table 5-12
Worldwide Semiconductor Memory Demand in Workstations by Device (Millions of Dollars)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
DRAM/SDRAM/etc.	884.6	571.1	448.8	568.3	839.7	1,274.1	1,176.5	15.6
SRAM	262	188	128	133	122	105	96	-12.5
Nonvolatile	2	2	2	2	2	2	1	-6.1
Total	**1,148**	**761**	**579**	**703**	**963**	**1,380**	**1,274**	**10.9**

Note: Includes aftermarket memory.
Source: Dataquest (August 1998)

Table 5-13
Total Aftermarket DRAM Revenue in PCs and Workstations

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Total DRAM/ADRAM (Millions of MB)	603.5	1,505.4	1,913.5	3,410.7	5,777.0	11,606.6	16,488.2	0.61
Revenue ($M)	5,943.8	5,726.8	3,145.8	3,843.5	5,753.5	11,307.5	9,378.8	0.10

Source: Dataquest (August 1998)

Table 5-14
Worldwide Semiconductor Memory Configuration Assumptions by System for PCs and Workstations (MB per System; KB per System for Cache)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Notebooks								
Main OEM (MB)	13.9	21.0	31.4	47.8	70.9	88.3	128.0	43.5
Upgrade Memory (MB)	4.0	6.0	7.6	15.6	28.0	54.6	72.0	64.4
Display Buffer (MB)	1.8	1.2	1.0	1.0	1.0	1.0	1.0	-3.6
Cache (KB)*	128.0	204.8	171.6	204.8	128.0	128.0	128.0	-9.0
Nonvolatile (MB)	0.1	0.3	0.3	0.3	0.3	0.3	0.3	0
Ultraportables								
Main OEM (MB)	13.9	21.0	31.4	47.8	70.9	88.3	128.0	43.5
Upgrade Memory (MB)	4.0	6.0	7.6	15.6	28.0	54.6	72.0	64.4
Display Buffer (MB)	1.8	1.2	1.0	1.0	1.0	1.0	1.0	-3.6
Cache (KB)*	128.0	204.8	171.6	204.8	128.0	128.0	128.0	-9.0
Nonvolatile (MB)	0.1	0.3	0.3	0.3	0.3	0.3	0.3	0
Other Mobile								
Main OEM (MB)	13.9	21.4	31.4	47.8	70.9	88.3	128.0	43.0
Upgrade Memory (MB)	4.0	5.5	7.6	15.6	28.0	54.6	72.0	67.3
Display Buffer (MB)	2.0	3.0	4.0	4.0	4.0	4.0	4.0	5.9
Cache (KB)*	128.0	204.8	171.6	204.8	128.0	128.0	128.0	-9.0
Nonvolatile (MB)	0.1	0.3	0.3	0.3	0.3	0.3	0.3	0
Deskbound PCs								
Main OEM (MB)	17.9	32.0	52.0	70.0	102.0	132.0	184.0	41.9
Upgrade Memory (MB)	7.8	18.0	20.0	30.0	42.0	72.0	88.0	37.4
Display Buffer (MB)	2.5	2.5	4.0	5.0	6.0	7.0	8.0	26.2
Cache (KB)*	256.0	204.8	253.4	143.4	64.0	64.0	64.0	-20.8
Nonvolatile (MB)	0.1	0.3	0.3	0.3	0.3	0.3	0.3	0
PC Workstations								
Main OEM (MB)	35.8	64.0	104.0	140.0	204.0	264.0	368.0	41.9
Upgrade Memory (MB)	15.6	36.0	40.0	60.0	84.0	144.0	176.0	37.4
Display Buffer (MB)	5.0	5.0	8.0	10.0	12.0	14.0	16.0	26.2
Cache (KB)*	256.0	204.8	281.6	204.8	128.0	128.0	128.0	-9.0
Nonvolatile (MB)	0.1	0.3	0.3	0.3	0.3	0.3	0.3	0
Overall Workstation								
Main OEM (MB)	70.1	86.1	123.8	171.9	227.1	290.1	407.4	36.5
Upgrade Memory (MB)	28.2	37.6	48.7	71.5	92.7	147.0	187.2	37.9
Display Buffer (MB)	7.5	7.8	10.0	11.7	13.5	15.5	17.5	17.6
Cache (KB)*	491.1	585.8	586.0	497.2	412.2	419.1	422.9	-6.3
Nonvolatile (MB)	0.1	0.3	0.3	0.3	0.3	0.3	0.3	0
Handhelds								
Main OEM (MB)	1.1	1.4	1.5	1.6	3.2	3.4	3.6	20.6
Upgrade Memory (MB)	0.6	0.7	1.5	1.6	1.6	1.7	1.8	19.4
Display Buffer (MB)	0.3	0.3	0.4	0.4	0.4	0.5	0.5	13.5
Cache (KB)*	119.5	251.3	484.9	776.2	906.7	1,055.4	1,220.2	37.2
Nonvolatile (MB)	0.1	0.3	0.3	0.3	0.3	2.9	3.9	72.5

*Does not include cache memory integrated onto the MPU die.
Source: Dataquest (August 1998)

Table 5-15
Worldwide Semiconductor Memory Revenue Configuration Assumptions by System for PCs and Workstations (Dollars per System)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Notebooks								
Main OEM	140.7	81.9	53.0	55.4	72.6	88.4	74.9	-1.8
Upgrade Memory	40.5	23.4	12.8	18.1	28.7	54.7	42.1	12.5
Display Buffer	18.2	4.7	2.3	1.5	1.4	1.3	0.8	-30.1
Cache	8.5	7.3	3.5	4.0	2.2	1.6	1.3	-29.8
Nonvolatile	2.7	2.1	1.2	0.9	0.6	0.5	0.4	-28.1
Ultraportables								
Main OEM	140.7	81.9	53.0	55.4	72.6	88.4	74.9	-1.8
Upgrade Memory	40.5	23.4	12.8	18.1	28.7	54.7	42.1	12.5
Display Buffer	18.2	4.7	2.3	1.5	1.4	1.3	0.8	-30.1
Cache	8.5	7.3	3.5	4.0	2.2	1.6	1.3	-29.8
Nonvolatile	2.7	2.1	1.2	0.9	0.6	0.5	0.4	-28.1
Other Mobile								
Main OEM	140.7	83.4	53.0	55.4	72.6	88.4	74.9	-2.1
Upgrade Memory	40.5	21.4	12.8	18.1	28.7	54.7	42.1	14.5
Display Buffer	20.3	11.7	9.0	6.2	5.5	5.3	3.1	-23.2
Cache	8.5	7.3	3.5	4.0	2.2	1.6	1.3	-29.8
Nonvolatile	2.3	2.1	1.2	0.9	0.6	0.5	0.4	-28.1
Deskbound PCs								
Main OEM	175.8	121.1	85.2	78.7	101.3	128.2	104.4	-2.9
Upgrade Memory	76.6	68.1	32.8	33.7	41.7	69.9	49.9	-6.0
Display Buffer	25.3	9.7	9.0	7.7	8.2	9.3	6.2	-8.5
Cache	17.0	7.3	5.1	2.8	1.1	0.8	0.6	-38.9
Nonvolatile	2.3	2.1	1.2	0.9	0.6	0.5	0.4	-28.1
PC Workstations								
Main OEM	322.2	221.8	156.0	144.2	185.6	235.0	191.4	-2.9
Upgrade Memory	140.4	124.7	60.0	61.8	76.4	128.2	91.5	-6.0
Display Buffer	50.6	19.5	18.0	15.5	16.4	18.7	12.5	-8.5
Cache	17.0	7.3	5.7	4.0	2.2	1.6	1.3	-29.8
Nonvolatile	2.3	2.1	1.2	0.9	0.6	0.5	0.4	-28.1
Overall Workstation								
Main OEM	627.0	327.1	192.0	176.6	203.6	252.3	205.6	-8.9
Upgrade Memory	252.3	141.8	75.6	73.4	83.1	128.5	94.8	-7.7
Display Buffer	156.4	107.4	55.3	31.2	22.2	19.8	13.0	-34.4
Cache	306.2	189.5	92.3	65.7	44.8	32.9	25.7	-33.0
Nonvolatile	2.3	2.1	1.2	0.9	0.6	0.5	0.4	-28.1
Handhelds								
Main OEM	10.8	5.4	2.5	1.8	3.3	3.4	2.1	-17.4
Upgrade Memory	6.1	2.9	2.5	1.8	1.7	1.7	1.1	-18.3
Display Buffer	0.0	0	0	0	0	0	0	0
Cache	8.0	9.0	9.8	15.2	15.6	13.2	11.9	5.8
Nonvolatile	2.3	2.1	1.2	0.9	0.7	5.6	6.1	24.1

Source: Dataquest (August 1998)

Chapter 6
Input/Output and Dedicated Systems

Tables 6-1 through 6-7 detail system and semiconductor market data on selected computer I/O systems.

Key Trends

Audio Boards

Key trends in audio boards are as follows:

- The audio board market faces increasing competition from integrated designs with sound chips on the motherboard. Price pressure is extreme and will continue for at least one more year.
- Wave table synthesis is nearly ubiquitous as software wavetable features ship with most audio subsystems.
- 16-bit audio is the overwhelming standard with some professional grade audio solutions climbing to 20-bit and 24-bit resolutions.

Graphics Boards

Key trends in graphics boards are as follows:

- Price erosion defines this market as the corporate computing market has been slow to demand 3-D graphics features. While it is difficult to buy non-3-D products today, the issue is one of corporate users buying down on the value scale rather than buying up.
- Boards are moving to greater than 1Kx1K-pixel resolutions, accelerated BitBLT-based, 128-bit data paths, and RAMDAC technology moving from 170 MHz to 230+ MHz.
- SGRAM has already replaced EDO memory. Pricing dynamics have spurred vendors to announce a flurry of SDRAM-based graphics boards because they can offer an 8MB SDRAM board for less than a 4MB SGRAM board for 1998. Rational pricing on SGRAM vis-à-vis SDRAM could eliminate those SDRAM-based products quickly. Minimal buffers start at 2MB and move to 4MB with optional SIMMs.
- Most high-end add-in boards have traditionally had a separate RAM-DAC but many new products feature integrated DACs with speeds up to 270 MHz.

Digital Video Boards

Key trends in digital video boards are as follows:

- There will be continued penetration into the multimedia content creator market (software title development, market communications, and training). Playback board growth will be limited to full-screen 30-fps acceleration. Other opportunities exist for TV tuner, capture pass-through, and integrated multimedia acceleration boards.

- MPEG-2 will emerge as a viable video editing solution as single-chip codecs (that is, not just decoders) come down in price and enable sub-$300 video editing solutions. MPEG-1 hardware has disappeared for mainstream application as software MPEG-1 has improved in quality and benefited from faster microprocessors with multimedia enhancements.
- Key semiconductor opportunities include compression decoders for MPEG-2 and JPEG, among others (and encoders for real-time algorithms), PAL/NTSC to CCIR decoders and encoders, ASICs (CMOS), digital video processors (scaling, among others), and ADRAM pixel buffers.

Leading digital video board OEMs worldwide are ATI, Creative Technologies, Diamond Multimedia, FutureTel, IBM, Intel, Matrox, Optibase, Optivision, Orchid, STB Systems, and Video Logic.

Monitors

Key trends in monitors are as follows:

- Color will grow to 98 percent of the market in 1999.
- 15-inch tubes were predominant in 1997; 17-inch tubes will be predominant in 1998.
- There will be a chip content of about $15 for primarily video amplifier (moving to 220 MHz), CRT controls, and USB connectivity.

Keyboards

The trend in keyboards is commodity items moving toward ergonomic and wireless versions (see Tables 6-1 through 6-7).

Leading keyboard OEMs worldwide are Keytronic, Silitek, and MaxiSwitch.

Table 6-1
Worldwide Audio Board Application Market

	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Board Units (M)	13,700	11,547	17,358	20,869	21,549	23,667	23,166	24,136	24,585	3.3
Board ASP ($)	64.6	66.3	56.0	44.3	40.0	43.0	50.0	50.0	50.0	2.4
Board Factory Revenue ($M)	885.0	765.0	972.1	925.0	862.0	1017.7	1158.3	1206.8	1229.2	5.9
Semiconductor Content ($)	32.3	33.1	28.0	22.2	20.0	21.5	25.0	25.0	25.0	2.4
Semiconductor Market ($M)	442.5	382.5	486.0	462.5	431.0	508.8	579.2	603.4	614.6	5.9

Source: Dataquest (August 1998)

Table 6-2
Worldwide Audio Board Market Share (Millions of Dollars)

	1996 Revenue	1997 Revenue	Rank	Market Share (%)
Creative	643.2	738.4	1	79.8
Yamaha	76.2	82.4	2	8.9
Aztech	223.0	62.4	3	6.7
Others	29.7	41.7		4.5
Total	**972.1**	**925.0**		-

Source: Dataquest (August 1998)

Table 6-3
Worldwide Graphics Board Application Market

	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Board Units (K)	12,634.5	16,677.5	26,617.5	41,417.8	45,683.7	48,320.8	54,440.5	60,339.3	66,071.4	9.8
Board ASP ($)	160.0	152.0	83.3	60.5	55.1	60.0	65.0	70.0	70.0	3.0
Board Factory Revenue ($M)	2,021.5	2,535.0	2,217.0	2,504.6	2,517.2	2,899.2	3,538.6	4,223.7	4,625.0	13.1
Semiconductor Content ($)	57.0	55.0	40.0	38.0	33.1	36.0	39.0	42.0	42.0	2.0
Semiconductor Market ($M)	720.2	917.3	1,064.7	1,573.9	1,510.3	1,739.5	2,123.2	2,534.2	2,775.0	12.0

Source: Dataquest (August 1998)

Table 6-4
Worldwide Graphics Board Market Share (Millions of Dollars)

	1996 Revenue	1997 Revenue	Rank	Market Share (%)
ATI	284.8	393.0	1	15.7
Diamond	436.1	341.1	2	13.6
Matrox	263.5	327.8	3	13.1
STB	165.7	212.4	4	8.5
Jaton	186.6	127.7	5	5.1
Others	880.3	1,102.6		44.0
Total	**2,217.0**	**2,504.6**		-

Source: Dataquest (August 1998)

Table 6-5
Worldwide Digital Video Board Application Market

	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Board Units (K)	605.0	1,080.3	1,188.3	1,307.1	1,437.8	1,581.6	1,739.8	1,913.7	2,105.1	10.0
With Hardware Compression and/or Decompression	169.0	351.5	369.0	387.5	406.8	427.2	448.5	471.0	494.5	5.0
With TV Tuner	100.0	189.0	236.3	295.3	369.1	461.4	576.8	721.0	901.2	25.0
Board ASP	310.0	228.0	216.6	205.7	195.5	185.7	176.4	167.6	159.2	-5.0
Board Factory Revenue ($M)	187.6	246.3	257.4	268.9	281.0	293.7	306.9	320.7	335.1	4.5
Semiconductor Content ($)	87.8	79.8	78.2	76.6	75.1	73.6	72.1	70.7	69.3	-2.0
Semiconductor Market ($M)	53.1	86.2	92.9	100.2	108.0	116.4	125.5	135.3	145.8	7.8

Source: Dataquest (August 1998)

Table 6-6
Worldwide Monitor Application Market

	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
System Units (K)	41,227.0	51,986.0	65,379.4	78,010.0	87,641.4	98,207.4	108,121.8	118,963.1	130,429.3	10.8
System ASP ($)	352.0	306.7	288.7	260.5	241.1	230.2	235.1	229.9	222.2	-3.1
System Factory Revenue ($M)	14,494.0	15,942.2	18,876.6	20,322.2	21,131.1	22,604.2	25,420.8	27,353.1	28,986.0	7.4
Semiconductor Content ($)	5.0	18.3	18.2	18.2	17.9	17.6	17.5	17.4	17.2	-1.1
Semiconductor Market ($M)	188.0	953.8	1,187.9	1,418.0	1,568.0	1,732.2	1,887.3	2,075.7	2,239.3	9.6

Source: Dataquest (August 1998)

Table 6-7
Worldwide Keyboard Application Market

	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
System Units (K)	55,961.6	73,869.3	87,110.2	100,449.8	115,314.7	131,343.8	151,353.3	175,336.1	200,916.9	14.9
Semiconductor Content ($)	2.45	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	0
Semiconductor Market ($M)	137.1	184.7	217.8	251.1	288.3	328.4	378.4	438.3	502.3	14.9

Source: Dataquest (August 1998)

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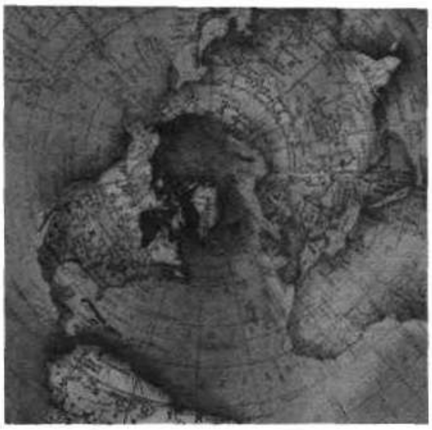

Dataquest

DRAM Density Drivers

Market Trends

Program: Personal Computer Semiconductors and Applications Worldwide
Product Code: PSAM-WW-MT-9801
Publication Date: April 6, 1998
Filing: Market Trends

DRAM Density Drivers

Market Trends

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Chapter 1

Executive Summary

Last year, GartnerGroup's Dataquest examined the impact that DRAM density transitions have on module production (DRAM Transitions and Their Impact on Modules, MMRY-WW-MT-9702, August 1997). This report takes another look at DRAM density transitions, in particular the next DRAM density transition, from the 16Mb to 64Mb. The difference between the two reports is that this report examines density transitions from the component manufacturing perspective.

The demand for DRAM products is pulled not only through raw bit demand but also requirements for speed and configuration architectures, based on the needs of both PC suppliers and higher-end computing systems. Unit shipment levels are generally pushed from the supply side into the market through pricing strategies and availability of product. For a new density to become a viable product, a period of profitability must follow the original investment in research and development and production equipment. Manufacturing economics—fab capacity, utilization, DRAM die size, and yield—are the foundation for determining when to make this density transition and what the associated profitability will be.

Project Leaders: George Iwanyc and Clark Fuhs

Chapter 2
DRAM Density Transitions

Historically, DRAMs follow a predictable trend: The density of the leading chip increases by a factor of four about every three years. In 1997, the majority of devices shipped were 16Mb DRAMs. Three years earlier, in 1994, the leading density was 4Mb, and in 1991, the 1Mb DRAM was the sales leader. Figure 2-1 shows the historical trend of DRAM unit shipments from 1974 through 1996.

Historically, transitions from one density to another have been relatively sharp, and a predictable product life cycle repeats itself for each generation of DRAM. During the transitions from one density to another, adjacent densities compete with each other. Today, 16Mb DRAM is the dominant density, with 64Mb DRAM emerging as a competitive threat.

The predictability of the product life cycles makes sense in the context of product pricing as well. Figure 2-2 shows the historical price-per-bit decline.

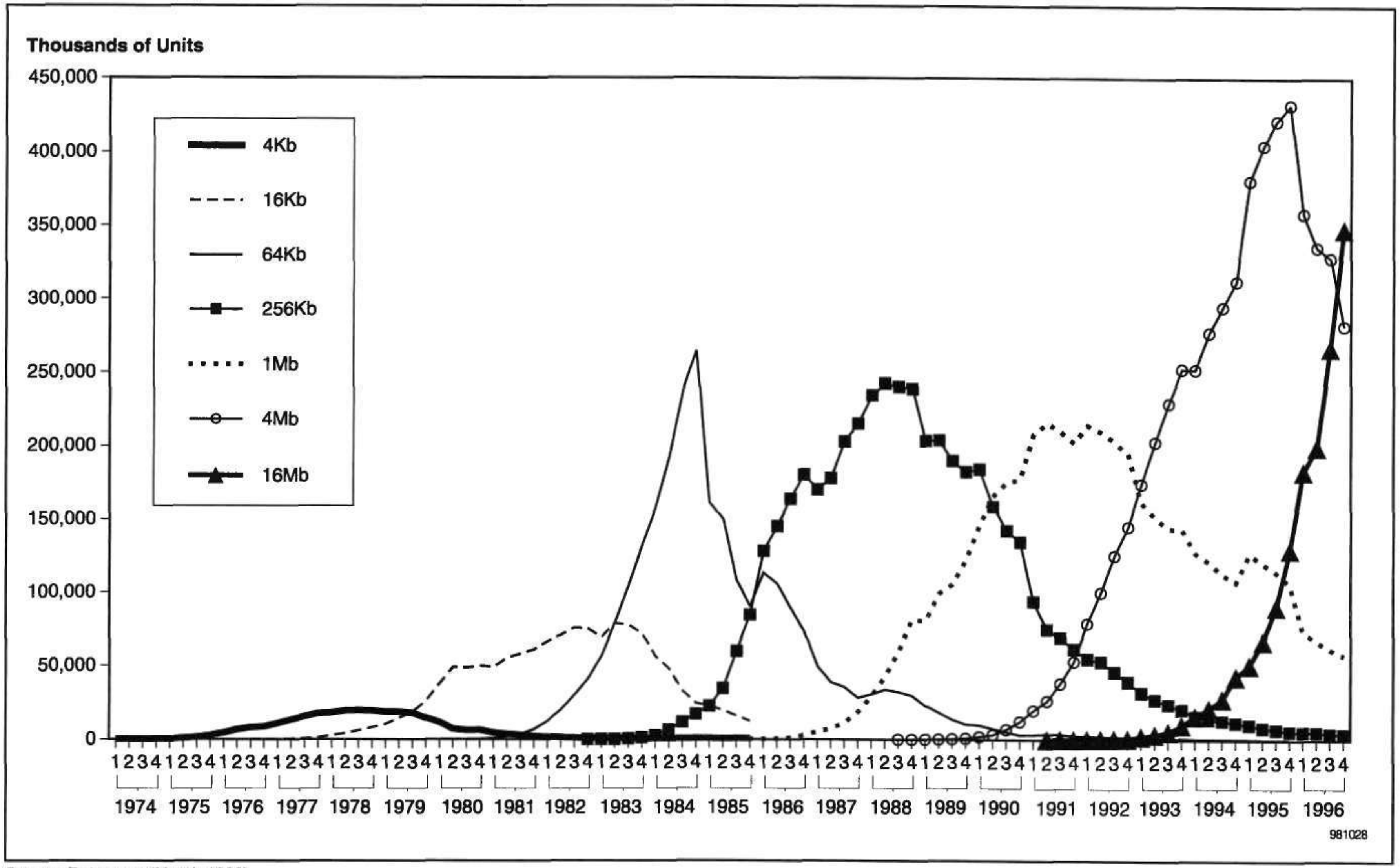
The price-per-bit trend is predictable, declining at just over 30 percent a year. Because DRAM is a commodity, pricing follows the long-term cost trend. A change in the cost structure would result in a change in product life cycle lengths. There was a noticeably aggressive price decline in 1985 and 1986, and the market is in a similarly aggressive downturn now. Within the context of the long-term trend, the 1985 and 1986 decline and the current decline appear to be market corrections and not fundamental changes to the trend.

Forecast

The timing of a density transition depends on a combination of economic viability and technological necessity. The objective of this report is to examine how these factors influence DRAM unit production and whether a fundamental change is occurring. To do this, two DRAM unit forecast scenarios—Dataquest's fall DRAM forecast and a new cost-driven forecast—are examined. The forecasts are presented in Figures 2-3 and 2-4. Overall bit production is the same in both scenarios. The dynamic variable is limited to which DRAM density, primarily 16Mb and 64Mb, is the most cost-effective to produce over the forecast horizon.

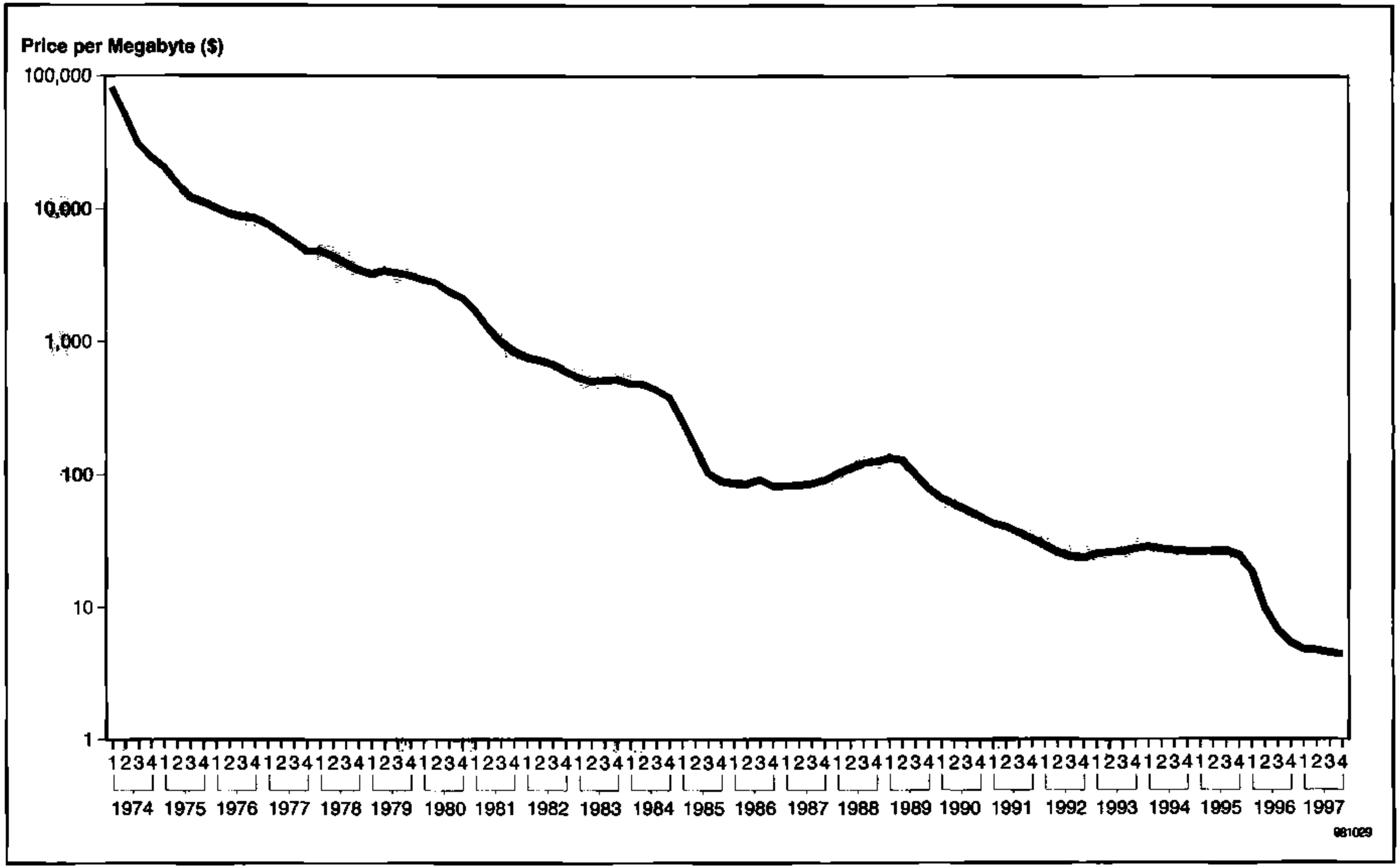
The two unit forecasts presented are dramatically different. However, the factors that can influence a DRAM bit forecast, such as estimates of silicon availability, PC unit shipments, and growth opportunities, are the same in each scenario. The difference is that the fall forecast attempts to rationalize unit production with current technology trends and historical manufacturing trends, while the cost driven scenario ignores technology and focuses on manufacturing efficiency. Another way to look at the two scenarios is to regard the fall forecast as a "best efforts" estimate, considered the most likely to occur. The cost-driven forecast provides a high-side boundary for 16Mb production and could occur under market conditions when there is no demand pull from the PC suppliers for the next-density part.

Figure 2-1
DRAM Quarterly Unit Shipments by Density, 1974 through 1996



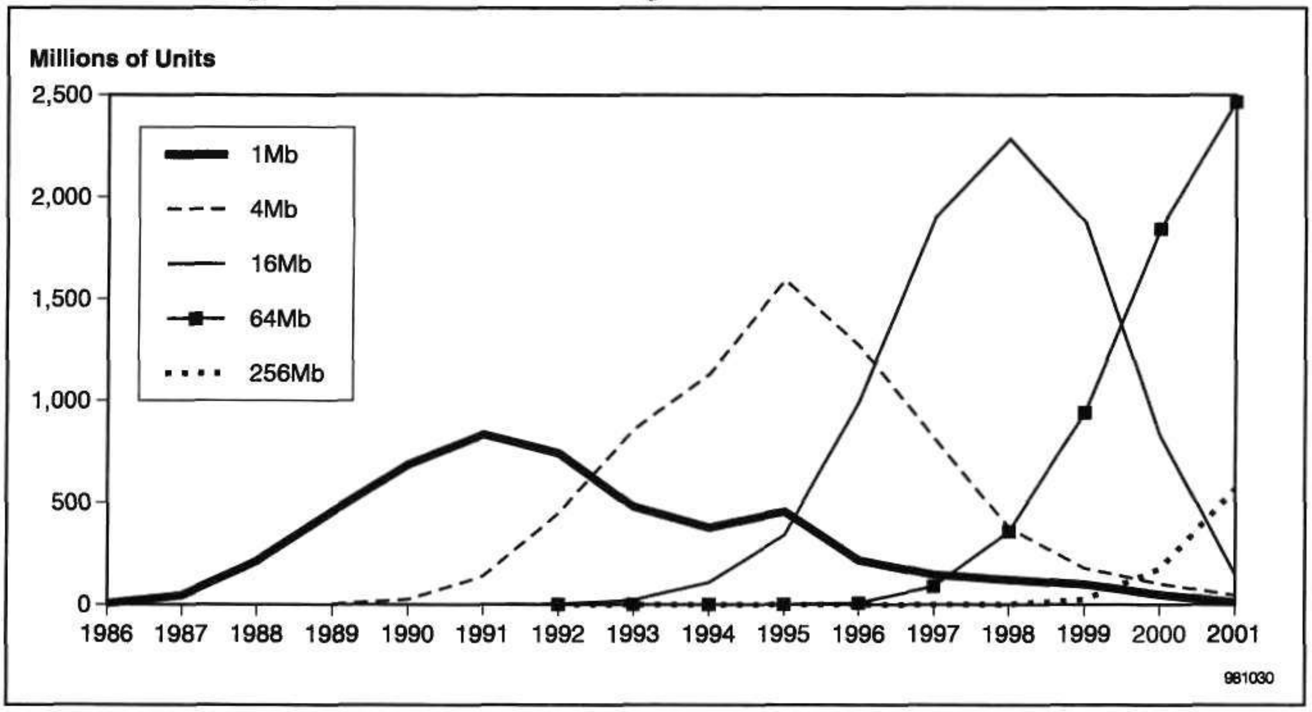
Source: Dataquest (March 1998)

Figure 2-2
Price-per-Megabyte History, 1974 to 1997



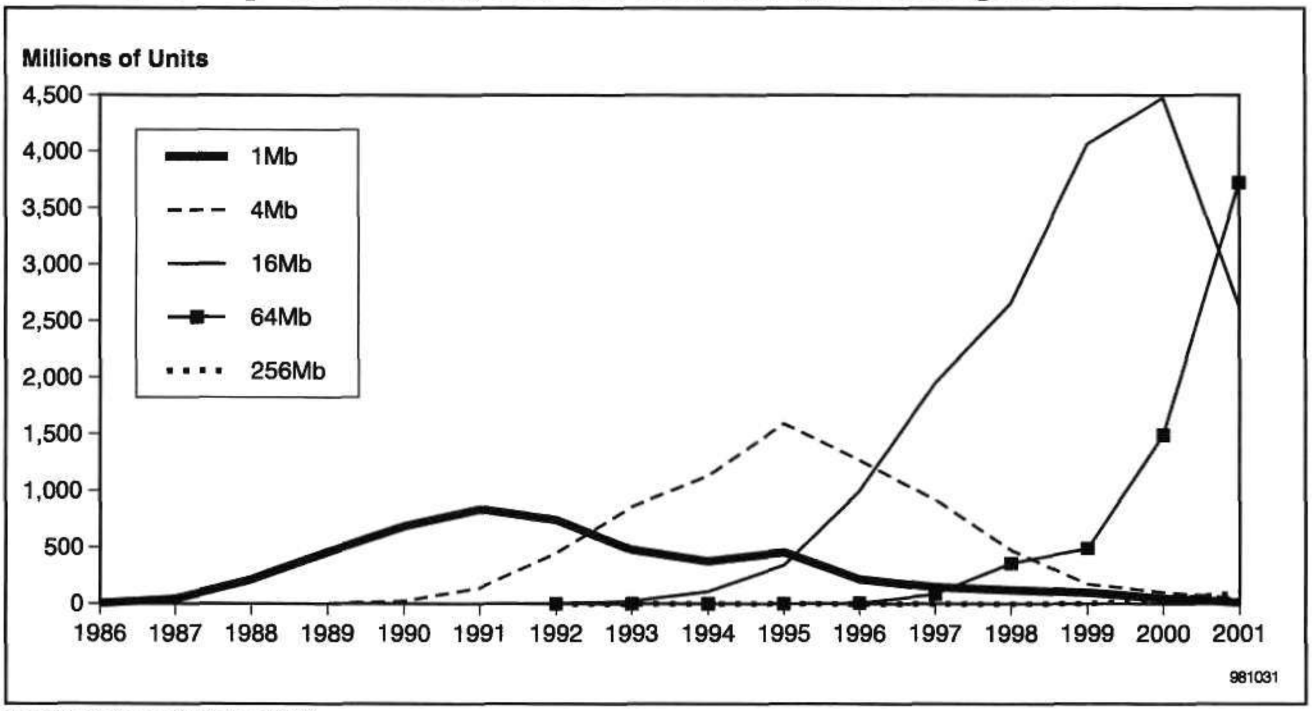
Source: Dataquest (March 1998)

Figure 2-3
DRAM Unit Shipment Forecast, 1997 through 2001



Source: Dataquest (March 1998)

Figure 2-4
DRAM Unit Shipment Forecast, Cost-Driven Scenario, 1997 through 2001



Source: Dataquest (March 1998)

A review of the forecast methodology and assumptions is in order. The following summarizes the methodology that served as the basis for the fall 1997 DRAM forecast:

The near-term forecast data (for the next two years) is based on Dataquest's research for DRAM supply/demand quarterly statistics, for which the following process is used:

- Survey each manufacturer for its DRAM production plans. Examine these against Dataquest's fab model to ensure that the data provided by the manufacturer makes sense.
- Compare the data provided against a demand model and see if there is enough demand to absorb all the parts planned on.
- Double-check historical data against other benchmarks (financial reports and other sources internal and external to the manufacturer) to determine the veracity of surveyed data in the past.

For the extended-range portion of the forecast (three to five years in the future), the following process is used:

- Make projections of historical trends from Dataquest's 23 years of historical data.
- Compare DRAM projections against projected production capacity as determined by the Semiconductor Equipment, Manufacturing, and Materials Worldwide (SEMM) program.
- Rationalize against long-range demand from demand forecasts provided by the Semiconductor Application Markets Worldwide (SAMM) program.

The following summarizes the strategic assumptions that served as the basis for the fall 1997 DRAM forecast:

- The dramatic 1996 DRAM down cycle would bottom out in 1997, and a more normal DRAM market would remain, barring more of the simultaneous upsets of 1992 through 1995, such as the bursting of the Japanese stock bubble, the dollar-to-yen ratio slide, or difficulty in producing the x16 version of the mainstream density (such as a 4Mbx16 synchronous DRAM).
- Personal computer applications, including multimedia-type display applications, would continue to drive much of the growth of the worldwide memory market throughout the rest of this decade.
- Communications applications ranging from low-voltage wireless systems to hubs and routers used for computer networking provide additional sources of growth for the worldwide memory market.
- There is solid overcapacity in DRAMs, brought about through overinvestment in the highly profitable years of 1994 and 1995. This overcapacity is causing profit margins to disappear and, with them, investment in new plants and equipment. The consequence of the underinvestment in 1997 and 1998 would be undercapacity in late 1999 and early 2000, fueling an industry cycle that Dataquest forecasts would be corrected late in 2000.

- Dataquest expects worldwide unit shipments of PCs to more than double from 1997 through 2001; PC shipments should expand from fewer than 71 million units in 1996 to nearly 152 million units in 2001.
- The amount of DRAM in each PC is likely to more than quadruple during this period. The amount of factory-installed DRAM had tripled from 8MB in 1995 to 24MB by the end of 1996. In 1997, PC buyers would demand even more memory—from 24MB to 32MB—for many applications.
- Intel's Pentium II ramp-up during 1997 to 1999 would have a dramatic impact on PC main memory. For example, Dataquest estimates conservatively that the combined Pentium II and Windows NT ramp-ups meant that 10 percent or more of PCs would ship from the PC factory with 64MB of DRAM by the end of 1997.

The following assumptions about DRAM unit dynamics used in the fall forecast were ignored in the cost-driven scenario:

- The 64Mb DRAM would have little market impact until after 1997, with the 64Mb price-per-bit crossover expected during 1999.
- 16Mb DRAM unit shipments would peak during 1998; 4Mb units are in decline.

Many of the assumptions used in the fall forecast are still valid, but some significant changes have occurred. One change is the market disruption caused by the Asian financial crisis. This will affect the forecast, but for the purpose of this exercise, an updated forecast does not materially change the argument. Changes in fab capability and capacity do affect the cost basis, so these factors have been addressed as they existed during the fall forecast. The manufacturing cost issues used in this analysis are presented in Chapter 3 of this report.

The assumptions that are fundamental to the cost-based scenario forecast are the following:

- DRAM suppliers are rational business managers, meaning that, given a set of pricing and production parameters, suppliers will operate fabs to generate maximum profit. Each DRAM supplier will also act in its own best interest and manufacture the DRAM density mix that is the most profitable for it.
- The PC market exclusively drives the DRAM bit crossover.
- PC OEM purchasing agents will buy the lowest-cost-per-bit DRAM, and they will not pay a price-per-bit premium for any technical efficiencies gained from a switch to the next density.
- There are no demand pull issues, such as capacitive loading, driving the next product generation.
- Workstation and other high-end system OEM purchasing agents are willing to pay a price-per-bit premium, possibly as high as 30 to 50 percent, for the next density.

Dataquest's discussions with industry contacts and suppliers have confirmed that all these assumptions seem a rational and reasonable basis for establishing a methodology for a cost-based analysis.

Forecast Scenario Comparison

The fall forecast predicts that the 16Mb density will reach a unit volume maximum in 1998, with 2.3 billion units. The cost-scenario forecast predicts that the 16Mb density will not reach this point until 2000, with 4.5 billion units, nearly twice the fall forecast. The bit and unit crossover points are also different. The fall forecast predicts that the bit crossover will occur in the fourth quarter of 1998 (the quarterly information is from *DRAM Supply/Demand Quarterly Statistics: First Quarter 1998 Outlook*, DSDR-WW-MS-98Q1, January 1998) and the unit crossover will occur in 2000. The cost scenario predicts that the bit and unit crossovers will occur about one year later than predicted by the fall forecast.

The difference between the two forecasts in crossover points and unit volume is considerable. The fall forecast is in line with historical crossover trends. The cost-scenario forecast differs in that it pushes back the transition point to four years. A four-year life cycle is slightly high but not unheard of, because it just occurred with the last density transition, from 4Mb to 16Mb. The huge unit difference is the result of applying two additional years worth of device shrinks and added capacity to manufacturing 16Mb devices. Both forecasts differ from predictions that the 16Mb part would be short lived.

DRAM Product Life Cycle

Is the length of the DRAM product life cycle changing? The belief in a short-lived 16Mb DRAM may be in part a response to the long 4Mb life. The argument is that the 16Mb would be a correction back to the trend. The cost-scenario forecast represents the opposite—arguing that a change in the length of the DRAM life cycle is occurring. Since PC base memory growth historically has not kept up with the pace of DRAM density growth, a lengthened product life cycle is conceivable.

An examination of historical crossover trends suggests that there is little reason to believe that an extremely short 16Mb product life is likely. Table 2-1 shows the calendar quarter when past price-per-bit, bit, and unit crossovers occurred for each DRAM density. Table 2-2 shows the length in quarters between density transitions for each of these crossovers. The quarter that is counted as the crossover quarter is the first quarter in which the new density outperforms the prior density for the entire quarter. On a monthly basis, the month the crossover occurred may actually be in the prior quarter.

Table 2-1
DRAM Density Crossover Points—Price per Bit, Bits, and Units (Quarter and Year of Occurrence)

	4Kb to 16Kb	16Kb to 64Kb	64Kb to 256Kb	256Kb to 1Mb	1Mb to 4Mb	4Mb to 16Mb
Price per Bit	Q2/79	Q1/83	Q3/85	Q1/90	Q3/91	Q3/94
Bits	Q3/78	Q2/82	Q3/85	Q4/88	Q4/91	Q4/95
Units	Q3/79	Q2/83	Q1/86	Q2/90	Q1/93	Q4/96

Source: Dataquest (March 1998)

Table 2-2
Time Difference between Density Transitions for Price per Bit, Bit, and Unit Crossover (Number of Quarters)

	4Kb/16Kb and 16 Kb/64Kb	16Kb/64Kb and 64Kb/256Kb	64Kb/256K and 256Kb/1Mb	256Kb/1Mb and 1Mb/4Mb	1Mb/4Mb and 4Mb/16Mb	Average	Standard Deviation
Price per Bit	15	10	18	6	12	12	4.19
Bits	15	13	13	12	16	14	1.49
Units	15	11	17	11	15	14	2.42

Source: Dataquest (March 1998)

There have been only five density transitions, so the data set is relatively small. The unit crossover data does show an alternation between short and long life cycles. This supports the idea of a short life cycle for the 16Mb density, but the data does not support a crossover in 1998. The shortest unit crossover period is 11 quarters, which equates to a transition in 1999.

There have not been two successive quarters of the crossover point lengthening. This alone makes it difficult to argue, based on history, that life cycles are lengthening. Even a 2001 unit transition, as suggested in the cost scenario, is not unprecedented. The longest unit crossover period to date has been 17 quarters. If this is applied to the 64Mb, the unit transition would occur in the first quarter of 2001.

128Mb and 256Mb DRAM

This examination ignores the viability of a 128Mb DRAM density or, stated differently, the start of a 2x density increase product cycle. The 128Mb part was proposed primarily to answer granularity problems with the 256Mb density. A 64-bit-wide dual in-line memory module (DIMM) manufactured with 128Mbx16 parts results in a minimum module increments of 64MB, a reasonable module granule for PCs in the latter part of the forecast horizon. A full 4x transition to the 256Mb density would result in a 128MB module granule if 16-bit-wide parts are used. This granule is too large for PCs, with the alternative being 256Mbx32 part.

A 32-bit-wide part may prove to be difficult to manufacture and unnecessary. One reason for the long 4Mb-to-16Mb density transition was manufacturing difficulties associated with the then-new 16-bit-wide interface that the PC industry wanted for granularity reasons (a detailed look at this transition is presented later). It took most DRAM manufacturers a year to work out these difficulties. A similar challenge is likely with a transition to 32-bit-wide parts. A 32-bit-wide part requires more I/O connections, making the chip more rectangular in design. It is believed that a new packaging method would be needed to handle the rectangular shape. The industry will likely try to avoid this technology shift. A 32-bit-wide part may also prove to be unneeded, because an interface transition to Direct Rambus or SLDRAM should occur in the same time frame, and granularity issues may be rendered moot with this future implementation of burst architectures for communication between the DRAM and the PC bus. Neither proposed interface would require an x32 part.

A cost-effective 128Mb DRAM most likely would be designed with the same design rules as a 256Mb DRAM, but it would come at a die size penalty when compared on the basis of bit-size efficiency. The implementation of a full production 128Mb DRAM requires a profitability period to follow the original investment in research and development and production equipment. This implies that the three-year, 4x increased product life cycle would have to lengthen for a 2x solution to offer sufficient return on investment. It is likely that the 4x increased life cycle would have to nearly double to six years to offer a 2x increased solution ample time to provide the required return of investment. This indicates that historical trends would not support a 128Mb density, but a change where product life cycles lengthened would.

There is every indication that DRAM manufacturers are serious in their efforts to develop a 128Mb DRAM. The development of the 128Mb part, however, is ignored in this analysis because, within the forecast horizon, the 128Mb is expected to be in very limited production.

Demand Issues Driving Density Transitions

Are there demand pull issues that could overcome manufacturing economics and trigger density transitions, such as the 128Mb density? Yes, system performance benefits from bigger memory allotments, and the easing of technical troubles caused by capacitive loading and power consumption could result in OEMs requesting larger DRAM densities. OEMs, however, are faced with their own economic trade-offs regarding product features and the associated costs. This forces OEMs to decide whether they are willing to pay a price premium for the benefits of larger DRAM densities.

Capacitive Loading

As bus speed accelerates, the effects of signal line loading start to become significant. This was not a significant factor at 25 MHz, but it became very important at 50 MHz (to the point that the cache memory needed a new 32-bit-wide SRAM rather than the 8-bit devices that had been used in all prior PC caches), and it has swung into prominence even on the DRAM bus at 66-MHz bus clock speeds. The problem at 100 MHz becomes nightmarish!

It is not too difficult to understand what causes the problem. It all comes down to looking at the data bus as a low-pass RC filter. This low-pass filter allows the bus to operate better at lower frequencies than it can at higher frequencies. The cut-off frequency for this filter can be controlled by reducing the values of resistance (R) and capacitance (C) in the filter.

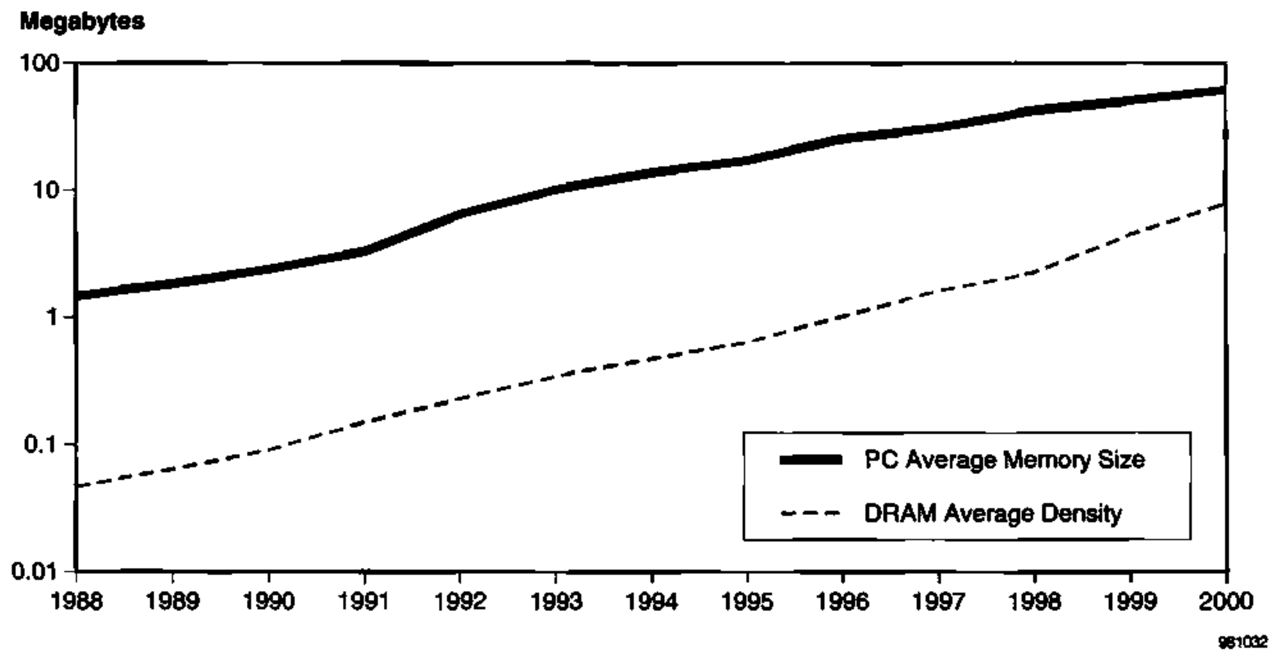
All conductors are resistive to a degree, and all conductive area is capacitive. The smaller the area of the data bus, the lower the capacitance. The shorter the data bus lines, the lower the resistance. So designers work hard to reduce the length of the bus lines, thus reducing both R and C. If the number of DRAMs connected to the bus is reduced, the bus can be shorter, lowering both R and C.

DRAMs also have input capacitance, and the output drivers on microprocessors and logic chips have output resistance. Unlike the length of bus lines, these values cannot be designed to be lower. About the only possible option is to reduce the number of capacitive DRAM input pins attached to a resistive driver's output. How can this be done?

The first way is to reduce the number of DRAM input pins attached to a logic IC's output pin. This can be done by using the smallest number of the highest-density DRAM chips the designer can justify. This approach embraces the use of wide, high-density DRAMs. This approach does not lend itself to flexibility and memory expansion too well. Figure 2-5 shows Dataquest's estimates of PC main memory sizes from 1988 through 2001, compared to the average DRAM density.

The figure shows that there is a trend toward fewer DRAM components in PC main memory. This trend, however, may not be sufficient to solve the technical issue with capacitive loading in certain applications in high-end PC segments. This creates a scenario in which OEMs may purchase higher-density parts at a premium.

Figure 2-5
PC Main Memory Sizes Compared to Average DRAM Chip Density, 1988 through 2000



Source: Dataquest (March 1998)

The second way, which is used when a very large memory array dictates the use of a large number of the densest-available DRAMs, is to put a buffer between the address input of a module and the address input pins of all of the DRAMs on that module. This turns the DIMM into a "registered" DIMM because the buffer uses a register to store the address (a technique known as pipelining). This comes at the expense of DRAM speed—it takes an extra clock cycle to put the address into the register, slowing the DRAM access by one clock cycle. The advantage is that the RC filter now sees only the capacitive input of the buffer, the equivalent of a single DRAM IC. In most cases, the register delay will still allow the computer to run faster than it could if the DRAMs were tied to the address pin without the buffer register, because the capacitance of the RC filter would not allow the processor to access the bus at its maximum rated speed.

It is possible that the move toward lowering input capacitance, coupled with the desire to support flexibility and memory expansion, will drive the acceptance of odd DRAM densities, such as the 128Mb device. However, Dataquest is guarded about the possibilities for success of this approach.

Purchasing Behavior

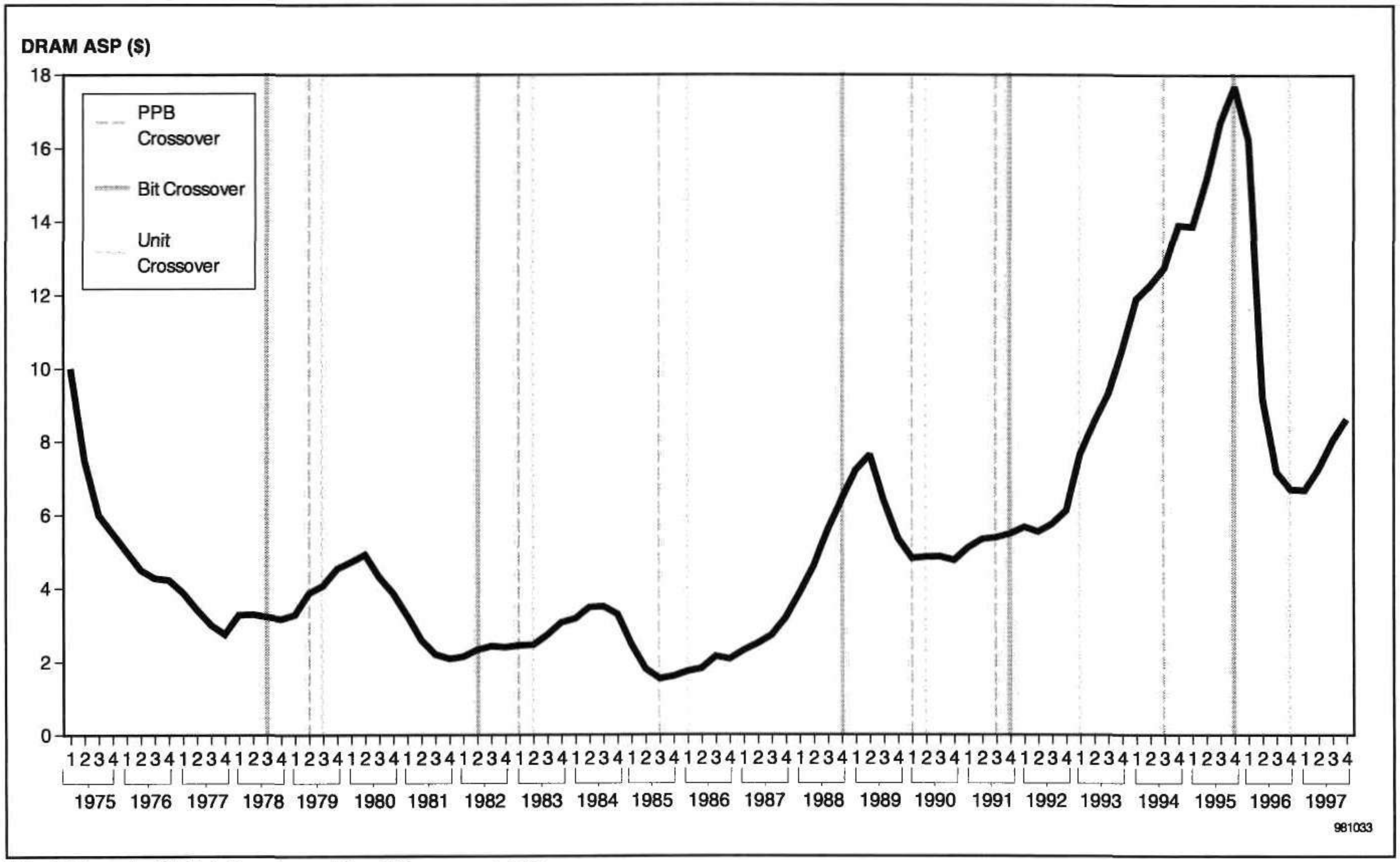
PC OEM purchasing behavior is integral to both forecasts but particularly for the cost-scenario forecast. PCs account for nearly half the memory market's revenue and over 70 percent of the DRAM market. This dependency on PCs forces DRAM manufacturers to aim their production at this market. The key to density transitions is the price premium that PC OEMs are willing to pay.

The timing of price-per-bit, bit, and unit crossovers within a given density transition indicates that there has been a change in purchasing behavior. Figure 2-6 shows the crossover points relative to DRAM average selling price, and Table 2-3 shows the time difference between crossover points.

For all the transitions up to the 1Mb density, the bit crossover occurred earlier or at the same time as the price-per-bit crossover. This indicates that buyers were willing to pay a premium to get the next density. For the next two transitions, the price-per-bit crossover occurred before the bit crossover. This indicates that buyers waited longer before committing to the new density and did not pay much of a premium for the next density.

What changed? The growing importance of DRAM modules is one important change. OEMs are concerned with megabytes and not with whether a 16Mb or 64Mb DRAM is used to make those megabytes. DRAM modules enable PC OEMs to be indifferent to component density and wait for price parity.

Figure 2-6
DRAM Average Selling Prices



Note: Third quarter 1985 is both a price-per-bit and bit crossover quarter.
Source: Dataquest (March 1998)

Table 2-3
Time Differences between Price per Bit, Bit, and Unit Crossover for Each Density (Number of Quarters)

	4Kb to 16Kb	16Kb to 64Kb	64Kb to 256Kb	256Kb to 1Mb	1Mb to 4Mb	4Mb to 16Mb	Average	Standard Deviation
Bits and Price per Bit	-3	-3	0	-5	1	5	-1	3.34
Units and Bits	4	4	2	6	5	4	4	1.23
Units and Price per Bit	1	1	2	1	6	9	3	3.15

Source: Dataquest (March 1998)

The following simple example shows why OEMs can be indifferent. Thirty-two megabytes is a typical base memory configuration for today's PCs. For a synchronous DRAM (SDRAM) system, an OEM would normally use one DIMM to populate a PC with this amount of memory. For an EDO system, either one 32MB DIMM would be used or, if still supported, two 16MB single in-line memory modules (SIMMs). Different 16Mb and 64Mb combinations can be used to manufacture these modules. Typical configurations, in megabytes, are shown as the number of chips times the DRAM chip type:

- 4Mbx32 (a 16MB SIMM) = 8 x (4Mbx4) or 2 x (4Mbx16)
- 4Mbx64 (a 32MB DIMM) = 16 x (4Mbx4) or 4 x (4Mbx16)

The module interface is the same whether 16Mb or 64Mb DRAM is used. As long as the different module configurations have been qualified, the most important attribute is cost.

PC OEMs are unlikely to return to an environment in which they are capable of paying premiums for higher-density DRAM. All PC OEMs are faced with tight margins, ever-shortening product life cycles, and the need to improve inventory turns. PC OEMs have moved to assembly methods inspired by the build-to-order model, where ideally they build product only when they have received an order from a customer. Inventories for components are kept to the minimum required to meet demand, depending on the price volatility of the component in question. Speculating on a density transition adds unneeded risk to the procurement process. Conservative OEMs are likely to wait until they are relatively certain of price parity before committing to the next DRAM density.

Another important PC trend is the growing importance of the low-cost PC or, as popularly known, the sub-$1,000 PC. The dollar content of memory in the sub-$1,000 PC is about $80 to $90. The low-cost PC is likely to continue down the price curve, and the prospect of a $500 PC sometime in the future is not unreasonable. This will put pressure on the cost of all the components in the PC, particularly on a component such as memory that can be scaled. The drastic DRAM price decline of the last two years has enabled the low-cost PC to be configured with essentially the same amount of memory as higher-priced basic and midrange PCs. Once DRAM pricing starts to become firmer, this is likely to change. If cost were not already the primary purchasing barometer, it would be sure to become one in this PC segment.

Chapter 3
Manufacturing Issues and DRAM Economics

Supply-side dynamics, or manufacturing capacity and related issues, are key considerations in the making of a DRAM forecast. The DRAM market has both "demand pull" and "supply push" forces.

Demand for DRAM products is pulled not only through raw bit demand but also through requirements for speed and configuration architectures based on the needs of both PC suppliers and higher-end computing systems. Unit shipment levels are generally pushed from the supply side into the market through pricing strategies and product availability issues. It has been stated already that PC suppliers are not willing to pay a price-per-bit premium for the 64Mb density over the 16Mb DRAM, so it is reasonably to conclude that the supply base cannot effectively push product without using price in the present oversupply. This is a normal consequence of a product's being a commodity.

This chapter will examine the pendulum's swinging to the side of favoring manufacturing considerations exclusively in the construction of a unit forecast for DRAM. The specific focus is the question: When does the bit crossover occur for the 64Mb DRAM relative to the 16Mb DRAM?

Some Initial Perspective

The manufacturing and capacity perspective is concerned mainly with the bulk shipment vehicle for DRAM to the market. Since over 70 percent of the bit demand for DRAM is driven by the PC market, a manufacturing view would tend to discount other markets, including the high-end workstation market, in determining cause-and-effect relationships in answering the bit crossover question posed in the previous paragraph.

From a manufacturing perspective, a DRAM fab is a generic production facility running wafers at a particular technology line width with the process flows required. When considered in this fashion, a fab could run 4Mb or 256Mb DRAMs, because they tend to have three to four levels of polysilicon and two levels of metal. Technology line width is the driving force in requiring specific types of equipment, such as high-density etch, deep-UV lithography, or chemical mechanical polishing (CMP). A piece of equipment does not distinguish what is on the wafer, it just processes it correctly to a set of specifications driven by line width. The conclusion: The product being manufactured is neither limited nor defined by line width technology. Therefore, there is no such thing as "64Mb technology," only "a 64Mb DRAM product" and "0.25-micron technology."

If all the assumption in the cost-based scenario are considered true, then the following conclusion follows logically: The bit crossover for the 64Mb DRAM relative to the 16Mb DRAM will occur at a technology line width at which the 64Mb DRAM is produced at a lower cost per bit than the 16Mb DRAM.

This conclusion can be used to derive a set of figures to determine when the crossover will occur, and it is based purely on manufacturing economics.

A Recent Historical Example: Demand Pull versus Economics

The industry was actually blessed in early to mid-1995 with a set of conditions that clearly demonstrates which forces will win in a struggle between the demand pull of the PC industry and manufacturing economics, a set of conditions that was stable enough for a time to make it possible to actually track what was happening and understand it. These conditions occurred during the 4Mb-to-16Mb transition.

The industry was on the brink of the 4Mb-to-16Mb transition in 1995. The products available, average (not smallest) die sizes, yields, and their pricing relationship are summarized in Table 3-1. The main product shipping was the 4Mb DRAM, even though it was not the cheapest available on a price-per-bit basis. It is interesting to investigate the reasons that drove this result and the factors behind the relative prices among the parts.

The problem was a granularity issue between the x4 and x16 versions of the 16Mb (this phenomenon is well documented in Dataquest publications). It need be stated here only that PC OEMs were interested in the flexibility of allowing many levels of memory into their product lines with the Pentium processor, and that meant that the x16 configuration was viewed as the only 16Mb part marketable to the PC market in 1995. Since then, given the increase in memory shipping per PC, the x4 configuration has been widely used.

Why was the 4Mb DRAM the product of choice? Simply put, because it was the cheapest per bit to make and therefore the most profitable. When comparing the 4Mb to the x16 version of the 16Mb DRAM, cost per bit can be compared in terms of three things: die size ratio (which affects gross die per wafer), relative net yields (which affect net die per wafer), and process complexity issues (which affect cost per wafer).

Table 3-1
DRAM Products and Pricing Relationships in Early to Mid-1995

Product Density	Configuration	Average Die Size (mm^2)	Estimated Net Yield (%)	Price per Bit Relative to 4Mb DRAM
4Mb	1Mx4	50	88 to 90	-
16Mb	1Mx16	90 to 95	50	7% to 10% premium
16Mb	4Mx4	80	70 to 75	10% to 20% discount

Source: Dataquest (March 1998)

The process complexity issues relate to what is required to make a 4Mb product versus a 16Mb product. The need for the storage capacitor to hold a charge increases as the product becomes more dense, and the number of cells to route also increases. This results in an increase in the number of steps in the process per mask level, in defect density requirements, and in the overall number of masks. In general, the number of masks increases by 15 to 20 percent for the denser product, and the relative processing cost can be about 10 percent higher. This adds about 25 to 30 percent to the cost per wafer.

Die size and net yield ratios are fairly easy to identify and quantify. The die size ratio was about 1.8 to 1.9 (90-95 mm^2 versus 50 mm^2) and the relative net yield ratio was also about 1.8 between the 4Mb and the x16 version of the 16Mb DRAM. Multiplying these factors together (using the formula noted below) leads to a cost-per-bit differential favoring the 4Mb DRAM by about 5 to 10 percent, and the resulting price followed accordingly. Why did the DRAM suppliers not drop the price of the x16? Because they would have made less profit per bit compared to the 4Mb density.

- Relative cost per bit: 16Mb/4Mb = (1.9 die size ratio) x (1.25 process cost factor) x (90/50 yield factor) x (1/4 bit density) = 1.07

Relative cost-based pricing also explains why the x4 configuration for the 16Mb DRAM was selling at a discount. In fact, the x4 16Mb DRAM was the most profitable, but it was not what the market wanted, so bit crossover was delayed. This example established for Dataquest the following rule of thumb:

- Dataquest's First Law of DRAM Manufacturing: Cost-per-bit crossover for DRAM densities occurs at the combination at which the denser part is at most 1.9x the die size of the less dense part and at which at least a 60 percent yield is achieved.

Armed with this rule of thumb and some hard data on die sizes, it is now possible to embark on the analysis that will answer this question: When will cost-per-bit crossover occur for the 16Mb to 64Mb transition?

Why Do DRAM Suppliers Want to Push the Market to Greater Density?

The standard answer is to reduce cost per bit and achieve higher profit. Dataquest believes that most people familiar with the industry know the standard answer to this question, although technically it is not the accurate answer. The example of 1995 showed that the 4Mb was the most profitable part, and the following analysis will show that, today, the most profitable part is the 16Mb part. So why is the supplier base trying to push for 64Mb DRAMs? The standard answer needs to be modified to be: to *eventually* reduce cost per bit *over time* and achieve higher profit.

Table 3 points out that the number of bits per area silicon consumed takes a step-function jump upward as production migrates to the next density. In fact, this was the root cause of the initial oversupply during 1996. The number of bits produced per wafer essentially doubled or tripled, simply by changing a mask set in the fab, exploding the bit capacity of the industry. With each jump in density comes this silicon efficiency and lowering of costs.

However, the reality is that at any point in time, given a fixed price per bit, there is only one density that is the most profitable. Take the case of the generic fab mentioned earlier. Today, at 0.35-micron, with the relative die sizes and yields of the 16Mb and 64Mb DRAM, the 16Mb offers the lowest cost per bit. And in the PC market, which will pay a given price per bit, the 16Mb therefore is the most profitable. While it is true that at a price-per-bit premium of 30 percent, the 64Mb DRAM is actually more profitable; however, the market size is limited to high-end workstations and is therefore not going to be able to drive bit crossover.

There is a cost floor of about $1.50 to $1.70 that no DRAM part can really penetrate, based simply on the material costs involved in the manufacturing, mostly driven by the package. In other words, there is a diminishing return on lowering absolute cost per die through the process of shrinking, because the cost to package the part becomes a higher proportion of the cost. If costs get to this floor, then the die size ratios experienced in the front-end fab start to become overshadowed, driving the denser part to be more cost-effective more quickly, because the absolute die costs for the denser part are higher.

The dimension of time, in manufacturing terms, can also be expressed as a mainstream production line width. For example, 0.35 micron would equate to mid-1997, 0.32 micron would equate to early 1998, 0.28 micron would equate to late 1998, 0.25 micron would equate to mid-1999, and so on. There is, therefore, another rule of thumb:

- Dataquest's Second Law of DRAM Manufacturing: At any specific line width, only one density with market demand has the lowest cost per bit.

Now the task becomes answering the following question: At what line width will cost-per-bit crossover occur for the 16Mb-to-64Mb transition?

For this, it is necessary to look at relative die size and yield relationships.

A Comparison of Manufacturing Economics

For the most part in 1997, the 64Mb DRAM was priced at a 25 to 30 percent premium over the 16Mb DRAM. This level has eased a little today, but the premium generally remains at about 20 percent. Table 3-2 shows the relative die size and yield information for the 16Mb and 64Mb DRAM for 0.35-micron technology. With a die size ratio of 2.3 to 2.4 and yields at about 45 to 50 percent for the denser part, it is quite understandable why this price differential exists.

Table 3-2
DRAM Products and Pricing Relationships for 0.35-Micron Technology in 1997

Product Density	Configuration	Average Die Size (mm^2)	Estimated Net Yield (%)	Price per Bit Relative to 4Mb DRAM
16Mb	1Mbx16 SDRAM	50 to 55	85	-
64Mb	4Mbx16 SDRAM	120 to 130	45 to 50	25% to 35% premium

Source: Dataquest (March 1998)

Over time, as line width shrinks, the die size ratio would be expected to get smaller and the yields for the density part to get larger. Over the last several months, companies have begun to announce their die sizes for 16Mb and 64Mb SDRAM at 0.25 micron, which is expected to be the mainstream line width in mid-1999, ramping up during late 1998. A synopsis of the announcements is shown in Table 3-3.

It is interesting to note that the die size ratio is still quite high, at 2.4 to 2.6. At these ratios, yields at 0.25 micron would have to be about 75 to 80 percent for the 64Mb DRAM in for that product to have the lowest cost per bit. Because this is highly unlikely, given the infancy of 0.25-micron production, from a manufacturing perspective, the 0.25-micron generation still belongs to the 16Mb DRAM. Micron Technology Inc., in a recent investor conference, stated that it believed that the 16Mb generation would have at least one more shrink beyond 0.25 micron, essentially verifying the view that the 16Mb would be the most economical at 0.25 micron.

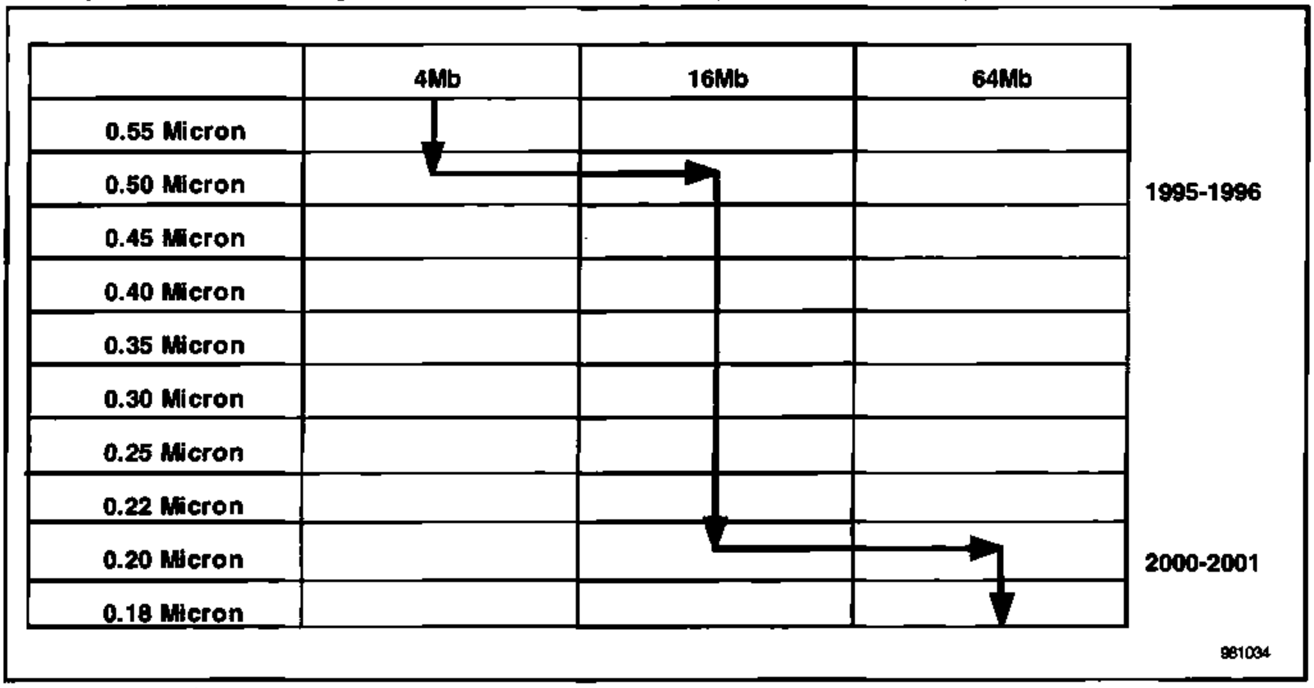
In fact, Dataquest's view is that die size ratios will not favor the 64Mb DRAM until at least the 0.22-micron generation, but probably not make the transition until the 0.2-micron line width (see Figure 3-1). It is possible that the cost floor will be hit for the 16Mb part at 0.22 micron. Dataquest has extended this analysis over time to plot the die size ratio and estimated 64Mb DRAM yields by quarter through the year 2000 (see Figure 3-2). This analysis suggests that the cost-per-bit transition will occur near the middle of 2000—the second quarter, just for argument's sake. Therefore, from a pure manufacturing perspective, the conclusion is that the 16Mb-to-64Mb crossover for bit shipments will be the second quarter of 2000.

Table 3-3
DRAM Products and Pricing Relationships for 0.25-Micron Technology

Product Density	Configuration	Average Die Size (mm^2)	Estimated Net Yield (%)	Price per Bit Relative to 4Mb DRAM (Expected)
16Mb	1Mx16 SDRAM	32 to 34	88 to 90	-
64Mb	4Mbx16 SDRAM	70 to 80	55 to 60	10% to 15% premium

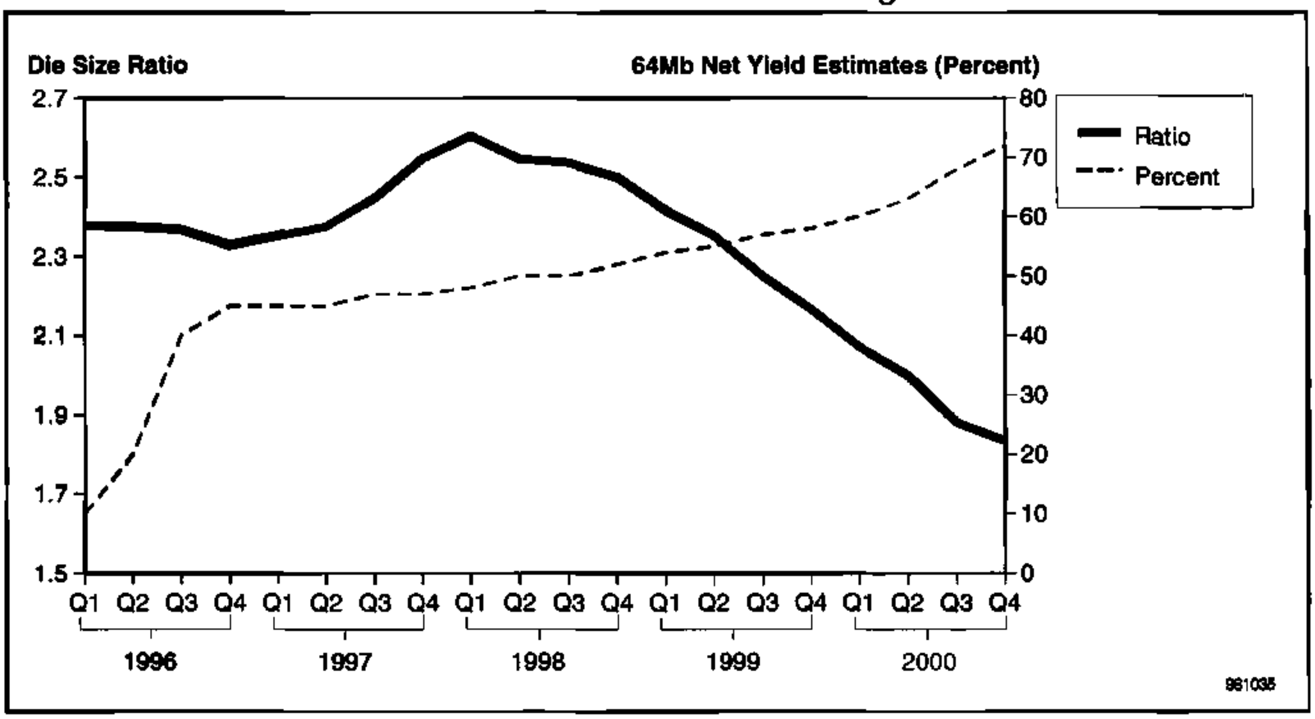
Source: Dataquest (March 1998)

Figure 3-1
Likely Technology Migration for DRAM Density Based on Cost per Bit



Source: Dataquest (March 1998)

Figure 3-2
Die Size Ratio for 64/16Mb DRAM and Estimated Yield Migration of 64Mb



Source: Dataquest (March 1998)

What Does the New Conclusion Mean for the Forecast?

Just what does this obviously contrarian view of the bit crossover mean for the unit shipment forecast for DRAM and for any capacity issues? Actually, some pretty interesting and equally contrarian conclusions can be derived.

If the current bit demand forecast is used and the only assumption is that the workstation market has converted to the 64Mb DRAM (limiting the percentage of bits shipped in the 64Mb density to about one-third through early 2000), the manufacturing economics scenario unit forecast looks something like that shown earlier in Figure 2-3.

Because the 16Mb DRAM is actually less silicon efficient than the 64Mb density, this increased unit forecast would tend to bring the front-end fab capacity into balance as early as the second quarter of 1999, but the real constraint will more likely be the packaging and assembly capacity, which will reach a run rate of 1.3 billion units per quarter by the fourth quarter of 1999, as opposed to Dataquest's current forecast of a peak of around 800 million units per quarter in early 1999.

If the manufacturing scenario happens as was shown in Figure 2-3, we could see 16Mb prices as high as $3.50 to $3.75, with the 64Mb DRAM selling at a 10 percent price-per-bit premium. There is historical evidence in the World Semiconductor Trade Statistics (WSTS) data to support these kinds of price trends. All this makes for a profitable DRAM company by late in 1999.

If, on the other hand, the current thinking is correct that a bit crossover will occur late in 1998, then both units and silicon requirements will be lower after this year. The growth rate of bits per square inch of silicon will remain high, about 80 to 100 percent in 1999, keeping pace with bit demand and maintaining the industry in oversupply throughout 1999.

Chapter 4

Dataquest Perspective: The Manufacturing Scenario versus Reality

Dataquest has just concluded a very logical and sensible analysis, leading to a cost-based forecast that appears on the surface to be quite unbelievable. The entire DRAM supplier community is scrambling to make the 64Mb DRAM the density of choice but must live with the constraint of a bulk consumer (the PC supplier) that will not pay a price-per-bit premium to convert. The incredible shrinking 16Mb DRAM makes achieving a cost-competitive 64Mb DRAM a tall and challenging task. History has shown, time and again, that the simple will of the DRAM suppliers is not enough to "push" the market to the higher density. This must be a "demand pull" event.

Are there conditions that would lead the PC market to accept a price-per-bit premium? Perhaps, driven by technology and configuration constraints to operate the bus at 133 MHz, PC suppliers must use the denser DRAM to properly configure their systems. However, this demand pull event is still some 15 to 18 months away from becoming significant enough to matter.

What is the reality of the timing for the bit crossover? As is most often the case, probably between the fourth quarter of 1998 (Dataquest's current forecast) and the second quarter of 2000 (the manufacturing economics scenario). But, as the results of the forecast modification shown earlier indicate, the answer has tremendous ramifications for the supply/demand balance of the industry and for intermediate-term profitability.

These are issues that Dataquest will be watching through 1998 in the formulation of forecast updates. There will be much attention paid by the press to price parity between the 16Mb and 64Mb DRAM. Care must be taken that the comparisons are done with the correct configurations in mind. Because a 64Mb EDO part with a x4 or x8 configuration will not be demanded longer term by the PC suppliers, a price-per-bit crossover using this part as the metric is quite meaningless, in much the same way that the x4 version of the 16Mb was never pulled by the market in 1995.

If forced at this time to choose between the two bit crossover scenarios—in the first quarter of 1999 or second quarter of 2000—Dataquest would favor a date earlier in the window rather than later. Although this scenario is not rational from a manufacturing economics point of view (given the assumptions presented in this report) and would likely extend the overcapacity into 2000, maintaining pricing pressures and capital spending restraint, it is the more probable scenario. Why? Simply put, we do not expect the suppliers to respond rationally.

In 1995, profitability was high, so the market tended to behave in a rational and cost-effective manner. However, today, suppliers are desperately looking for an edge and will abandon short-term profitability to gain that edge. If a DRAM supplier believes there is an edge to be gained in higher market share at the 64Mb density, then there will be the response to "price forward," meaning pricing today using tomorrow's cost structure. This can drive price parity, even though it does not make manufacturing economic sense to do so in today's structure.

Even the commodity product concept of "buying market share" has limits, however, and a 20 percent cost-per-bit differential is a big pill to swallow. However, it is conceivable that, in early 1999, that penalty could be 10 percent, thus driving the bit crossover to be "supply pushed."

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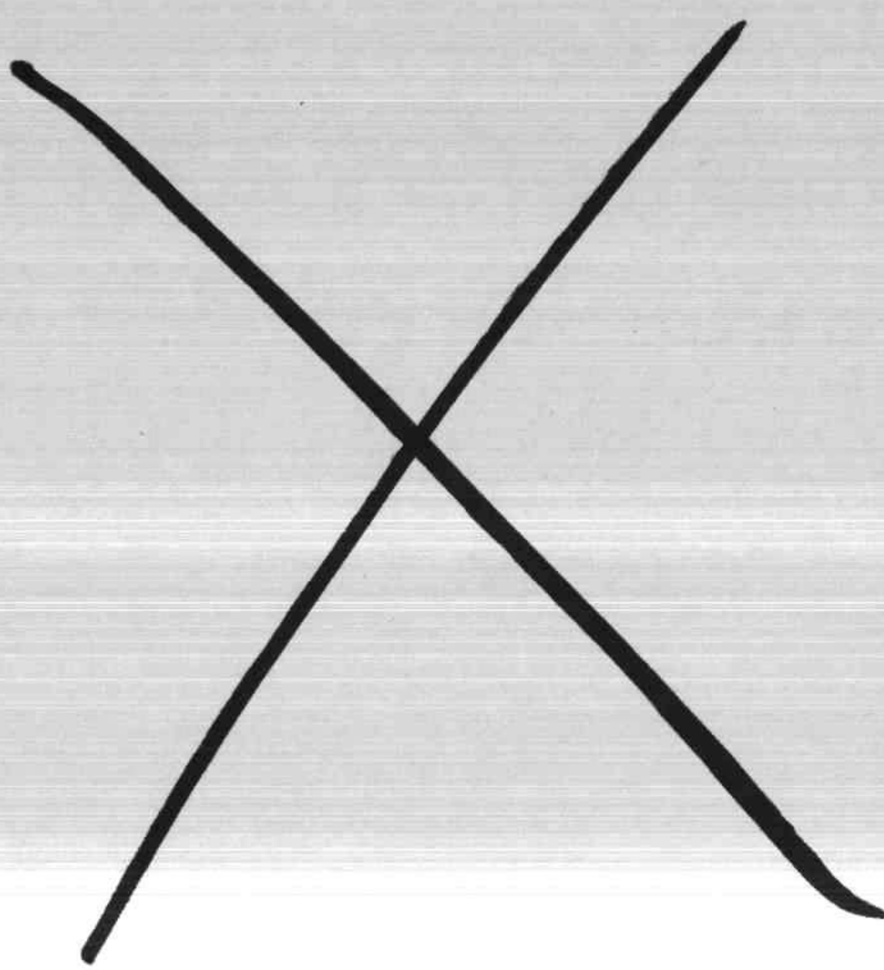

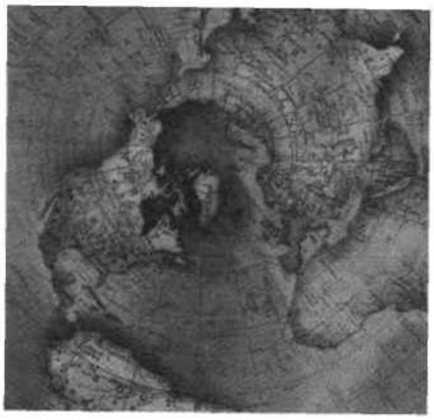

Dataquest

Semiconductor Application Market Definitions, 1998

Dataquest Guide

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Semiconductor Application Market Definitions, 1998

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Chapter 1
Market Statistics Overview and Methodology

Each year, Dataquest surveys leading systems vendors to estimate annual sales and to develop industry market size estimates. In semiconductors, the surveys currently cover the activity of more than 150 vendors worldwide (this varies annually according to mergers, acquisitions, liquidations, start-ups, and other factors) in four world regions.

This primary research is supplemented with additional research to verify market size, shipment totals, and pricing information. Sources of data used by Dataquest include, but are not limited to, the following:

- Interviews with manufacturers, distributors, and resellers
- Information published by major industry participants
- Estimates made by reliable industry spokespersons
- Government data or trade association data
- Published product literature and price lists
- Relevant economic data
- Articles in both the general and the trade press
- Published company financial reports
- Reports from financial analysts
- Information and data from online and CD-ROM data banks
- End-user surveys

Dataquest believes the data presented in the Market Statistics documents is the most accurate and meaningful available. Despite the care taken in gathering, analyzing, and categorizing the data, careful attention must be paid to the definitions used and assumptions made. Various companies, government agencies, and trade associations may use slightly different definitions of product categories and regional groupings, or they may include different companies in their summaries. These differences should be kept in mind when making comparisons between data provided by Dataquest and that provided by other research organizations.

Chapter 2
Semiconductor Application Market Segmentation

Semiconductor application markets, as analyzed by Dataquest, are based on six application segments. This section describes these six segments to guide both survey participants and clients. These definitions may occasionally be revised, altered, or expanded to reflect changes in electronic technology.

The six electronic equipment segments that Dataquest has defined are data processing, communications, industrial, consumer, military/civil aerospace, and transportation. Each segment is broken into smaller systems group categories. Most categories are groups of products; some categories are simply one-product categories. The breakdown of electronic equipment segments provides information on which electronic products are included within the segments; it does not indicate what data is available.

The following list gives Dataquest's semiconductor application markets hierarchy:

Data processing

- Computer
  - Supercomputer
  - Mainframe computer
  - Midrange computer
  - Entry-level server
  - Workstation
  - PC
  - Motherboard
  - Handheld computer
- Data storage device
  - Rigid disk drive
  - Removable disk drive
    - Flexible disk drive
    - Rigid disk cartridge drive
  - Optical disk drive
    - Magneto-optical and phase-change disks
    - WORM optical disk drive

            - DVD
                - DVD-ROM
                - DVD-Recordable drive
                - DVD-ReWritable drive
            - CD drive
                - CD-Recordable drive
                - CD-ReWritable drive
            - PD drive
        - Tape drive
        - Other data storage
            - RAID subsystem
- Input/output device
    - Printer
        - Serial printer
        - Line and specialty printer
        - Page printer
    - Monitor
    - Other input/output device
- Dedicated system
    - Copier
        - Analog copier
        - Digital copier
    - Expandable organizer (personal organizer)
    - Chip card
        - Memory card
        - Smart card (IC card)
    - Other dedicated system
- Other data processing
    - Sound/audio board
    - Digital video board
    - Graphics accelerator board

Communications

- Premise telecom
  - Image and text communications
    - Facsimile machine (for facsimile card, see modem)
    - Video teleconferencing
    - Telex/teleprinter
    - Videotex
  - Data communications equipment
    - Modem (modem card and fax card)
    - Digital WAN system
    - Front-end processor
    - LAN card
    - LAN/internetworking
      - Hub
      - Switch
      - Router
    - Remote access system
    - VSAT
  - Premise voice system
    - Premise switching
    - Voice messaging
    - Interactive voice response
    - Automatic call distributor
  - Telephone terminal
    - Answering machine
    - Telephone
      - Corded telephone
      - Standard telephone
      - Multifunction corded telephone
      - Cordless telephone (analog and digital)
      - Internet/screen phones
      - Other telephone terminal
- Public telecom
  - Transmission
  - Central office switch

- Mobile communications
  - Cellular/broadband PCS/ESMR handset
    - Analog cellular
    - Digital cellular/broadband PCS/ESMR
  - Pager (one- and two-way)
  - Mobile communications infrastructure
  - Other mobile communications
- Broadcast and studio
  - Audio
  - Video
  - Other broadcast and studio
- Other telecom

Industrial

- Security/energy management
  - Alarm system
    - Intrusion detection
    - Fire detection
  - Energy management
- Manufacturing system
  - Semiconductor production
  - Control
  - Process control
  - Control and processing display
  - Robot
- Test and measuring equipment
  - ATE-semiconductor equipment
  - Nuclear electronics
  - Other test and measurement
- Medical equipment
  - Diagnostic
  - Therapeutic
  - Patient monitoring/measuring system
  - Surgical support
  - Irradiation equipment
- Other industrial system

Consumer

- Audio
  - Personal/portable stereo
  - Stereo component
  - Musical instrument
- Video
  - VCR, VTR
  - Camcorder
    - Analog camcorder
    - Digital camcorder
  - Videodisc player
  - Television
    - Color television/HDTV
    - DTV
    - Black-and-white television
  - Cable/satellite set-top receiver
  - Set-top box
    - Analog
    - Digital
      - Direct broadcast satellite
      - Cable TV
      - Terrestrial
      - Others
    - Internet
- Personal electronics
  - Video game (system and cartridge)
    - Video game controller
    - Video game cartridge
  - Camera
    - Digital still camera
    - Other camera
  - Watch
  - Clock
  - Electronic toy

- Appliance
  - Heating, ventilation, and air conditioning
  - Microwave oven
  - Washer and dryer
  - Refrigerator
  - Dishwasher
  - Range and oven
- Other consumer

Military/civil aerospace

- Radar/sonar/reconnaissance
- Missile/space
- Navigation
- Electronic warfare
- Aircraft flight system
- Command, control

Transportation

- Entertainment
  - Auto stereo
- Vehicle/body control
  - Antilock braking system (ABS)
  - Other vehicle/body control
- Driver information
  - Automotive navigation system
  - Other driver information
- Power train
  - Auto engine control unit (ECU)
  - Other power train
- Safety and convenience
  - Air-bag control unit
  - Other safety and convenience

Chapter 3
Semiconductor Application Market Definitions

The semiconductor application market definitions in Tables 3-1 through 3-6 are presented in the same order as the market segmentation in the previous chapter.

Table 3-1
Semiconductor Application Market Definitions: Data Processing

Product	Definition
Data Processing	**Includes computers, data storage, input/output device, dedicated systems, and other data processing.**
Computer	Includes supercomputers, mainframe computers, midrange computers, entry-level servers, workstations, PCs, motherboards, and handheld computers. Includes the value of aftermarket sales of single in-line memory modules (SIMMs) and dual in-line memory modules (DIMMs). Does not include storage, keyboards, add-in cards for graphics, video, audio, LAN, and modems and displays except for built-in displays.
Supercomputer	A high-performance computer designed for either numerically intensive applications or commercial functions that require extensive and rapid computational capabilities. These systems include computing technologies such as vector, superscalar symmetric multiprocessing (SMP), and massively parallel processing. Massively parallel processing systems are defined as systems configured with 32 or more processors. Typically, these systems run in cool rooms, with or without raised floors, or environmentally controlled office habitats and require a dedicated support organization. Applications that lend themselves to the supercomputer platform include atmospheric simulation, pharmacological testing, and nuclear development, as well as very high-level decision support and online analysis.
Mainframe Computer	A general-purpose information system with a starting price of more than $100,000. CPU bit width ranges are typically 64 bits. The physical environment may or may not have special environmental controls and requires full-time support by professional computer systems support staff. The number of concurrent users exceeds 100. Dataquest views a mainframe system shipment as the CPU, the basic storage configuration (not including direct-access storage devices); the operating system (the system must be "bootable"); and the operator's console. Dataquest does not routinely count upgrades unless the system footprint changes.

Table 3-1 (Continued)
Semiconductor Application Market Definitions: Data Processing

Product	Definition
Midrange Computer	This category includes all multiuser systems that fall between workstations and mainframes. These are multiuser systems that may or may not run proprietary operating systems. With the evolution of client/server computing and the systems that define this market, traditional midrange product categories are becoming obsolete. The HP 9000 and the HP 3000, Digital Equipment Corporation's VAX systems, and the IBM AS/400 line are joined by the dedicated server products from vendors such as Auspex, NetFRAME, and Compaq to form the midrange product category. Office systems, proprietary turnkey computing solutions common in Japan, are also included in the midrange category. Systems designed as servers from workstation vendors are also included here. The category includes midrange-class servers. The key distinctions between the midrange-class server and the server-marketed PC (included under PCs) are price and the average number of CPUs included in the base system. Midrange-class servers ship with more than one CPU and generally cost more than $15,000.
Entry-Level Server	Typically, a server with roots in the PC/Intel architecture (IA). An entry-level server is a shared computer on a network that can be used for simple tasks such as handling print requests and for more complex tasks such as acting as a repository and distributor of data. Systems that were formerly labeled "Server-marketed PCs" by Dataquest are included in this category.
Workstation	Dataquest classifies workstations by a composite of attributes, including their hardware and software features and, more significantly, the manner in which they are brought to market; PCs marketed as workstations are included. These systems must meet a minimum technical specification and be sold and marketed as workstations. Workstations are typically based on 180-MHz or better Pentium II-class or RISC CPU architectures with high-performance graphics, operating system, and system architecture. In general, a workstation must include integrated floating-point processing, integrated networking, and a 32-bit or 64-bit multitasking operating system, as well as configurations that support high-resolution graphics capabilities (typically 1-megapixel display) and 3-D graphics functionality. The category includes traditional UNIX workstations, workstations running Windows NT or proprietary operating systems, and Pentium II-class (or compatible) systems running Windows NT or other advanced operating systems, such as NeXTSTEP and Solaris. Systems shipped with Windows 95 are not included; they are included in PCs. There are three segments of workstations: entry level, midrange, and superworkstation.

Table 3-1 (Continued)
Semiconductor Application Market Definitions: Data Processing

Product	Definition
	An entry-level workstation is typically priced between $2,000 and $7,500, usually less than $10,000 for a fully configured system. These systems are typically cost-reduced models targeted at price-sensitive end users. They may support only uniprocessor configurations and mainly run 2-D graphics with some limited 3-D graphics capabilities that may be integrated on the system motherboard. Typically, entry-level workstations do not have the expandability of a midrange workstation and cannot achieve the same levels of application performance or other capabilities available in more expensive models. Examples are the HP 9000 Model 712, IBM RS/6000 43P/140, Digital AlphaStation 255, and Sun SPARCstation 5. Also included are most of the Windows NT/Intel Pentium Pro-based PC workstations, such as the Intergraph TDZ 310, HP Vectra XW, Digital Personal Workstation 200I, Compaq Professional Workstation, and IBM IntelliStation.
	Midrange workstations are the traditional workstation configuration designed for the technical user who requires more power, better graphics, and more memory and storage. They have higher performance, may support two or more processors, and cost between $7,500 and $20,000. The list price of a fully configured model with the fastest processor options and top-of-the-line graphics subsystems can be as much as four times the price of a minimally configured system and considerably higher than the entry point for a superworkstation.
	Superworkstations have the highest combination of CPU and graphics performance and usually address scientific, engineering, and other computationally oriented problems. Base prices can be as low as $20,000 for a minimally configured system and can go up to more than $200,000 for multi-CPU systems that are essentially graphics supercomputers with the capability to handle very large and complex data models.
PC	A general-purpose computer that is distinguished from other computers by its adherence to hardware and software compatibility. This compatibility drives high unit volumes of commoditylike products that do not require on-site technical support. High-performance features (such as networking, graphics, and a virtual multiuser/multitasking operating system) are normally optional and not integral system features. Intel x86-compatible and Macintosh personal computers are two platforms in this product segment. A single-user PC's resident operating system is typically DOS, OS/2, Windows, or Mac OS. PCs have a performance ceiling that is lower in system compute performance, I/O channel speed, and disk speed than that of advanced workstations; normally, standard graphics are about 760 x 1280 pixels and optional high-end graphics are limited, compared to workstations. Although Dataquest's Computer Systems and Peripherals group views PCs as a unit comprising a CPU, a monitor, and a keyboard, the semiconductor applications programs, for the purposes of counting semiconductors, excludes motherboards, monitors, keyboards, storage, and other peripherals because they are covered elsewhere. Dataquest's PC shipment data also excludes systems assembled from component parts purchased in electronic stores or other outlets. This PC category does not include handheld computers or personal organizers. PCs can be subdivided into deskbound and transportable PCs.

Table 3-1 (Continued)
Semiconductor Application Market Definitions: Data Processing

Product	Definition
	Deskbound PCs are PCs with either a deskside or desktop configuration. Deskside PCs are designed to stand vertically beside or underneath a user's desk. The primary design distinguishes a deskside from a desktop unit in that it keeps a sideways orientation and in that drive bays usually remain horizontal when the CPU is placed on the floor. Desktop PCs are all PCs intended for use on a user's desktop or work surface and not designed to be readily moved from place to place. Switchable models, either desktop or deskside, fit into this category.
	A transportable PC is a system that meets all other personal computer criteria but is designed to be easily moved from place to place. The case style may be identified as a lunch box, and the system is completely self-contained and can be carried as a single unit, which includes a keyboard, a display, mass storage, and the main system unit. Its primary source of power is AC power. Its typical weight is 18 to 20 pounds. Included in this category are laptop PCs, which meet all criteria for a transportable personal computer but are smaller and lighter. In addition to the difference in size and weight, they are distinguished from transportables by case design, which is typically a clamshell. System weight is usually less than 15 pounds. A laptop's power source is either AC or DC. Included in this category are notebook PCs, which meet all criteria for laptop DC personal computers but are smaller and lighter. The case style typically measures 8.5 x 11 inches or A4 size. Weight typically is less than 8 pounds with the battery. Included as notebook PCs are tablet devices (which are distinguished by a pen-based operating system using a pen as a primary input device rather than a keyboard) and ultraportable PCs (a notebook PC without an internal floppy disk drive, typically weighing 4 pounds or less).
Motherboard	A PC system board consisting of a printed circuit board with semiconductor and nonsemiconductor components that are all soldered down; the value of the CPU and memory are excluded. The list of semiconductor components includes a minimum of a core logic chipset, clock controller, real-time clock, keyboard controller, any additional glue logic required to interface between the core logic chipset and CPU, cache memory, main memory, and expansion bus (such as PCI). The list of semiconductor components may include a graphics controller, mass storage interface, serial and parallel I/O, voltage converter, or audio controller, as long as they are soldered down.

Table 3-1 (Continued)
Semiconductor Application Market Definitions: Data Processing

Product	Definition
Handheld Computer	A general-purpose computer that is designed to be held comfortably in a user's hand. It is based on an operating system, microprocessor, and reference platform, like a personal computer, but is distinguished by its size, weight, and physical usage. It is typically designed to be carried in a pocket, briefcase, or purse; weighs two pounds or less; and does not require a flat surface for use. It is also designed to be used with batteries as its primary power source. As with other portable computers, input can be keyboard-based, pen-based, or both, with a potential for voice-based input. This category excludes expandable organizers, which are included in dedicated systems. This category also includes standard handhelds—general-purpose computers that are distinguished from organizers by their adherence to hardware and software compatibility standards. The standard handheld operating systems are licensed and available to multiple manufacturers, and application development and memory expansion are open to third-party developers and may be distributed in a standard format (such as PCMCIA). Standard handhelds typically measure 4 x 7 x 1 inches (this varies) and weigh about one pound (this is also likely to vary). The primary applications are personal information management (PIM) and communications. A subcategory of the standard handheld market is industrial handhelds, which are developed for field operations use and are "ruggedized" for other specialized use. These systems are not marketed to consumers. Inventory control devices are not included. Examples are the 3Com Pilot, the Casio Cassiopeia, the Hewlett-Packard OmniGo, and Windows CE systems.
Data Storage Device	Includes rigid disk drives, removable disk drives, optical disk drives, tape drives, and other data storage.
Rigid Disk Drive	A rigid disk drive (RDD) stores digital information on a round platter made of polished aluminum or a ceramic material. The information is written and read from the platters by recording heads mounted on the end of an arm. The arm is positioned over the desired area of the disk by a sophisticated control circuit that guides an actuator motor's movement. The data is amplified, decoded, and transmitted to the computer by the disk drive electronic circuits. The manner in which the information is presented to the computer is determined by the interface characteristics of the disk drive. Examples of interfaces include SCSI and the PC-AT bus, sometimes called IDE, EIDE, ATA, or UDMA.
Removable Disk Drive	A drive that houses a removable disk protected by a jacket. Dataquest defines two types of removable disk drives: flexible disk drives, and rigid disk cartridge drives.
Flexible Disk Drive	A drive that reads and writes data to removable flexible media made of a polyester substrate, which is coated with a magnetic material and housed in a protective jacket. Dataquest segments flexible disk drives into two main categories based on drive capacity. Low-capacity flexible drives are defined as drives with a capacity of less than 20MB, and high-capacity flexible drives are drives with a capacity of 20 MB or greater.
Rigid Disk Cartridge Drive	A disk drive that reads and writes data to magnetic rigid media that is housed in a protective jacket. The removable disk cartridge, which contains the media, is inserted into the drive for a read or write operation.

Table 3-1 (Continued)
Semiconductor Application Market Definitions: Data Processing

Product	Definition
Optical Disk Drive	An optical disk drive (ODD) is a data storage device that records and stores computer data on removable media using laser technology. Its categories are CD ROM; CD-Recordable-Recordable (CD-R); CD-ReWritable (CD-RW), phase-change disk (PD), DVD-ROM, DVD-Recordable, DVD-ReWritable, write-once read-many (WORM) optical drive; and rewritable ODD.
Magneto-Optical and Phase-Change Disks	Magneto-optical (MO) and phase-change disks are ODDs that use removable media that can be erased and reused many times (also called erasable optical disk drives). Many of these drives include multifunction capability. This category includes multifunction drives that are capable of reading from and writing to both rewritable and WORM media.
WORM Optical Disk Drive	A WORM drive can read and write data using various types of removable optical disk media.
DVD	Digital versatile disc (DVD) is essentially a high-density CD. DVD drives use discs that are the same size as CDs but have a much higher storage capacity. The category includes all versions: DVD-ROM, DVD-R, and DVD-ReWritable drives This category also includes rewritable optical drives that are compatible with DVD-ROM but depart from the DVD-RAM specification. An example of this is DVD+RW.
DVD-ROM	A drive that reads high-capacity CD-ROM discs with capacities ranging from 4.7GB to 17GB, depending on the number of surface and active layers, as well as current-capacity CD-ROM discs.
DVD-Recordable Drive	A drive that reads or records the DVD-ROM version of WORM technology.
DVD-ReWritable Drive	A drive that reads, writes, and rewrites media based on phase-change technology. The drive also reads DVD-ROM and DVD-R media.
CD Drive	CD-ROM discs are 4.7 inches (12cm) in diameter, have a 1.6-microinch-pitch single-spiral track, and have 2,048 data bytes per sector. This category includes CD-ROM, CD-R, and CD-RW drives.
CD-Recordable Drive	A drive that reads or records the DC-ROM version of the WORM technology. These discs conform to ISO 9660 standards and can be read in CD-ROM drives.
CD-ReWritable Drive	A drive that reads, writes, and rewrites CD-ROM standard media based on phase-change technology. The drive also records CD-R media and reads CD-ROM discs, as well as disks recorded on a CD-R drive.
PD Drive	A PD drive reads, writes, and rewrites non-CD-ROM standard media based on phase-change technology. The drive also reads CD-ROM discs, as well as discs recorded on a CD-R drive.
Tape Drive	Records and stores computer data on removable magnetic media. A tape drive is synonymous with a tape transport. It consists of the mechanism that controls the movement of the media past the read/write head or heads, the electronics that control the movement of the tape, and the processes required for recording or reading data. In products in which the drive level interface is embedded or integrated with the drive, the definition of a tape drive also includes this interface.
Other Data Storage	Consists of redundant arrays of independent/inexpensive disks (RAID) subsystems and in the future may include technologies such as holographic storage and solid-state drives.

Table 3-1 (Continued)
Semiconductor Application Market Definitions: Data Processing

Product	Definition
RAID Subsystem	A RAID subsystem is a set of disk drives (at least three) for which I/O is managed from either host-based software or a controller. All forms of RAID are in this category, including mirroring or striping. RAID configurations be embedded internally or externally to the server, as in a typical disk subsystem. Some examples of RAID systems include: IBM's RAMAC and 7133, EMC's Symmetrix 3000 and 5500, HDS 7700, Sun SPARCarray 3000 and 5000, and Digital Equipment's 410. For the purposes of the Semiconductor Applications programs database (and to avoid double-counting), this category includes the value of the RAID controller board, adapter cards, power, and packaging but does not include the value of storage drives, which are accounted for in other storage categories.
Input/Output Device	Includes all equipment that transfers data between the CPU and a peripheral device.
Printer	An output device that uses computer-originated, digital electronic signals to create alphabetic, numeric, or graphic symbols, that will print onto various types of media, and that has a print width of 80 columns of output at a pitch of 10 or greater.
Serial Printer	A serial printer produces images using a print head that travels across the width of the paper on a carriage mechanism. This category includes serial impact dot matrix printers (a printer that creates a character image by selectively placing individual dots on the substrate using mechanical force), serial nonimpact ink jet printers (a printer that creates the desired image one character at a time by emitting ink from an array of orifices or nozzles), and serial nonimpact thermal transfer printers (a printer that creates the desired image one dot at a time using point-specific heat to transfer ink from a ribbon to a receiving substrate).
Line and Specialty Printer	Includes printers that print one line at a time and specialty printers such as thermal printers and ticket printers, among others.
Page Printer (Laser)	A printer that prints one page at a time. These are electrophotographic printers in which laser beams are used to transfer images to a photoreceptor (drum). They have the ability to buffer, in part or in whole, a page of images received from an electronic source and then to transfer these images to a receiving substrate.
Monitor	A self-contained video display device that attaches directly to a computer and displays the contents of the computer's video memory. A monitor contains no data formatting or editing capability, nor does it contain any type of networking capability. Included are color monitors with interfaces capable of interpreting signals containing separate color components (normally the three primary colors, red, green, and blue) and monochrome monitors based on a single-color CRT. These monitors normally display in shades of white, green, or amber. They may or may not have the ability to display multiple shades of a monochromatic color. Also included are standalone flat panel displays (FPDs) and LCD monitors.

Table 3-1 (Continued)
Semiconductor Application Market Definitions: Data Processing

Product	Definition
Other Input/Output Device	Includes network computers (NCs), terminals, scanners, multifunction devices (which will include two of the following capabilities: fax, copier, scanner, or printer), monitor speakers, mice, joysticks, keyboards, headsets, card readers, and data converters, among others. Videoconferencing and PC telephony equipment are not included in this category but in the communications segment.
Dedicated System	Dedicated data processing systems such as copiers, personal organizers, chip cards, and other systems.
Copier	Both analog (optical technology) and digital (digital scanning technology) copiers.
Analog Copier	An analog copier captures and transfers images using optical or "light lens" technology in which the image is flash illuminated on the platen, then transferred to the photoconductor through a series of lenses and mirrors. The latent image is then transferred from the photoconductor to paper through the electrophotographic process.
Digital Copier	A digital copier captures images using digital scanning and transfers images using electronic impulses in which the image is scanned from the platen and digitized into electronic data. The electronic data is processed to enable the image to be transferred to the photoconductor. The electronic image data is transferred to the photoconductor through the light impulses of a laser or LED to "write" the image to the photoconductor material. The latent image is then transferred from the photoconductor to paper through the electrophotographic process, as with an analog copier.
Expandable Organizer (Personal Organizer)	A general-purpose computer that is distinguished by its size, in addition to its functionality. Organizers measure about 3 x 6 x 0.75 inches, weigh less than one pound, have a keyboard, and operate on batteries. Expandable organizers are distinguishable by the ability to allow the user to add applications and memory and by expansion that is typically proprietary to a particular device or device family. The primary application is personal information management. Organizers typically have proprietary operating systems. Personal organizers may eventually include some wireless communications capability. Examples are the Psion Siena and Sharp Zaurus.
Chip Card	A flat, plastic card, the size of a credit card, that has one or more integrated circuits on board. A chip card can exchange data with a chip card reader that physically interfaces with the card or uses radio frequency (RF) signals to add or extract data (contact or contactless).
Memory Card	A chip card that has a memory IC on board, most commonly EEPROM. Memory cards do not have a microprocessor or microcontroller but may include other types of logic on board, such as security or cryptography functions.
Smart Card (IC Card)	A chip card that has a microprocessor or microcontroller on board.
Other Dedicated System	Includes calculators, typewriters, word processors, point-of-sale systems (cash registers, bar code readers, and credit card checkers), dictating/transcribing equipment, and funds-transfer machines (ATMs/cash dispensers), among others.

Table 3-1 (Continued)
Semiconductor Application Market Definitions: Data Processing

Product	Definition
Other Data Processing	Includes sound/audio, digital, and graphics accelerator boards. This includes all boards, whether shipped to computer OEMs or to a channel.
Sound/Audio Board	PC add-in cards that are audio-centric and are compatible with industry-standard sockets.
Digital Video Board	PC add-in cards that are digital video-centric and are compatible with industry-standard sockets. This category includes DVD-video decode and encode boards.
Graphics Accelerator Board	PC add-in cards that are graphics-centric and are compatible with industry-standard sockets.

Source: Dataquest (September 1998)

Table 3-2
Semiconductor Application Market Definitions: Communications

Product	Definition
Communications	**Includes premise telecom equipment, public telecom equipment, mobile communications equipment, broadcast and studio equipment, and other telecom equipment.**
Premise Telecom	Includes telecommunications equipment on private premises such as image and test communication equipment, data communication equipment (WAN/LAN and remote access), premise voice systems, and desktop terminals (telephones excluding mobile handsets).
Image and Text Communications	Includes fax machines, video teleconferencing, telex/teleprinters, and videotex.
Facsimile Machine (For Facsimile Card, See Modem)	An electronic device that transmits printed matter or pictures and reproduces them. Includes those with answering machines and cordless handsets.
Video Teleconferencing	Equipment used to compress and play real-time video of meetings between groups or individuals. The category includes equipment that is permanently installed and configured in a room, equipment that can be moved from room to room on a rolling cart and that uses dedicated communications equipment apart from the computer (which in most cases is a workstation but could be a PC), equipment integrated into a PC or workstation (generally on one board that sits in a bus slot), and voice recognition boards that recognize human speech and translate it to computer text; it includes video telephones.
Telex/Teleprinter	A typewriterlike terminal with a keyboard and built-in printer, often a portable unit.
Videotex	An electronic service that provides access to remote computer databases using a computer, a terminal, or a modified television. Includes both "broadcast" videotex (one-way digital data transmissions) and "interactive" videotex (two-way, interactive communication). Broadcast videotex includes Oracle and Ceefax (British). Interactive videotex includes the Prestel (British) and Teletel (French) systems.
Data Communications Equipment	Includes modems, digital WANs, front-end processors, LANs, remote access equipment, and very small-aperture terminals (VSATs).
Modem (Modem Card and Fax Card)	An electronic device that provides modulation and demodulation functions for data signals transmitted over telephone lines. It converts digital data to analog data for transmission over leased lines or the analog public switched telephone network (PSTN). The category includes internal card modems, external modems, PC card modems, and fax cards.
Digital WAN System	The hardware and peripheral equipment that enable connections of multiple local area networks. Connections are made with a high-speed digital line called a backbone. Equipment includes T/E1 and T/E3 carrier multiplexers, fractional and sub-T1 multiplexers, inverse multiplexers, asynchronous transfer mode (ATM) concentrators, integrated access devices (IADs), cell switches (ATM switches), frame relay switches and access devices, and X.25 packet assembler/disassemblers and switches. Includes data service units (DSUs) and channel service unit (CSUs).

Table 3-2 (Continued)
Semiconductor Application Market Definitions: Communications

Product	Definition
Front-End Processor	Input/output system that interfaces with telecommunications lines for large server systems.
LAN Card	Local area network cards, or network interface cards (NICs), are the printed circuit boards that plug into the expansion slot or slots of a PC, workstation, server, or host terminal to allow connection to a LAN. NICs are designed in accordance with either IEEE or ANSI protocol standards; the most common are Ethernet, token ring, fiber-distributed data interface (FDDI), and ATM. (Workstation and host NICs are segmented into only FDDI, ATM, and Others categories.)
LAN/Internetworking	Includes hubs, switches, and routers.
Hub	A shared-media hub is a LAN device that connects multiple PCs through one segment on the network. For example, on a 12-port Ethernet hub, all ports share the 10-Mbps bandwidth available. A hub typically supports centralized control of optional functionality such as port monitoring and connectivity status.
Switch	A LAN device that provides a discrete LAN segment to one or more users on each switched port. For example, on a 12-port Ethernet switch, each port has its own dedicated 10-Mbps bandwidth. Switches are managed in a fashion similar to hubs. Switches that include layer-3 capability can also support routing functionality (see routers).
Router	A network control device used to determine the path for data transmission between devices within a network and between devices in different networks. Routers are typically software controlled and can be programmed, for example, to provide the least expensive, fastest, or least congested of the available data paths, depending on the network configuration and administrative preferences. Routers can also be deployed as filtering agents to provide discriminatory access to certain network segments and resources.
Remote Access System	Includes remote access concentrators and remote access servers. Remote access concentrators are very high-density systems with channelized T1/E1 or T3/E3 interfaces that combine modem pools, routing, and remote access server functionality into a single platform. Remote access servers are low density, with the largest having more than eight ports.
VSAT	A very small-aperture terminal (VSAT) is a satellite data communications terminal.

Table 3-2 (Continued)
Semiconductor Application Market Definitions: Communications

Product	Definition
Premise Voice System	Includes premise telecommunications functions as detailed below
Premise Switching	Voice equipment that provides switching or call-routing functions. Includes such equipment as PBX telephone systems (a telephone switching system on customer premises that allows telephones to interface to the public telephone central exchange or office when the user dials an access code) and key telephone systems (a customer-premises telephone-switching system that allows telephones to interface to the public telephone central exchange office only via key access, without using an access code). This category includes the electromechanical 1A2 and electronic segments. Requires the use of station equipment designed for the systems and key hybrid systems. Premise line cards are included within the equipment.
Voice Messaging	A computer-based system that enables flexible, nonsimultaneous voice communications.
Interactive Voice Response	A system that allows a user to access a host computer or resident database through the use of a keypad of a touch-tone telephone or through voice-recognition technology. Once the database is accessed, the user can input data, extract data, or manipulate data found in the computer database.
Automatic Call Distributor	A specialized phone system used for handling and routing many incoming calls.
Telephone Terminal	A multiplexer where all tributaries are terminated from the high-speed signal. The category includes answering machines and corded and cordless telephones; does not include cellular/ broadband PCS/ESMR phones.
Answering Machine	Both standalone and integrated answering machines, including any telephone terminal that includes an answering machine. Integrated telephone answering machines include devices that can play an outgoing message and record an incoming message and that include a telephone; they may be solid state (digital) or tape-based. Standalone answering machines include devices that can play an outgoing message and record an incoming message but that exclude a telephone; they may be solid state (digital) or tape based. To avoid double-counting, any corded or home cordless telephone that has an integrated answering machine is included in the answering machine category. Excluded are fax machine/answering machine products, which are categorized under Facsimile.
Telephone	Customer premise equipment (CPE) capable of transmitting voice communications via either wireless or wireline access. Includes corded telephones and cordless telephones and others; excludes mobile handsets.
Corded Telephone	Includes standard corded telephones and multifunction corded telephones.
Standard Telephone	Includes all one- and two-piece telephones that connect by a cord directly to the PSTN or a PBX. These have a limited range of additional capabilities; as a maximum, these would include a "last-number redial" facility and limited telephone number memory (a maximum of 10 numbers).

Table 3-2 (Continued)
Semiconductor Application Market Definitions: Communications

Product	Definition
Multifunction Corded Telephone	Includes feature, multiline, smart telephones, and standalone caller ID boxes. Feature telephones include, as a minimum, a liquid crystal display, last-number redial, and memory for 10 or more telephone numbers. They usually also include on-hook dialing or speakerphone capability. Multiline telephones have more than one phone line attached. Smart telephones are highly featured and may have VGA display, caller ID, an answering machine, and a modem, among other features.
Cordless Telephone	A telephone for use with the PSTN comprising two separate components: a portable handset containing microphone, loudspeaker, and dial keypad and a fixed base PSTN access unit, which are interconnected by a radio link rather than a wire. This category includes all telephones with a handset that has no wired connection to the PSTN or PBX. The major difference between cordless telephones and cellular phones is the lack of ability to roam from one base station to another or the ability to roam only at pedestrian speeds; these are categorized as home based and low mobility. Home-based cordless handsets are distinguished by the ability to communicate only with one base station in the home or small business. Low-mobility cordless handsets are cordless handsets that can be used to roam outside the home and can communicate with a service provider's infrastructure or multiple base stations in an office. They are usually distinguished from cellular by being able to communicate only at pedestrian speeds. Includes analog cordless telephones and digital cordless telephones.
Analog Cordless	Current examples of analog cordless are single-channel, 10-channel, 24-channel, CT-0, CT-1, and 900-MHz analog.
Digital Cordless	Current examples of digital cordless are PHS, DECT and CT-2, 900-MHz digital, and 900-MHz spread spectrum, among others.
Internet/Screen Phones	Telephone-based Internet appliances that typically incorporate touch screens or small keyboards. These devices often support both Internet browsing and e-mail functions. Likewise, they generally feature caller ID and personal information management functions. This category also includes standalone Internet telephony devices that transmit packetized voice over data networks.
Other Telephone Terminal	Includes standalone caller ID boxes, audioconferencing systems, and telephone headsets, among others.
Public Telecom	Key equipment involved in the public switching and transmission markets.
Transmission	Includes fiber-optic (SONET/SDH) and nonfiber-optic transmission systems consisting of primarily digital cross-connects, digital access transceivers, multiplexers, repeaters, optical fibers, wireless transceivers, power systems, and optical network units. Transmission systems comprise the local telephone line (local loop), the trunk lines (conduits between switches), and the long distance lines.
Central Office Switch	A telecommunications switch used by public carriers and competitors; includes subscriber line cards.

Table 3-2 (Continued)
Semiconductor Application Market Definitions: Communications

Product	Definition
Mobile Communications	Includes cellular/broadband PCS/ESMR handsets, pagers, and mobile communications infrastructure, among others.
Cellular/Broadband PCS/ ESMR Handset	Includes analog cellular and digital cellular/broadband PCS/ESMR handsets.
Analog Cellular	Includes all AMPS, TACS, NMT, and other cellular handsets.
Digital Cellular/Broadband PCS/ESMR	Includes all handsets (hand portable, transportable, and mobile) that have a radio link to a cellular or microcellular base station. The cellular system maintains a control link with each handset, whether stationary or moving at speed, and controls an automatic seamless handover from one cell base station to the adjacent cell as the handset user moves. Includes handsets that conform to the following standards: GSM, DCS 1800, PCS 1900, NA-TDMA (IS-54/ 136), CDMA (IS-95), PDC, and Omnipoint. Also includes any hybrids of the above, including cellular cordless handsets, ESMR handsets, and next-generation products such as Universal Mobile Telephone System (UMTS) and Future Public Land Mobile Telephone System (FPLMTS). Also includes smart phones, a category of wireless offering advanced voice and data capabilities such as fax and e-mail, Internet access, data access, and a schedule manager.
Pager (One- and Two-Way)	Includes all tone-only, tone-and-voice, digital (numeric), and alphanumeric paging devices; also includes paging devices developed for use in narrowband PCS service. These pagers have limited two-way messaging capability and can also serve as "mobile answering machines." Also includes pagers that have acknowledgment capability.
Mobile Communications Infrastructure	A system that includes base station and microcell equipment for PCS, cellular, paging, and other wireless radio communications. Interconnection between cell sites and mobile telephone switching offices (MTSOs) is typically done via microwave links, fiber optics, or high-capacity landlines. Two components are the base station controller (BSC) and the switch. The BSC controls the voice channels and power controls.
Other Mobile Communications	Includes two-way land mobile radio (walkie-talkies), emergency equipment for police and fire departments and the U.S. Secret Service, taxi communications, and radio checkout, among others.
Broadcast and Studio	Includes audio, video, and other broadcast and studio equipment.
Audio	Broadcast and studio audio equipment.
Video	Broadcast and studio video equipment.
Other Broadcast and Studio	Includes transmitters and RF power amplifiers, studio transmitter links, cable TV equipment (head end and transmission), closed circuit TV equipment, and other studio/theater and broadcast and sound equipment; also includes all equipment related to these items.
Other Telecom	Other telecom equipment not elsewhere counted, such as intercommunications systems.

Source: Dataquest (September 1998)

Table 3-3
Semiconductor Application Market Definitions: Industrial

Product	Definition
Industrial	**Includes security/energy management, manufacturing systems, test and measuring equipment, medical equipment, and other industrial systems.**
Security/Energy Management	Includes alarm systems and energy management.
Alarm System	Includes intrusion detection and fire detection systems.
Intrusion Detection	Includes all equipment for intrusion detection, such as control panels, touch pads, motion detectors, and alarms; excludes closed circuit TV, which is in the communications segment under Broadcast and Studio.
Fire Detection	Includes all equipment for fire detection, such as smoke alarms, phone interconnects, touch pads, and control panels.
Energy Management	Includes heating, ventilation, and air conditioning systems; excludes residential systems, which are included in Consumer Appliances.
Manufacturing System	Includes semiconductor production equipment, control and process control equipment, control and processing display equipment, and robots.
Semiconductor Production	Semiconductor manufacturing equipment for fabrication, such as steppers, spray processors, and scrubbers.
Control	Includes motor controls, starters, contactors, pilot circuit devices, crane controls, and other controls and parts.
Process Control	Controls for temperature, liquids, gas, and other variables, such as thermostats.
Control and Processing Display	Includes electronic systems (unified and nonunified architecture type), multifunction process computers, pneumatic systems, annunciators, physical property and kinematic test and measuring equipment, and other process instruments and parts.
Robot	Includes both servo-controlled and nonservo-controlled robots, hobby and experimental robots, and all accessories and parts.
Test and Measuring Equipment	Includes automatic test equipment (ATE)-semiconductor equipment, nuclear electronics, and other test and measurement equipment.
ATE-Semiconductor Equipment	Includes semiconductor dedicated and board automatic test equipment.
Nuclear Electronics	Includes all equipment using nuclear technology except diagnostic medical equipment and all specialized equipment for nuclear applications.
Other Test and Measurement	Includes equipment for testing, measuring, and analyzing, such as microwave testers, time measuring and counting equipment, multimeters, signal-generating equipment, and standards and calibration equipment, oscilloscopes, and test and measurement equipment.

Table 3-3 (Continued)
Semiconductor Application Market Definitions: Industrial

Product	Definition
Medical Equipment	Includes diagnostic, therapeutic, patient monitoring and measuring systems, surgical support equipment, and irradiation equipment.
Diagnostic	Includes electrocardiography, electromyography, endoscopic, respiratory, and audiological equipment; scanning devices and nuclear magnetic resonance imaging devices; and other diagnostic equipment.
Therapeutic	Includes pacemakers, defibrillators, electrosurgical and diathermy equipment, and other therapeutic equipment.
Patient Monitoring/Measuring System	Includes equipment for intensive care, perinatal care, respiratory care, and other patient monitoring equipment.
Surgical Support	Includes equipment for surgical support systems.
Irradiation Equipment	Includes medical X-ray equipment of all types such as diagnostic, dental, and therapeutic, as well as parts and accessories.
Other Industrial System	Includes vending machines, automatic service equipment, commercial clothes-washing equipment, teaching machines and aids, particle accelerator electronic equipment, electron microscope, and scientific equipment not elsewhere counted.

Source: Dataquest (September 1998)

Table 3-4
Semiconductor Application Market Definitions: Consumer

Product	Definition
Consumer	**Includes audio, video, personal electronics, appliances, and other consumer electronics.**
Audio	Includes consumer audio equipment.
Personal/Portable Stereo	A personal/portable stereo with any combination of compact disc player, MiniDisc player, DVD audio player, cassette player/recorder, or headphones; also includes boom boxes and clock radios.
Stereo Component	Includes radio receivers, cassette players/recorders, CD/MD/DVD audio players, amplifiers, equalizers, mixers, and speakers that can be individually purchased for the home. Includes rack audio systems (which have rack-mounted components usually sold as a set) and minishelf systems that typically do not have a handle (as boom boxes do) and are not built for portability; excludes personal/portable stereos.
Musical Instrument	Electronic musical instruments such as keyboards.
Video	Includes consumer video equipment.
VCR, VTR	Includes videocassette recorder (VCR) and videotape recorder (VTR); does not include TV-VCR combinations.
Camcorder	Includes analog and digital camcorders.
Analog Camcorder	Traditional analog camcorders, which may include vibration or shake compensation and digital zoom.
Digital Camcorder	Camcorders based on the Digital Video (DV) format specification for home-use digital camcorders.
Videodisc Player	Includes DVD players, laser disc players, and Video CD players. Does not include DVD products targeted at the PC market; those are a subcategory of Optical Disk Drives. Does not include the DVD encode/decode board, which is in Other Data Processing. Video CD players use MPEG-1 technology for storage of full-motion video and are also used in karaoke applications. DVD players use MPEG-2 technology and Dolby digital technology for storage of full-motion video and audio, currently for playback only but eventually for recording and rewriting also. Laser disc players play back video stored in an analog format on an optical disk.
Television	Includes televisions.
Color Television/HDTV	Includes LCD-based and TV-VCR combinations and analog high-definition TV (HDTV) receivers.
Digital Television/DTV	Digital TV (DTV) includes SDTV (standard-definition TV) and digital HDTV.
Black-and-White Television	Monochrome televisions.
Cable/Satellite Set-Top Receiver	TV converter boxes that allow viewers to view programs from cable TV, telephone, or wireless network sources.
Set-Top Box	Converter boxes that sit on top of TVs and allow viewers to view programs from cable TV, telephone, wireless networks, or broadcast satellite sources; includes pay-TV receivers.
Analog Set-Top Box	A set-top box that decodes and enables access to analog-based TV services; includes analog cable, analog satellite, and analog wireless cable.

Table 3-4 (Continued)
Semiconductor Application Market Definitions: Consumer

Product	Definition
Digital Set-Top Box	Digital converter boxes sit on top of a TV and act as converter devices for digital information over cable TV, satellite, terrestrial, telephone, or wireless networks to television sets. These boxes are capable of digital reception and decompression.
Direct Broadcast Satellite	Direct broadcast satellite (DBS) devices have a set-top box element plus a receiving satellite dish to receive signals from a satellite.
Cable TV	TV converter boxes that allow viewers to view digitally compressed programs from cable TV.
Terrestrial	Set-top box receiver/decoder that allows the viewing of digitally compressed TV signals transmitted from land-based TV transmitter masts.
Others	Includes DTV set-top boxes, multipoint multichannel distribution system (MMDS), advanced digital subscriber line (ADSL), and local multichannel distribution system (LMDS) pay-TV receivers.
Internet	Internet television set-top boxes use the television as the primary user interface. These devices are connected to the Internet via the phone line or cable TV line and employ a variety of analog or digital modem technologies. These appliances generally have few or no voice telephone capabilities. This product is exemplified by the WebTV.
Personal Electronics	Includes video games, cameras, electronic watches, clocks, and toys.
Video Game (System and Cartridge)	Microprocessor-based devices that are handheld or console based and play video games housed on cartridges or CD-ROMs; includes CD-ROM peripherals.
Video Game Controller	Controller hardware for both handheld and console video games.
Video Game Cartridge	Video games delivered by semiconductor ROM.
Camera	Includes traditional and digital still cameras.
Digital Still Camera	Still camera that records images on memory chips or a disk instead of film.
Other Camera	Camera that records images on film.
Watch	Electronic watches.
Clock	Electronic clocks.
Electronic Toy	Electronic toys such as remote-control toy vehicles and "talking" toys, among others.
Appliance	Consumer appliances.
Heating, Ventilation, and Air Conditioning	Heating, ventilation, and air conditioning systems for residences.
Microwave Oven	Microwave ovens for residences.
Washer and Dryer	Washers and dryers for residences.
Refrigerator	Refrigerators for residences.
Dishwasher	Dishwashers for residences.
Range and Oven	Includes microwave/range/oven combinations.
Other Consumer	Includes automatic garage door openers, electronic tape measures, electronic tire gauges, and other consumer equipment not counted elsewhere.

Source: Dataquest (September 1998)

Table 3-5
Semiconductor Application Market Definitions: Military/Civil Aerospace

Product	Definition
Military/Civil Aerospace	**Includes radar/sonar/reconnaissance, missile/space, navigation, electronic warfare, aircraft flight systems, and command/control systems.**
Radar/Sonar/Reconnaissance	All forms of radar system (ground, ship, airborne, and space), sonar systems, electro-optic sensors, identify-friend-or-foe (IFF) systems, proximity fuses, passive sensors, and dedicated support equipment; includes both civilian and military use.
Missile/Space	Guidance, control, and electronics payload for spacecraft and their launch systems and dedicated ground support equipment; includes both civilian and military use. Also includes missile guidance and control and dedicated support equipment.
Navigation	Navigation equipment used by aircraft, ships, and ground vehicles, including autopilots, beacons, collision-warning devices, and direction finders; includes both civilian and military use.
Electronic Warfare	Includes countermeasures (for example, jamming), counter-countermeasures, and various specialized electronics and communications intelligence systems.
Aircraft Flight System	Onboard avionics systems (cockpit instruments and distributed controls) not counted elsewhere; includes both military and civilian use.
Command and Control	Specialized computer and networking systems not covered in the data processing and communications categories.

Source: Dataquest (September 1998)

Table 3-6
Semiconductor Application Market Definitions: Transportation

Product	Definition
Transportation	**Includes entertainment, vehicle/body control, driver information, power train, and safety and convenience.**
Entertainment	Currently, this category includes only auto stereo.
Auto Stereo	Includes integrated AM/FM stereo radio receivers, AM/FM radio/cassette combinations, AM/FM radio/cassette/CD combinations, all in-car audio stereo AM/FM radio-based systems, amplifiers, terrestrial digital audio broadcast (DAB) receivers, and DSP surround-sound Pro Logic.
Vehicle/Body Control	Includes antilock braking systems (ABS) and other vehicle/body control.
Antilock Braking System	Includes electronic ABS control units for two-wheel ABS systems, and four-wheel ABS systems for passenger cars, electronic ABS control units for two-wheel and four-wheel ABS systems for light trucks, electronic ABS control units for commercial vehicles, ABS systems for trailers and heavy trucks, and electronic ABS control units for motorcycles; also includes ABS with integrated traction control systems.
Other Vehicle/Body Control	Includes active suspension, central door locking, integrated body computer with security/advanced on-board diagnostics, keyless entry, lighting control, multiplex node control (diagnostic), multiplexed door operations, power window/mirror/seat/sunroof, and tire pressure monitor; also includes dynamic vehicle control systems—semiactive suspension/active suspension, driving stability/chassis control, collision avoidance, and electronic/electrical power steering.
Driver Information	Includes automotive navigation systems and other driver information.
Automotive Navigation System	Includes only navigation systems with CD-ROM digital map system, global positioning system (GPS) positioning, LCD monitor and gyroscope for dynamic vehicle navigation, and visual and audio interaction navigation systems.
Other Driver Information	Includes traffic information systems/traffic guidance systems, route guidance systems, electronically controlled dashboard instrumentation, trip computers, diagnostic displays, digital clocks, digital compasses (electronic), and speech recognition/synthesis.

Table 3-6 (Continued)
Semiconductor Application Market Definitions: Transportation

Product	Definition
Power Train	Includes auto engine control unit (ECU) and other power train.
Auto Engine Control Unit	Includes electronic engine control units for gasoline and diesel fuel carburetor/injection engines for cars and trucks. Electronic engine control units for gasoline-powered cars include electronically controlled carburetor systems, single-point injection systems, and multipoint injection systems; also includes electronic control units where ignition control (breakerless/distributorless or adaptive/digitally programmed) is integrated with carburetor or injection control unit. Electronic engine control units for diesel-powered cars include electronically controlled direct injection systems and indirect injection (distributor) systems; manages spark or fuel injection or both.
Other Power Train	Includes engine immobilizers, cruise control, intelligent cruise control, automatic transmission electronic control units, semiautomatic transmission control, adaptive transmission control, and standalone ignition control systems.
Safety and Convenience	Includes air-bag control units and other safety and convenience systems.
Air-Bag Control Unit	Includes electronic control units for single or dual air-bag systems for driver and front passenger, electronic control units for rear-seat air-bag systems for rear passengers, and electronic control units for side-impact air-bag systems for front and rear-seat passengers.
Other Safety and Convenience	Includes side-impact air-bag crash sensors (front or rear seats), standalone car alarm systems, noise-cancellation systems/electronic mufflers, and heating, ventilation, and air conditioning (HVAC) and climate control systems (electronically adjusted temperature control).

Source: Dataquest (September 1998)

Chapter 4
Worldwide Geographic Region Definitions

Definitions

The following section provides Dataquest's regional geographic definitions. The regional country definitions used for Dataquest's semiconductor application markets research differ somewhat from the official definitions but match at the regional level.

Asia/Pacific Region

Countries being covered are Australia, China, Hong Kong, India, Indonesia, South Korea, Malaysia, Singapore, Taiwan, and Thailand.

Rest of Asia/Pacific

The rest of Asia/Pacific includes American Samoa, Ashmore and Cartier Islands, Baker Island, Bangladesh, Bhutan, Bouvet Island, Brunei, Cambodia, Christmas Island, Cocos (Keeling) Islands, Cook Islands, Coral Sea Islands, Federated States of Micronesia, Fiji, French Polynesia, Guam, Howland Island, Jarvis Island, Johnston Atoll, Kingman Reef, Kiribati, Laos, Macau, Maldives, Marshall Islands, Midway Islands, Mongolia, Myanmar (Burma), Nauru, Nepal, New Caledonia, New Zealand, Niue, Norfolk Island, Northern Mariana Islands, North Korea, Pakistan, Palau, Palmyra Atoll, Papua New Guinea, Paracel Islands, Philippines, Pitcairn Islands, Solomon Islands, Spratly Islands, Sri Lanka, Tokelau, Tonga, Tuvalu, Vanuatu, Vietnam, Wake Island, Wallis and Futuna, and Western Samoa.

Western Europe Region

Countries being covered are Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and United Kingdom.

Rest of Western Europe

The rest of Western Europe includes Andorra, Cyprus, Faroe Islands, Gibraltar, Greenland, Guernsey, Iceland, Isle of Man, Jersey, Liechtenstein, Luxembourg, Malta, Monaco, San Marino, and Svalbard.

Central/Eastern Europe Region

Countries being covered are Belarus, Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Russia, Slovakia, and Ukraine.

Rest of Eastern Europe

The rest of Eastern Europe includes Albania, Armenia, Azerbaijan, Bosnia and Herzegovina, Croatia, Georgia, Kazakhstan, Kyrgyzstan, Macedonia, Moldova, Romania, Slovenia, Tajikistan, Turkmenistan, Uzbekistan, and Yugoslavia (Serbia and Montenegro).

Japan Region

Japan

Latin America Region

Countries being covered are Argentina, Brazil, Chile, Colombia, Mexico, Peru, and Venezuela.

Rest of Latin America

The rest of Latin America includes Anguilla, Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, Bermuda, Bolivia, Cayman Islands, Clipperton Island, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, Falkland Islands (Islas Malvinas), French Guiana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Montserrat, Navassa Island, Netherlands Antilles, Nicaragua, Panama, Paraguay, Puerto Rico, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Tortola (British Virgin Islands), Trinidad and Tobago, Turks and Caicos Islands, Uruguay, and Virgin Islands (St. John, St. Croix and St. Thomas).

Middle East/Africa Region

No countries are being covered in this region.

Rest of Middle East/Africa

The rest of the Middle East/Africa region includes Afghanistan, Algeria, Angola, Bahrain, Bassas da India, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Cote d'Ivoire, Djibouti, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Europa Island, Gabon, Gambia, Ghana, Glorioso Islands, Guinea, Guinea-Bissau, Iran, Iraq, Israel, Jordan, Juan de Nova Island, Kenya, Kuwait, Lebanon, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mayotte, Morocco, Mozambique, Namibia, Niger, Nigeria, Oman, Qatar, Reunion, Rwanda, Saint Helena, Sao Tome and Principe, Saudi Arabia, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Syria, Tanzania, Togo, Tromelin Island, Tunisia, Turkey, Uganda, United Arab Emirates, Western Sahara, Yemen, Zaire, Zambia, and Zimbabwe.

North America Region

Countries being covered are Canada and the United States.

Semiconductor Applications Regional Definitions

As noted previously, the semiconductor regional definitions differ somewhat from Dataquest standard regional definitions because of semiconductor industry reporting standards. The following shows the regional definitions (for specific country detail in each region, see the prior section):

- Americas
  - North America
  - Latin America

- Japan
- Europe, Middle East, and Africa
  - Western Europe
  - Central and Eastern Europe
  - Middle East/Africa
- Asia/Pacific

Chapter 5
Research Metrics

Overall general research metric definitions are as follows:

- Manufacturer: A producer of branded or unbranded finished products. A manufacturer could be a contract manufacturer, an original manufacturer, or both.
- Original component manufacturer: A manufacturer that designs and produces components such as semiconductors and design tools either for sale under its brand name or for use internally.
- Original equipment manufacturer (OEM): A manufacturer that produces and sells goods from components usually bought from other manufacturers. An OEM makes, designs, or builds complete products for sale.
- Contract equipment manufacturer: A manufacturer that produces equipment for sale under another company's brand to the specifications of the other company's design.
- Contract component manufacturer: A manufacturer that produces components under an original manufacturer's brand name or that produces components for a vendor that brands them.
- Vendor: A vendor is the last entity in the chain that brands a product and sells it either directly to end users or through a channel. A vendor may design and manufacture its own products, assemble complete systems from components produced by others, or procure products from an OEM or contract manufacturer. A vendor may also provide services, maintenance or nonmaintenance, for its own products or for other vendors' products and may also provide services for information technologies.
- End user: The final user of a product or the final purchaser of maintenance or nonmaintenance service for the information technology products. The final purchaser may or may not be the actual end user, but the product stops at the end user.
- Brand: The name put on a product marked by an original manufacturer's or vendor's name.
- Production location: The location where the bulk of the semiconductor content is added to the electronic equipment.
- Equipment factory revenue: The value of production. It is the money value of the commodity transaction between the manufacturer and the point of entry into distribution.
- Equipment factory units: The sum of finished products from a factory.
- Equipment unit shipments: The sum of finished products delivered from the factory to the end user, another vendor, or a distribution channel.
- Factory average selling price (ASP): The average price received by a manufacturer for a finished product delivered to the end user, another vendor, or a distribution channel.

- Compound annual growth rate (CAGR): The annualized rate of revenue or unit shipment growth over a given time period, assuming growth takes place at an annually compounded rate.
- Semiconductor content: That portion of equipment value attributable to semiconductors.
- Semiconductor total available market (TAM): Estimated total semiconductor consumption by the producers of a particular type of electronic equipment.

Chapter 6
Exchange Rate Definitions

Exchange rates are the market-determined rates at which foreign currencies may be converted into a specified currency (for example, U.S. dollars) expressed as foreign currency units per one unit of the specified currency (for example, yen per dollar). The process for determining the exchange rates is outlined in the Dataquest Research Methodology Guide (RSOP-NA-GU-9703).

Dataquest's research of electronic equipment markets and semiconductor consumption within those markets combines data from many countries. Most countries use currencies other than the U.S. dollar, and these have fluctuating exchange rates relative to the dollar. Because we research electronic equipment production and semiconductor consumption in several regions of the world with the goal of reporting comparable regional values and worldwide market trends, Dataquest uses the U.S. dollar as a common currency for comparisons and aggregation. As a general rule, we collect data and formulate forecasts in local currencies and then convert them to U.S. dollars using applicable exchange rates. Dataquest maintains a database of historical exchange rates that is updated monthly. Dataquest does not forecast exchange rates. Instead, we assume future exchange rates will reflect current exchange rates. Dataquest always reports the exchange rates incorporated in our research.

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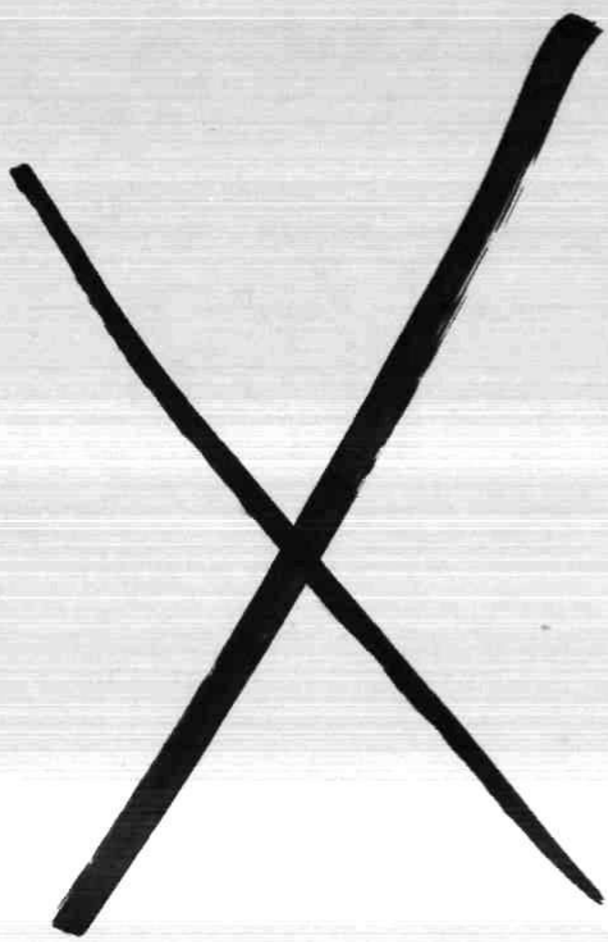

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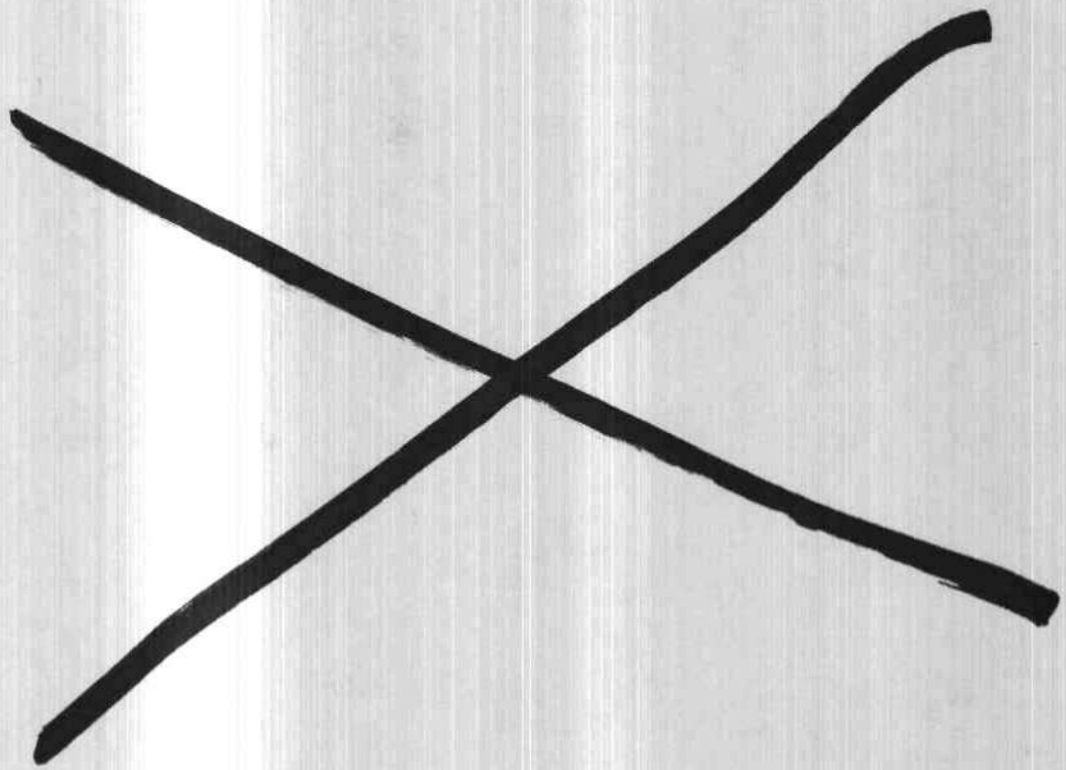

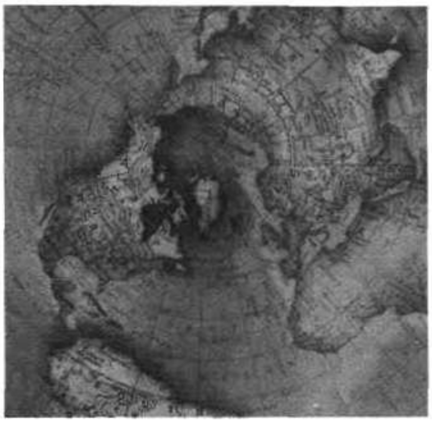

Dataquest

Trends in the PC Graphics and Audio Chip Industries

Industry Trends

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MARIA VALENZUELA

Program: Personal Computer Semiconductors and Applications Worldwide
Product Code: PSAM-WW-IT-9801
Publication Date: June 29, 1998
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Trends in the PC Graphics and Audio Chip Industries

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Chapter 1
Executive Summary

In contrast to the bull market that characterized the U.S. stock markets through 1997, PC graphics and PC audio vendors suffered bearish business conditions. Price pressure, sluggish revenue growth, and high levels of competition for mainstream products defined these markets last year.

The PC audio chip market actually suffered a decline in revenue because of a DRAM-like price collapse on single-chip Industry Standard Architecture (ISA)-based products. Intense price pressure also helped to postpone the shift from ISA to PCI for the audio interface. This year brings new opportunities for revenue growth and a bolder shift to PCI as new low-cost products emerge. Long-term growth for PC audio is boosted by higher attach rates but tempered by the forecast popularity of basic audio that requires only an Audio Codec 97 (AC-97) codec without a separate digital controller. Differentiation for vendors is critical but hinges mostly on advanced audio features that are unlikely to be required in business PCs.

The PC graphics chip market slowed last year to single-digit growth, saved from decline only by revenue gains in the mobile graphics segment. A wholesale shift to 3-D graphics is driven by low prices rather than compelling productivity applications for the typical business desktop PC. Embedded memory is the primary revenue driver for the mobile graphics segment.

Overall market conditions will improve for the PC graphics and audio chip markets for 1999 to 2000; 1998 will continue to be volatile. Vendor consolidation coupled with new hardware requirements driven by advances in software, such as Microsoft Corporation's Chrome GUI, will boost the profitability of these markets through the five-year forecast horizon.

Project Analyst: Geoff Ballew

Chapter 2
Introduction and Methodology

This document provides reference information and analysis about the markets for semiconductor devices in personal computers.

The information in this report is gathered from both primary and secondary sources. Primary sources include surveys and interviews of industry vendors and customers, as well as analyst knowledge and opinions. Secondary sources include government and trade sources on sales, production, trade, and public spending. Semiconductor content assumptions are based on both surveys of producing OEMs and physical teardown evaluations by Dataquest analysts of representative personal computers.

The forecast methodology is based on various methods and assumptions, depending on the specific market. To form a solid basis for projecting system demand and capital, government and consumer spending, assumptions are made for various regions of the world. For specific markets, saturation and displacement dynamics are considered as well. Key exogenous factors such as new software introductions, exchange rate changes, and government policies are also considered. Semiconductor content forecasts are based on interviews of system marketers and designers (including makers of enabling semiconductor technology), along with an analysis of historical trends.

Chapter 3
Audio Trends

The year 1997 was a rough year for the PC audio chip industry. Plunging average selling prices (ASPs) resulted in a smaller market for calendar year 1997 compared to 1996 despite rising unit shipments. The audio chip market took the brunt of the price pressure in the PC market as PC OEMs worked to deliver compelling systems for less than $1,000. Price pressure slowed the adoption of PCI audio in favor of sticking with the tried-and-true single-chip ISA products. This chapter includes a discussion of technology trends, block diagrams of several audio implementations, a table comparing the features of several audio chips, market share statistics, and a forecast.

Technology Trends

Synthesis Techniques

Audio chip vendors have made wavetable synthesis ubiquitous by providing software wavetable engines with most audio chipsets that do not have a hardware wave table synthesizer. Microsoft plans to include a software wavetable engine as a standard feature of Windows 98. FM synthesis is still provided with dedicated logic for purposes of backward compatibility with legacy software but will fade slowly as the industry moves away from the ISA architecture. Ironically, after all of the controversy surrounding audio synthesis on the PC, many software developers have made the point moot by relying more on playback of .wav files or CD-Audio material from a CD-ROM or a rigid disk drive (RDD).

The controversies of audio synthesis involve the hoops the industry has jumped through to maintain compatibility with the SoundBlaster legacy audio standard as well as inconsistent playback quality for wavetable audio. Software developers have been unpleasantly surprised by variations in playback quality, which makes it difficult for them to manage playback quality trade-offs through the design process.

Bus Interface

True plug-and-play for the audio subsystem remains in the future as price pressure and legacy software issues postpone the transition to PCI from ISA. Last year, audio board vendors shipped over 2 million PCI audio cards. Sales of PCI audio chips for implementation on PC motherboards were minimal for the same period. This trend is changing, however, with several cost-reduced PCI audio chips available today. Additionally, the PC99 requirement of no ISA-based peripheral cards gives PCI audio a much-needed boost. This requirement will help shift the industry to PCI audio, as will some low-cost PCI-based parts that have been recently announced. ISA audio chips can still be soldered to the motherboard but not put on ISA add-in cards. The result is a bolder shift to PCI beginning the second half of this year but with long life expectations for the ISA audio chip market. We will not see a watershed period where the majority of new designs change overnight.

AC-97

Audio Codec 97 (AC-97) is a specification for an audio codec but, the term is also used to describe chip products that meet the specification. The near-term vision behind AC-97 is to improve PC audio quality by separating the digital controller and DSP functions of an audio subsystem from the codec functions. This reverses the trend of integration that has characterized the audio chip industry during the past several years. Cost cutting drove the integration of audio subsystems to single-chip implementation, but AC-97 promises to take cost cutting one step further as CPUs continue to get faster. AC-97 involves eliminating the digital controller and DSP elements of audio peripheral chips for low performance implementations. If a system logic chip set has an AC-97 interface, an audio subsystem can be added using only an AC-97 codec and software running on the host CPU for the controller and DSP functions.

Modem on Audio

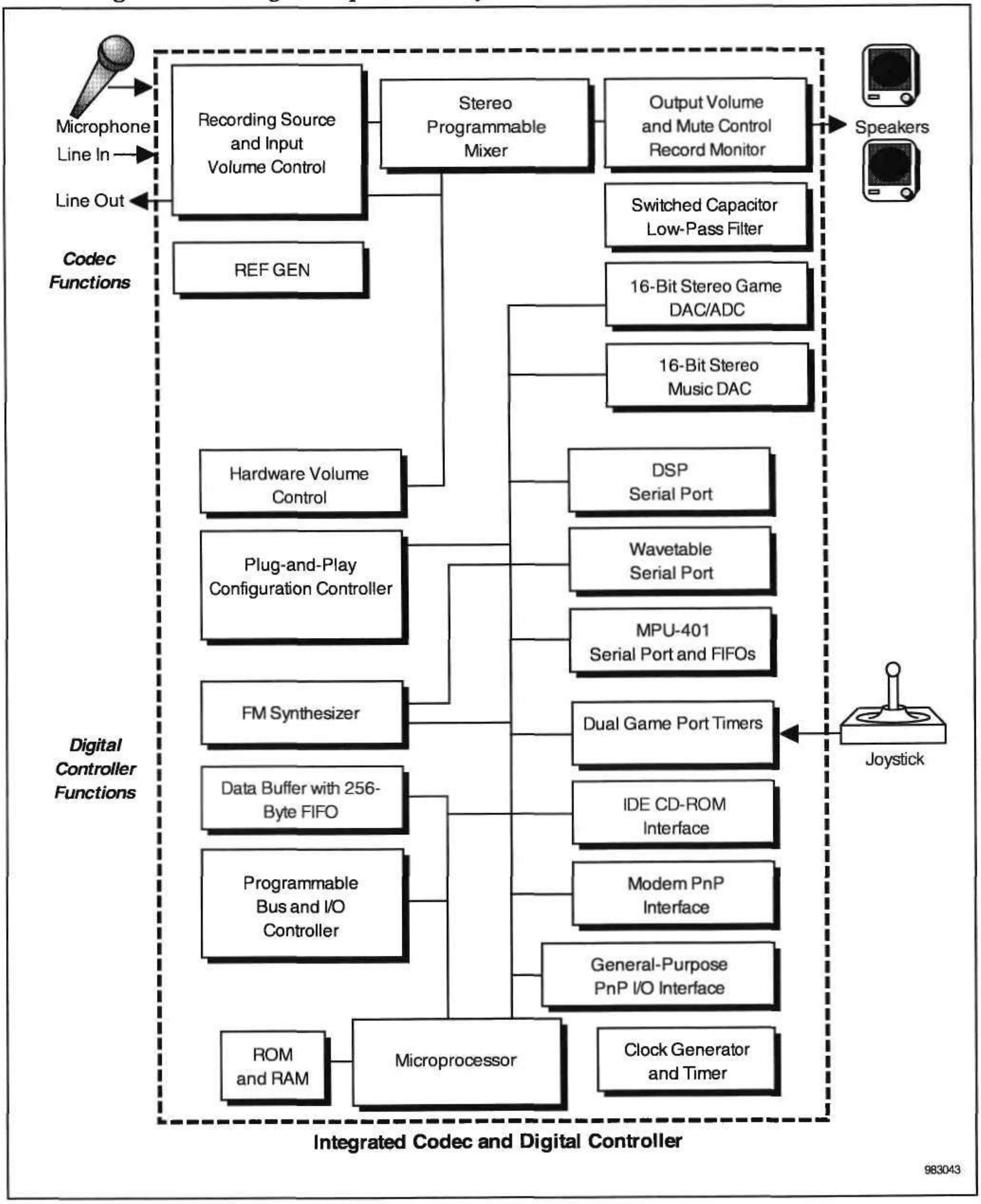
The trend of modem functions on the audio subsystem is becoming market reality. Combination solutions in the past, most notably IBM's Mwave and more recently Oak's Tel-Audia, have failed, but the landscape is changing to give dual-purpose, audio and modem chipsets a boost. High-end audio features effectively require powerful DSP cores and those same cores can be used as a modem data pump too. Dataquest believes the audio vendors have made more progress on offering "modem on audio" than the modem vendors have made toward offering "audio on modem." Rockwell's acquisition of Brooktree makes Rockwell the only one of the big three modem chip vendors with any significant audio technology. Lucent Technologies and Texas Instruments Inc. have not disclosed any significant PC audio technology. Two audio chip vendors, Cirrus Logic and Analog Devices, have a history of selling traditional modem chipsets, but Dataquest believes all significant audio chip vendors are investigating modem functions as a way to add value to their audio solutions.

Figures 3-1 and 3-2 show audio functions are integrated into one or two chips for a complete audio chip subsystem. Table 3-1 shows the main features of a variety of currently available and announced parts.

Market Statistics

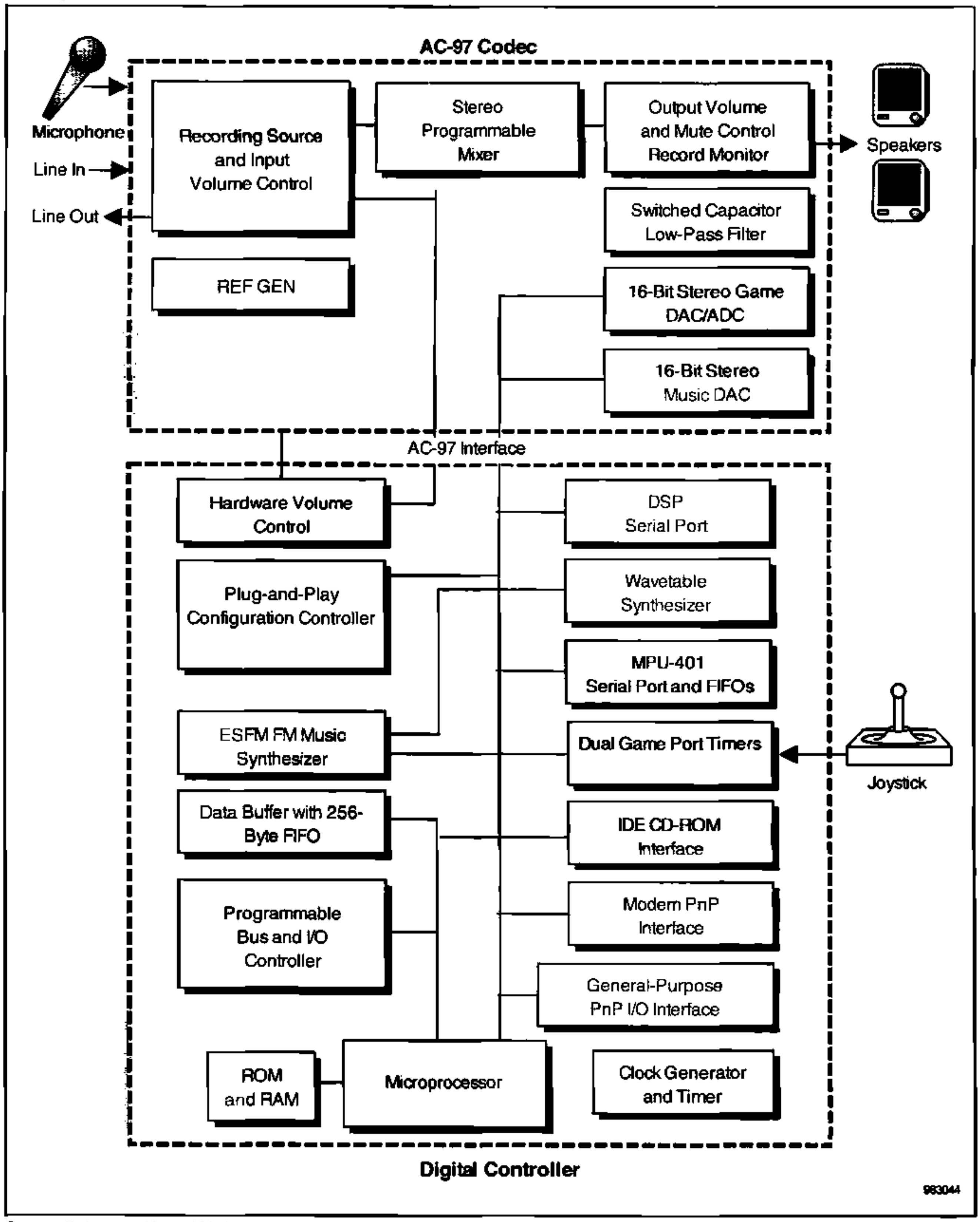
The rank order of the largest audio chip vendors did not change significantly from 1996 to 1997, but that stability belies the competitive changes within different segments of the PC audio chip market. Creative Technologies' business shifted back to mostly board-level products rather than the more even mix of chip-level and board-level sales the company had in 1996. Creative has the strongest brand name in the PC audio card business and has refocused its business on board-level sales. ESS Technology is the largest vendor when ranked by unit shipments but is shown as the No. 2 vendor because Dataquest uses revenue for market share rankings. The only change in rank order was Yamaha's jump to the No. 3 position, displacing Cirrus Logic. Yamaha's own board-level sales and design presence on a variety of Intel motherboards as well as many Toshiba notebook designs boosted demand for Yamaha chips. Table 3-2 shows the 1997 market statistics, with 1996 revenue statistics included as a reference point.

Figure 3-1
Block Diagram for a Single-Chip ISA Subsystem



Source: Dataquest (June 1998)

Figure 3-2
Block Diagram for a Two-Chip Audio Subsystem That Uses an AC-97 Codec, PCI Subsystem



Source: Dataquest (June 1998)

Table 3-1
Feature Comparison of Selected PC Audio Chips

Vendor	Product Name/Number	Type	Synthesis	Spatial Enhancement	True 3-D Sound	Interface	Package
Aureal	Vortex 8820	Integrated controller/codec	FM, WT	Yes	Yes	PCI	TQFP-100
	Vortex 8830	Integrated controller/codec	FM, WT	Yes	Yes	PCI	TQFP-100
Creative Technologies	Vibra 16X	Integrated controller/codec	FM, WT, WG	Yes	No	ISA	TQFP-100
Crystal Semiconductor	CS4237B	Integrated controller/codec	FM	SRS	No	ISA	TQFP-100
	CS4238B	Integrated controller/codec	FM	Qsound	No	ISA	TQFP-100
	CS4610	Controller	WT, WG	None	Yes	PCI	PQFP-100
	CS4611	Controller	WT, WG	None	Yes	PCI	PQFP-100
	CS4297	AC-97 codec	NA	None	NA	AC-97	TQFP-48
ESS Technology	ES1878	Integrated controller/codec	FM	No	No	ISA	TQFP-100
	ES690	Controller	WT	No	No	MPU-401	PQFP-52
Opti	OptiSound 82C931	Integrated controller/codec	FM	None	No	ISA	PQFP-100
VLSI	Songbird VL82C829	Controller	FM, WT, WG	No	Yes	PCI	PQFP-160
Yamaha	OPL3-SA	Integrated controller/codec	FM	No	No	ISA	TQFP-100
	OPL4-ML	Controller	FM, WT	No	No	ISA	TQFP-100
	Sondius-XG	Controller	WT, WG	No	No	ISA	Not Avail

NA = Not available
Source: Dataquest (June 1998)

Table 3-2
PC Audio Chip Market Share Statistics

	Standalone Codecs (K) 1997	Chipsets Shipped on Board-Level Products (K) 1997	Chipsets Sold as Chips (K) 1997	Total Units (K) 1997	Chip Revenue ($M) 1997	Chip Revenue ($M) 1996	Rank 1997	Rank 1996	ASP 1997	Revenue Americas 1997	Revenue Japan 1997	Revenue Europe 1997	Revenue Asia/Pacific 1997
Creative Technologies	-	16,865	1,135	18,000	170	198	1	1	9.44	68	25.5	59.5	17
ESS Technology	-	-	22,300	22,300	150	160	2	2	6.73	37.5	15	22.5	75
Yamaha	3,000	2,000	13,500	18,500	145	56	3	4	7.84	37.7	39.15	1.45	66.7
Cirrus Logic	3,000	-	14,927	17,927	110	97	4	3	6.14	39.6	7.7	11	51.7
OPTi	-	-	5,000	5,000	28	50	5	5	5.60	11	1.375	11	4.125
Aztech	-	3,600	400	4,000	28	22	6	9	6.88	-	-	-	28
Oak Technology	0	0	300	300	5	0	7	-	15.00	-	4.5	-	-
Analog Devices	0	-	500	500	4	43	8	6	7.00	1.4	0.35	0	1.75
S3	-	-	167	167	1	0	9	-	8.00	-	-	-	1.336
Others	81	0	1,100	1,181	5	53	-	-	4.45	-	-	-	5.25
Total	**6,081**	**22,465**	**59,329**	**87,875**	**645**	**678**	-	-	**7**	**195.2**	**93.575**	**105.45**	**250.861**

Source: Dataquest (June 1998)

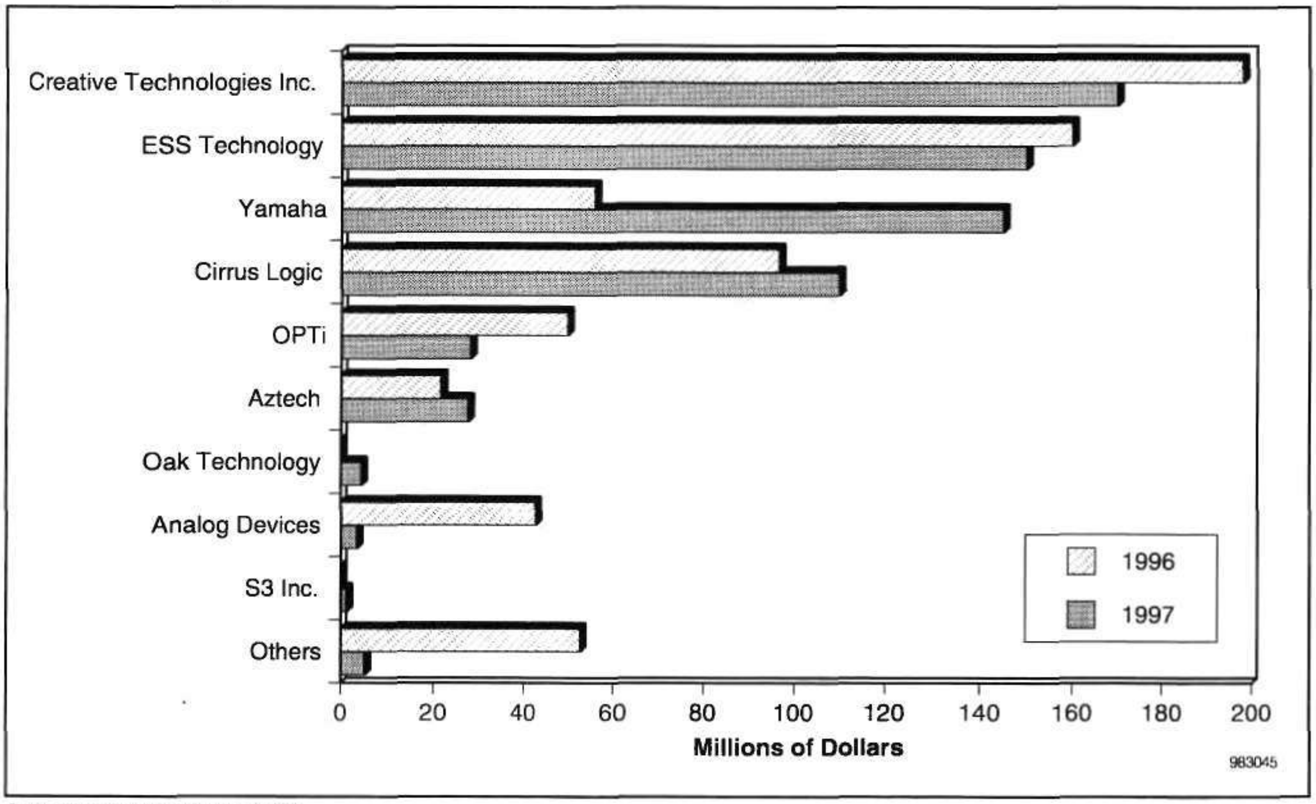
Market Forecast

The year 1997 was a tough year for the PC audio chip industry, with a 5 percent decline in revenue despite sharply higher shipments. Revenue growth returns this year, 1998, but pales in comparison to historical growth rates. Unit growth remains strong as attach rates continue to increase, driven by even lower implementation costs for basic audio features. Several core logic chipsets introduced in the next year will include AC-link interfaces. A system with an AC-link interface requires only an AC-97 codec and a speaker for basic audio. The cost of adding audio features in that case is only a couple of dollars. More expensive solutions must be differentiated with a value proposition vis-à-vis the $2 solution. Opportunities to add value include high-end audio features such as positional 3-D, virtualized multichannel sound, AC-3 decoding, and telephony features. All of these features have impact in consumer PCs. Integration of telephony and audio will also be popular for mobile PCs. That integration allows PC users to turn their PCs into telephone answering machines and fax machines in hotel rooms and other remote locations where analog phone lines exist.

Consumer PCs and mobile PCs are forecast to be the most profitable segments for PC audio chip vendors, because those are the markets where advanced audio functions are most likely to be valued (see Figure 3-3 and Table 3-3). Desktop PC designs marketed for business environments will increasingly get audio features, but basic audio is sufficient for most corporate environments. USB speakers and USB microphones could eliminate analog audio circuitry inside the PC box, but the transition will take several years for mainstream adoption and may not be complete for many years beyond that. USB audio solutions may not be less expensive because D/A or A/D converters will be required in each peripheral, which could increase costs. The chip content of USB audio peripherals is not explicitly included in Dataquest's PC audio chip forecast, but will compete with traditional AC-97 codec business. Dataquest may include a USB audio forecast in the future, but at this time, the revenue forecast for AC-97 codecs effectively includes those functions in digital peripherals. Table 3-4 and Figure 3-4 show the PC audio chip forecast, with PC and workstation unit shipments noted for reference.

Note that the penetration rate of audio feature for PCs and workstations exceeds 100 percent. Retail sales of audio add-in cards as well as motherboard shipments not included in the PC forecast are the cause of the greater-than-100-percent penetration rate.

Figure 3-3
PC Audio Chip Market Share



Source: Dataquest (June 1998)

Table 3-3
Regional Breakouts for PC Audio Chip Revenue (Percent)

Region	Revenue (%)
Americas	30.3
Europe, Africa, Middle East	14.5
Japan	16.3
Asia/Pacific	38.9
Total ($M)	**645.1**

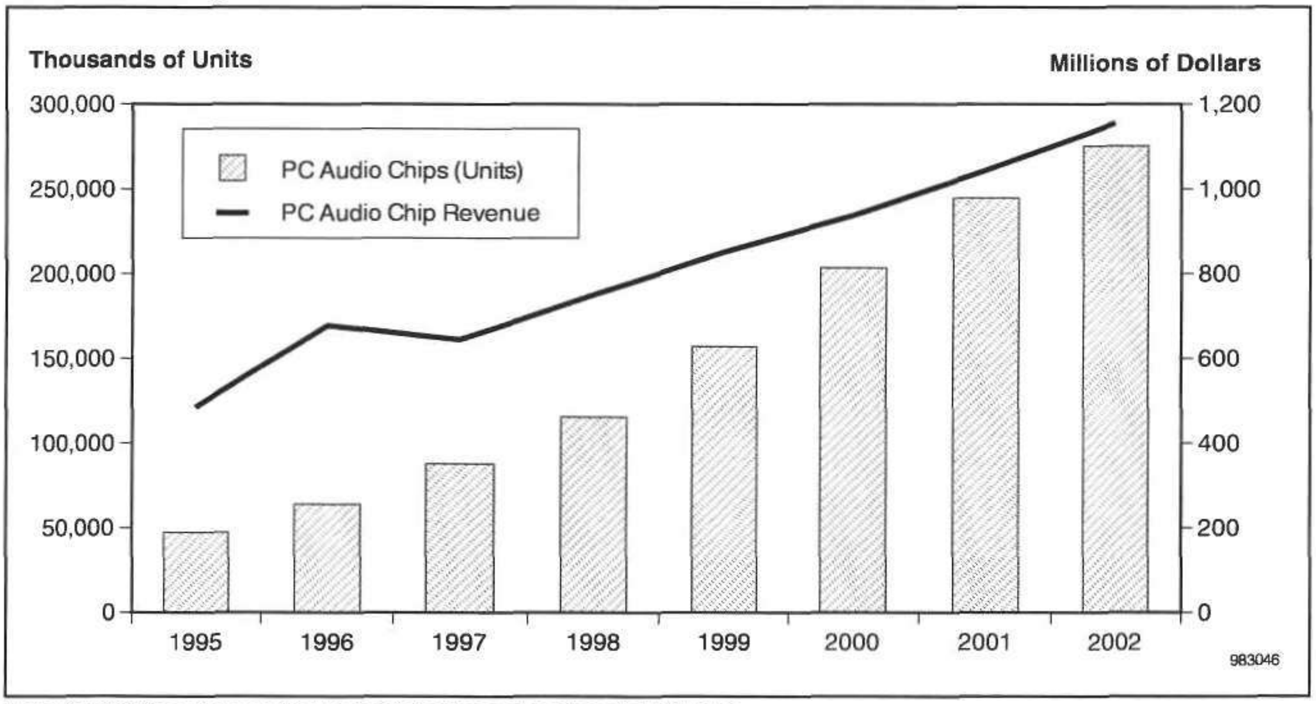
Source: Dataquest (June 1998)

Table 3-4
PC Audio Chip Forecast

	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
PC Audio Chip Units (K)	47,392	64,026	87,875	115,384	156,990	203,341	244,632	275,200	25.6
Growth Year-to-Year (%)		35.1	37.2	31.3	36.1	29.5	20.3	12.5	-
PC Audio Chip Revenue ($M)	484.6	678	645.1	750.9	851.1	936.9	1,044.30	1,154.80	12.3
Growth Year-to-Year (%)		39.9	-4.9	16.4	13.3	10.1	11.5	10.6	-
Controller/Codec Bundles	34,141	54,776	81,794	102,245	130,825	156,416	182,153	206,917	20.4
Separate Codec Units (K)	13,251	9,250	6,081	16,206	52,330	117,312	178,510	206,917	102.5
Separate Hardware Controller Units (K)	13,251	9,250	6,081	13,139	26,165	46,925	62,479	68,283	62.2
Standard	13,251	9,250	5,831	11,139	21,165	34,925	40,479	38,283	45.7
Advanced Programmable	0	0	250	2,000	5,000	12,000	22,000	30,000	160.5
Software Controllers Using CPU Units (K)	0	0	0	3,067	26,165	70,387	116,032	138,635	-
Integrated Codec/Controllers Units (K)	20,890	45,526	75,712	86,040	78,495	39,104	3,643	0	-100
PCs and PC Workstations Units (K)	60,171	69,985	80,890	93,868	109,030	128,612	148,752	170,842	16.1
Implied Penetration Rate* (%)	56.7	78.3	101.1	108.9	120	121.6	122.5	121.1	-

Source: Dataquest (June 1998)

Figure 3-4
PC Audio Chip Forecast



Note: Greater than 100 percent due to retail sales and nonbranded PC sales.
Source: Dataquest (June 1998)

Chapter 4
Graphics Trends

Trends in the graphics industry revolve around vendors' abilities to deliver 3-D graphics and embedded memory products competitively and cost effectively. These two features, embedded memory and 3-D graphics, are the growth engines for graphics revenue. They were also the growth engines for last year, but while embedded memory delivered on revenue growth, 3-D graphics sputtered as a shortage of high-end products and intense competition for lower-performing products eroded ASPs. Overall revenue for the PC graphics chip industry grew in 1997, but only because of strength in the mobile graphics segment. Revenue for deskbound graphics controllers actually declined a few percentage points in spite of record unit shipments. The competitive scene remains hot as all major competitors unveil their new products through the late spring and early summer.

Technology Trends

3-D Graphics Applications

3-D graphics is now the major differentiator for desktop graphics products and will begin to play a role in the mobile graphics segment this year. 2-D performance is still critical for winning benchmarks, but it is so high across the range of current graphics products that few PC users can distinguish the difference in actual usage. The trouble with 3-D graphics being the differentiator is simply that mainstream business software does not use 3-D acceleration. Because "Office 97"-type applications do not use 3-D acceleration today, chip vendors cannot charge a premium for 3-D performance. 3-D graphics acceleration has a much clearer value proposition for consumer and professional markets, where entertainment and professional applications such as CAD do benefit from 3-D graphics acceleration. Many in the industry joke about benchmarks, such as Ziff-Davis' 3-D Winbench being the "killer app" for 3-D on the corporate desktop. Benchmark scores do have tremendous marketing value even when they do not translate reliably into an improved user experience. That is currently the scenario for 3-D graphics on the typical business desktop, but changes are afoot. Microsoft's Chrome product requires 3-D graphics acceleration in PCs simply to run the graphical user interface (GUI) and will boost 3-D graphics acceleration the same way that the 2-D GUI boosted demand for better 2-D graphics acceleration.

3-D Graphics Features

The list of "must-have" features for new graphics chips evolves continuously, and spring product introductions effectively set the tone for the rest of the year. The latest products targeted for consumer applications now include trilinear filtering for texture mapping, enhanced fogging and alpha-blending capabilities, deeper z-buffers, antialiasing, and on-chip triangle set-up engines. Those features are paired with faster rendering engines for higher pixels-per-second and triangles-per-second performance, two metrics that, along with 3-D Winbench scores, are frequently cited as evidence of product quality.

During the next year, new products will increasingly get more sophisticated features such as anisotropic filtering, real-time image compositing and stencil buffers. Those features, coupled with even higher overall performance will set the groundwork for widespread adoption of Microsoft's Chrome interface for all segments of the PC market.

Bus Interface

Accelerated Graphics Port (AGP) is the preferred interface technology for PC graphics chips because of its enhanced functionality compared to PCI. Specifically, AGP's superiority stems from a higher priority interrupt compared to PCI, direct access to main memory, and higher clock rates for faster bus operation.

PCI products will continue to ship in high volume, however, because of AGP's limitations. First of all, AGP is not supported by any of the Pentium-class core logic chipsets from Intel. Pentium-class is defined as "socket 7"-oriented. Many Pentium-class core logic chipsets from alternative vendors do support the AGP bus, so PCs featuring AMD and Cyrix microprocessors can be configured with AGP graphics chips. The new processors from AMD and Cyrix do not use the "Socket 1" interface used for most new Intel microprocessors and therefore cannot use Intel's AGP-oriented core logic products. Another limitation of the AGP interface is that only one AGP peripheral is allowed in a system. The AGP interface allows two connect points, one for the graphics chip and one for the core logic chipset. This necessarily makes AGP graphics subsystems unexpandable if the graphics chip is soldered to the motherboard. Of course, a PC user could disable the AGP graphics chip and install a PCI add-in card, but falling back to PCI is undesirable as an upgrade path. A new feature of AGP, called 3-point AGP, addresses this problem by enabling an AGP socket when the motherboard AGP graphics chip is disabled. 3-point AGP will be available for PCs in 1999 as new core logic chipsets supporting the feature come to market.

Integrated Memory

Integrated memory is the most competitive feature in the mobile graphics market. That does not mean that many vendors have it. Neomagic is far and away the leader because the company includes integrated memory on every graphics chip it sells. Competitors Intel (formerly Chips & Technology), Trident, and S3 have all announced products with on-chip frame buffers but have not achieved much success in competing with Neomagic. Greater visibility on the success of competitors' integrated products will stem from product announcements through the spring and fall, but momentum is clearly on Neomagic's side at this time.

Integrated memory buffers used to be only 1.25MB but have jumped to the 2MB to 2.5MB range as larger LCD panels rise in popularity. The 1.25MB buffers were fine for 800x600 resolution panels, but the larger 1,024x768 panels need more memory.

The benefits of integrated memory are many and varied. Board space and power are always at a premium for mobile PCs. Integrated memory graphics products address both of these issues without sacrificing performance. Pricing for integrated products appears to be at parity plus a small premium compared to the nonintegrated solutions. A premium is warranted because power consumption and its impact on battery life is not the sole power issue; power dissipation is also a problem. Because graphics products with integrated buffers use less power, they dissipate less heat and can be located nearer to the CPU without exacerbating the heat dissipation problems involving the CPU. Nonintegrated graphics solutions typically need to be separated from the CPU for heat considerations, which makes the whole task of PCB layout within the tight volume constraints of a mobile PC design even harder than it is otherwise. Table 4-1 shows the main features of a variety of currently available and announced parts.

Figures 4-1 through 4-3 show general block diagrams of a deskbound PC graphics controller, a mobile PC graphics controller, and some high-level differences between PCI and AGP graphics implementations.

Market Statistics

The battle for market share in the PC graphics market is perpetually exciting because fortunes are made and lost virtually overnight in this volatile market. S3 remained the largest graphics chip vendor in 1997 but lost the design momentum to keep its revenue growing and ended the year with a revenue decline compared to last year. Two Canadian companies seized the next two spots on the market share table—ATI and Matrox climbed to the No. 2 and No. 3 position, respectively. Dataquest wonders if formal training in ice hockey gives vendors the aggressive tactics necessary to compete as a large graphics chip vendor. Table 4-2 shows the overall graphics controller market share statistics. Figure 4-4 shows the revenue data from Table 4-1 graphically. Tables 4-3 and 4-4 show the market share statistics for the deskbound graphics and mobile graphics segments. Figures 4-5 and 4-6 show the revenue data from Tables 4-3 and 4-4 graphically.

Market Forecast

The outlook for graphics revenue is robust in comparison to the past year. Revenue growth will outpace unit growth as integrated memory and 3-D graphics continue to grow. Integrated memory will boost the five-year compound annual growth rate (CAGR), 1997 to 2002, to 22 percent, adding $750 million to the graphics controller market in 2002. Graphics revenue growth would only reach 15 percent CAGR for the five-year period if integrated memory is not included. That 15 percent growth rate is comparable to PC unit growth because Dataquest forecasts that pricing for graphics products will remain competitive as low-end products will compete with integrated graphics functions in core logic chipsets starting in the latter half of 1999. Tables 4-5 and 4-6 show the Dataquest graphics controller revenue and unit forecasts. All units in this forecast have a VGA controller and are designed to be used as a primary graphics controller. Additional revenue opportunities exist for vendors selling 3-D-only graphics accelerators for gaming and professional applications. Figure 4-7 shows the forecast graphically.

Table 4-1
Feature Comparison of Selected PC Graphics Controllers

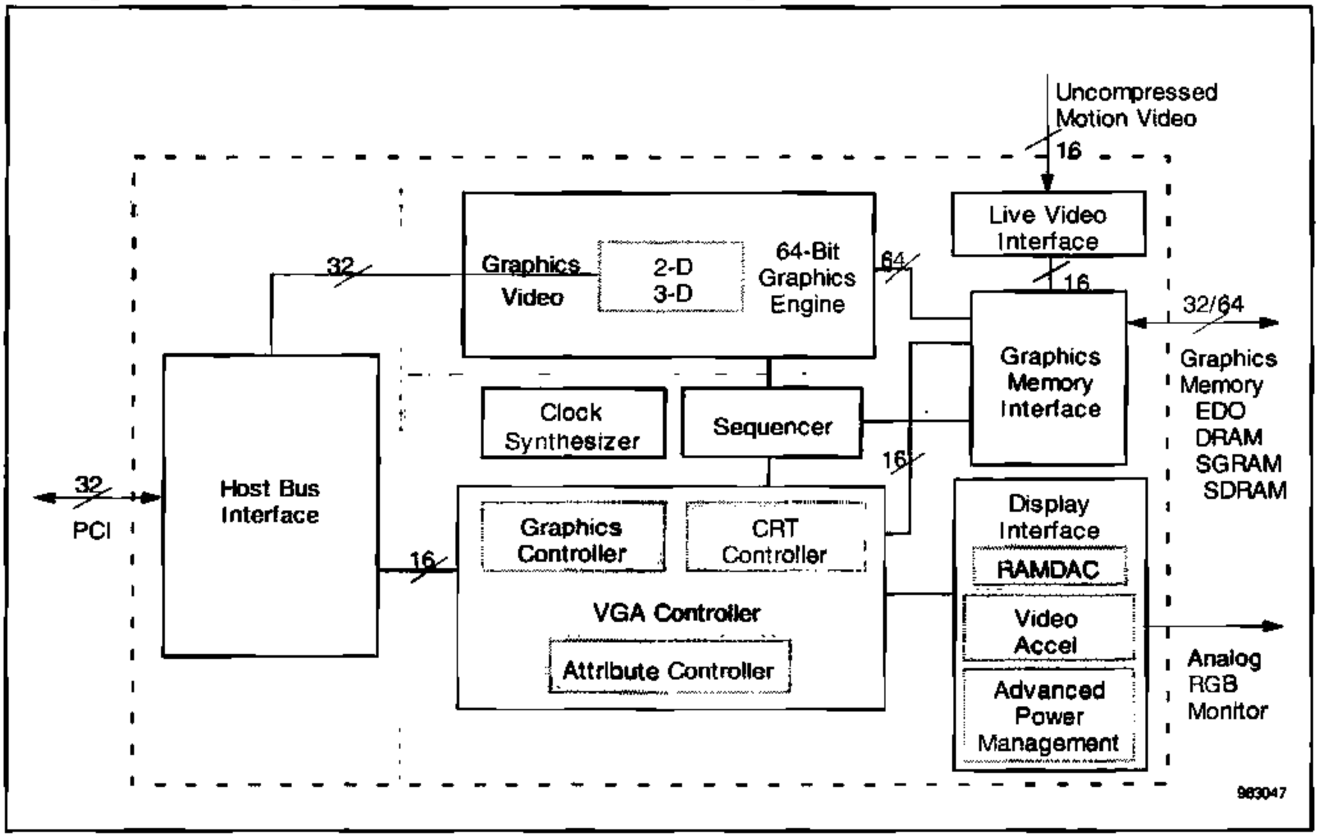
Company	Product Name	Product Number	Target Platform	2-D plus Video	3-D	TV Features	MPEG-2 Motion Compensation	Bus Interface	Package	Memory Type
3Dfx	Voodoo Graphics		Deskbound	No	Yes	No	No	PCI	PQFP	EDO
	Voodoo2		Deskbound	No	Yes	No	No	PCI/AGP	PQFP	EDO
	Voodoo Rush		Deskbound	No	Yes	No	No	PCI	PQFP	EDO
	Voodoo Banshee		Deskbound	Yes	Yes	Yes	No	PCI/AGP	BGA	SGRAM
3DLabs	Permedia2		Deskbound	Yes	Yes	No	No	PCI/AGP	BGA-256	SGRAM
	Permedia3 (TBA)									
Alliance	ProMotion	AT3D	Deskbound	Yes	Yes	No	No	PCI	PQFP-208	EDO
ATI Technologies	3D RAGE II+DVD		Deskbound	Yes	Yes	Yes	Yes	PCI	PQFP-208	SGRAM
	3D RAGE PRO		Deskbound	Yes	Yes	Yes	Yes	AGP/PCI	BGA-256	SGRAM
	3D RAGE LT		Mobile	Yes	Yes	Yes	No	PCI	BGA-256	EDO/SGRAM
Avance		ALG25128	Deskbound	Yes	No	No	No	PCI	PQFP	EDO
Chips & Technology (Intel)	HiQVideo	65550	Mobile	Yes	No	No	No	PCI/VL	T/PQFP-208,BGA-256	EDO
	HiQVideo	65554	Mobile	Yes	No	No	No	PCI	BGA-256	EDO
Chromatic	Mpact2 (3DVD)	3600	Deskbound	Yes	Yes	Yes	Yes	PCI/AGP	BGA-352	RDRAM
Cirrus Logic	Laguna3D	GD-5464	Deskbound	Yes	Yes	No	No	PCI	PQFP-208	RDRAM
	Laguna3D/AGP	GD-5465	Deskbound	Yes	Yes	No	No	AGP/PCI	PQFP-208	RDRAM
	VisualMedia	GD-7555	Mobile	Yes	No	No	No	PCI	BGA, PQFP-256	EDO
	VisualMedia	GD-7556	Mobile	Yes	No	Yes	No	PCI	BGA, PQFP-256	EDO
Intel	Auburn	i740	Deskbound	Yes	Yes	No	No	PCI/AGP	BGA-352	SGRAM
Matrox		G100	Deskbound	Yes	Yes	-	No	PCI/AGP	BGA	SGRAM
		G200	Deskbound	Yes	Yes	-	No	PCI/AGP	BGA	SGRAM
NeoMagic	MagicGraph	128ZV	Mobile	Yes	No	No	No	PCI	PQFP-176	Integrated
	MagicGraph	128XD	Mobile	Yes	No	No	No	PCI	PQFP-176	Integrated
	MagicGraph	256AV	Mobile	Yes	No	No	No	PCI/AGP	PQFP	Integrated
NVIDIA	Riva 128ZX		Deskbound	Yes	Yes	Yes	No	PCI/AGP	BGA	SGRAM
	Riva TNT		Deskbound	Yes	Yes	Yes	-	PCI/AGP	BGA	SGRAM
Rendition	Verite	R1000	Deskbound	Yes	Yes	No	No	PCI	PQFP	EDO
		R2200	Deskbound	Yes	Yes	Yes	Yes	PCI/AGP	BGA	SGRAM

Table 4-1 (Continued)
Feature Comparison of Selected PC Graphics Controllers

Company	Product Name	Product Number	Target Platform	2-D plus Video	3-D	TV Features	MPEG-2 Motion Compensation	Bus Interface	Package	Memory Type
S3	ViRGE/GX2		Deskbound	Yes	Yes	Yes	No	PCI/AGP	BGA-328	SGRAM
	ViRGE/MX		Mobile	Yes	Yes	Yes	No	PCI/AGP	BGA-256	EDO/SGRAM
	ViRGE/MXi		Mobile	Yes	Yes	Yes	No	PCI/AGP	PQFP	Integrated
	Savage3D		Deskbound	Yes	Yes	Yes	-	PCI/AGP	BGA-336	SGRAM
	Trio3D		Deskbound	Yes	Yes	-	No	PCI/AGP	PQFP/BGA	EDO/SGRAM
Trident	3DImage	975	Deskbound	Yes	Yes	Yes	No	PCI	PQFP-208	SGRAM
	3DImage	975DVD	Deskbound	Yes	Yes	Yes	Yes	PCI	PQFP-208	SGRAM
	3DImage	985	Deskbound	Yes	Yes	Yes	No	PCI/AGP	BGA-316	SGRAM
	3DImage	985DVD	Deskbound	Yes	Yes	Yes	Yes	PCI/AGP	BGA-316	SGRAM
	Cyber	9385	Mobile	Yes	No	No	No	PCI	T/PQFP, BGA-256	SGRAM
	Cyber	9388	Mobile	Yes	No	Yes	No	PCI	BGA-316	Integrated
	3D Cyber	9397	Mobile	Yes	Yes	Yes	No	PCI	BGA-316	SGRAM

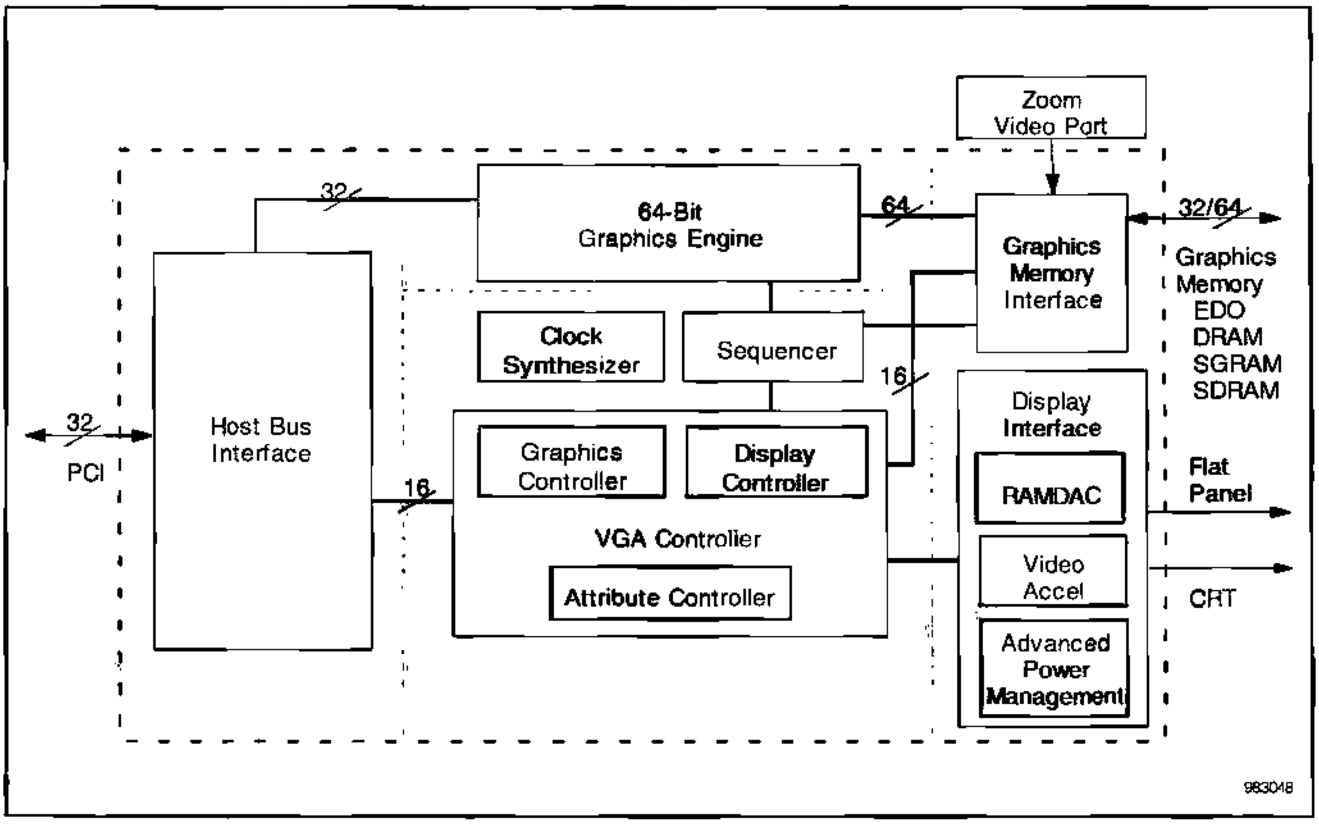
Source: Dataquest (June 1998)

Figure 4-1
Example Block Diagram for a Deskbound PC Graphics Controller



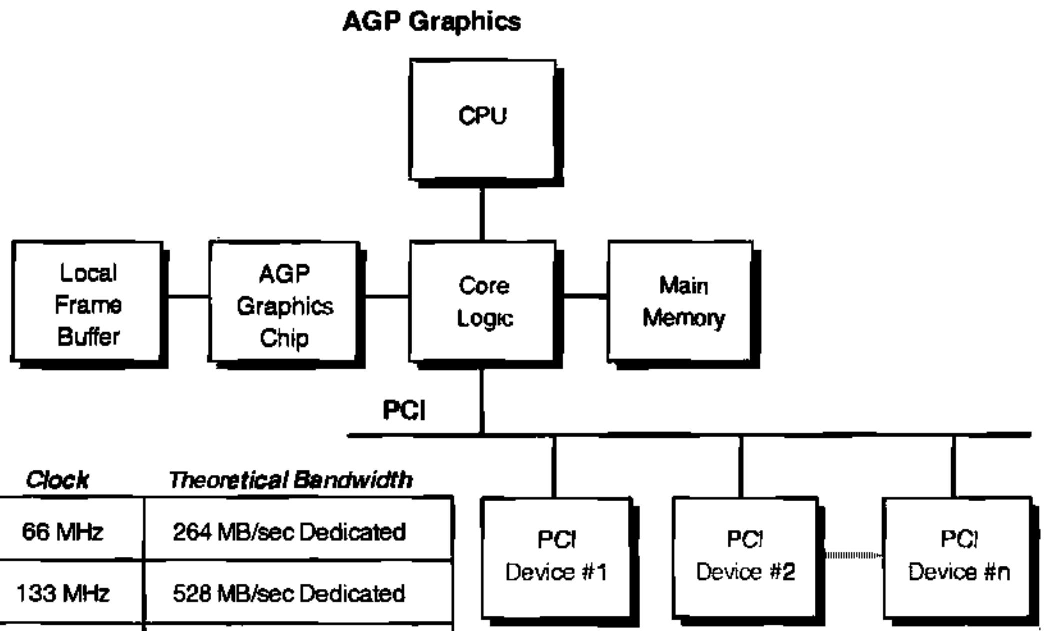
Source: Dataquest (June 1998)

Figure 4-2
Example Block Diagram for a Mobile PC Graphics Controller

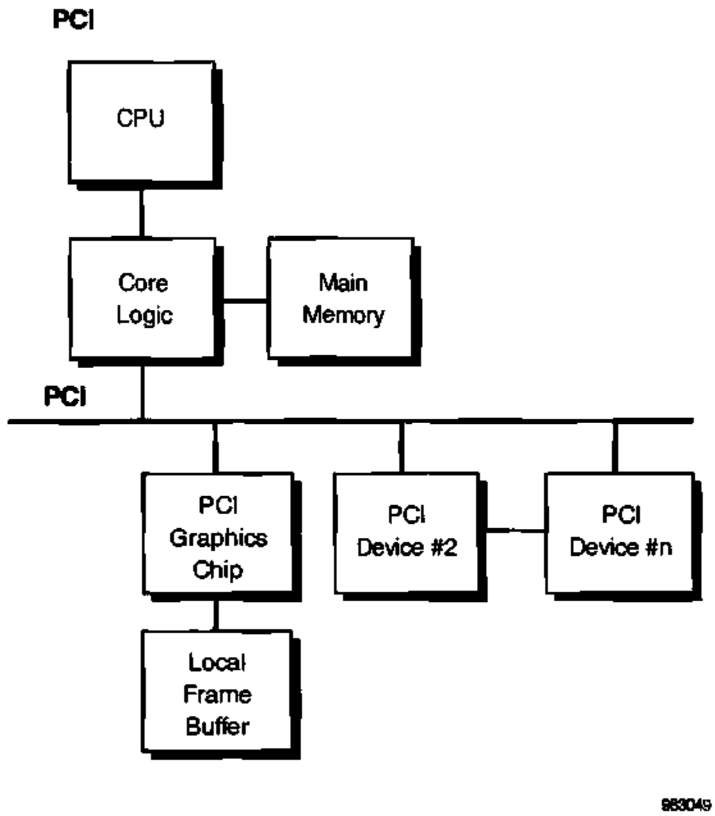


Source: Dataquest (June 1998)

Figure 4-3
Graphics Implementations: PCI versus AGP



	Clock	*Theoretical Bandwidth*
1x AGP	66 MHz	264 MB/sec Dedicated
2x AGP	133 MHz	528 MB/sec Dedicated
PCI	33 MHz	132 MB/sec Shared



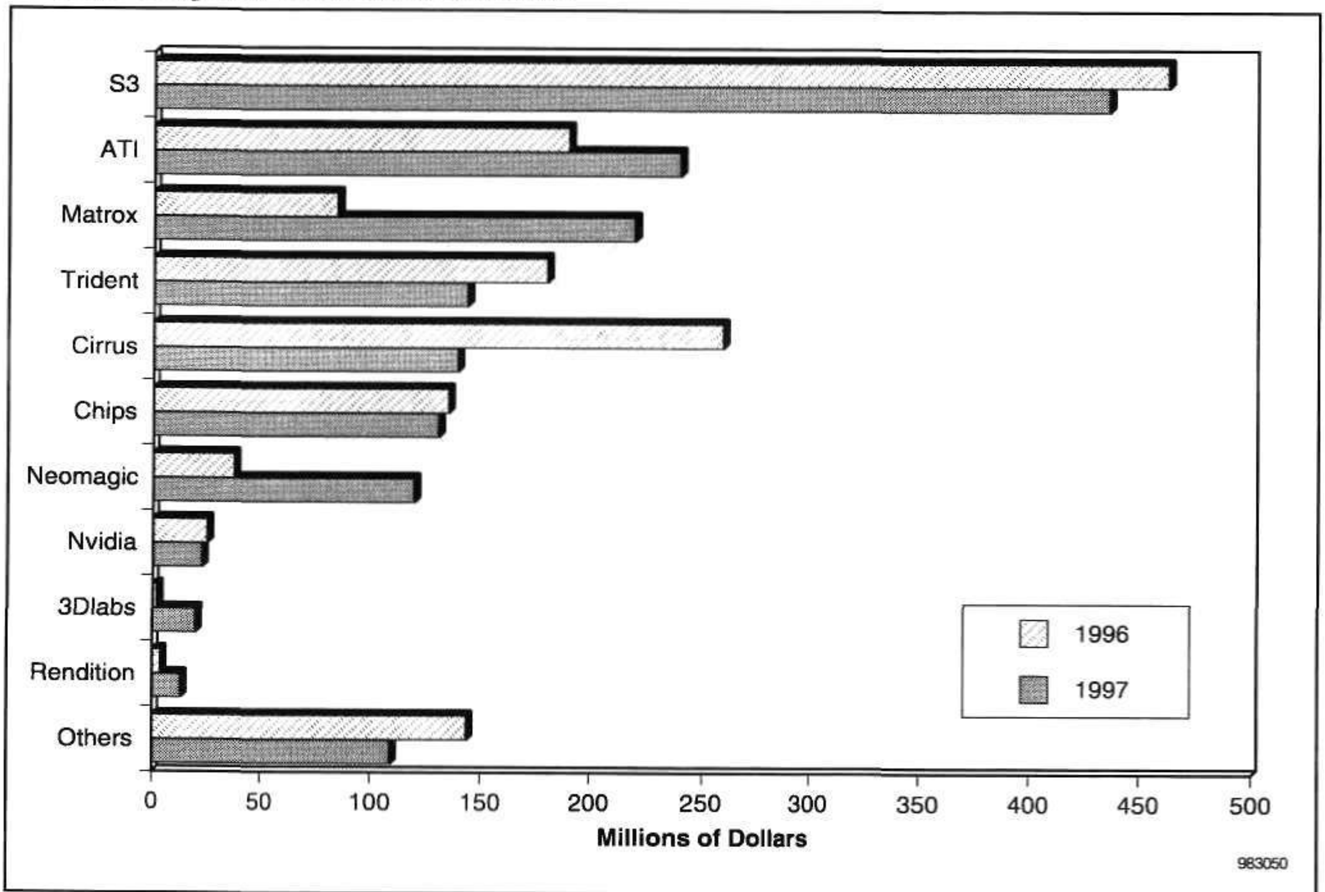
Source: Dataquest (June 1998)

Table 4-2
Overall PC Graphics Controller Market Share Statistics (Millions of Dollars)

	Thousands of Units, 1996	Thousands of Units, 1997	1996	1997	Rank 1997	Rank 1996
S3	29,037.5	38,185.0	462.8	436.2	1	1
ATI	10,000.0	15,580.0	190.0	240.0	2	3
Matrox	2,950.0	9,500.0	85.0	220.0	3	6
Trident	12,750.0	11,357.0	180.0	143.6	4	4
Cirrus	17,250.0	10,200.0	259.0	139.2	5	2
Chips	6,430.0	5,400.0	135.0	130.5	6	5
Neomagic	900.0	3,100.0	37.5	119.5	7	7
Nvidia	25.0	901.0	25.0	22.5	8	9
3Dlabs	70.0	970.0	2.0	19.8	9	NR
Rendition	150.0	650.0	3.8	13.0	10	19
Others	10,160.5	8,876.3	143.7	108.9	-	-
Total	**89,723.0**	**104,719.3**	**1,523.8**	**1,593.2**	-	-

NR = Not ranked
Source: Dataquest (June 1998)

Figure 4-4
Overall Graphics Controller Revenue



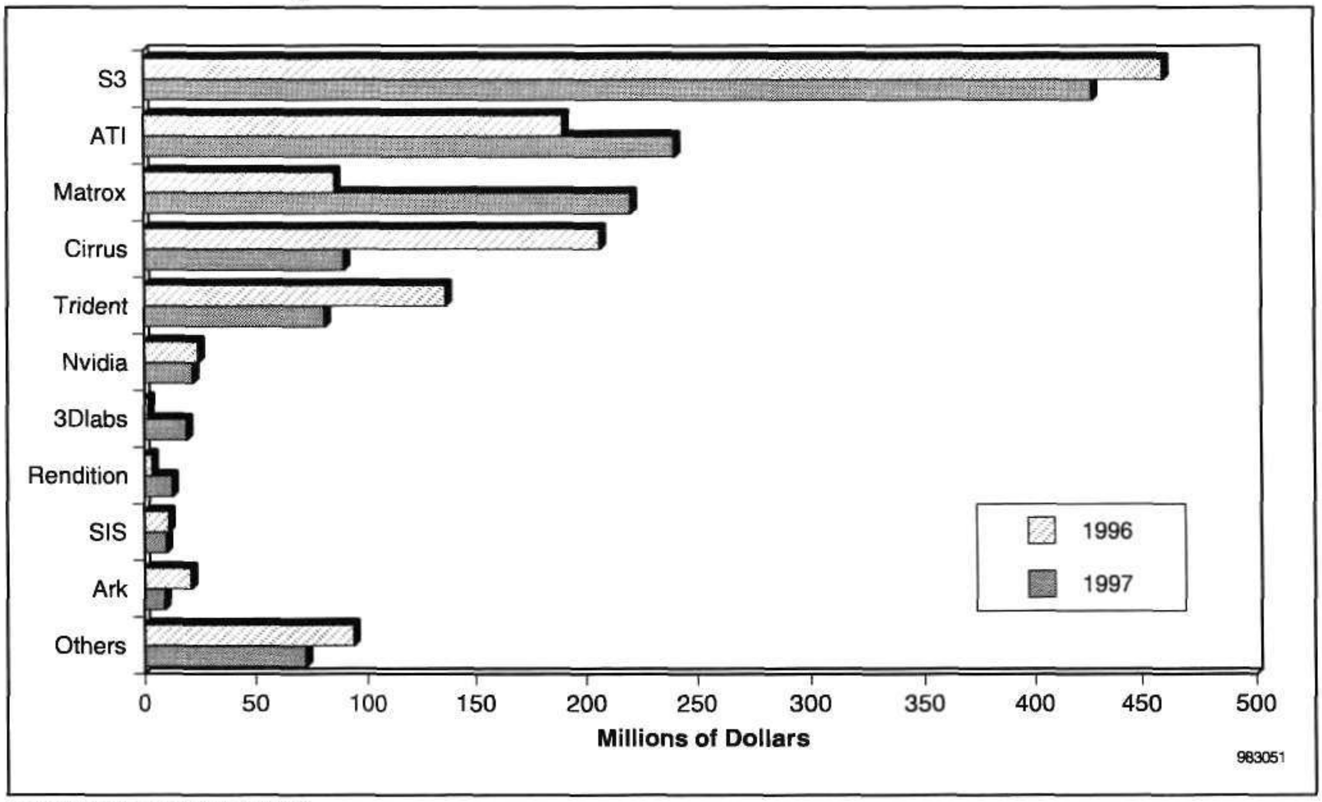
Source: Dataquest (June 1998)

Table 4-3
Deskbound PC Graphics Controller Market Share Statistics (Millions of Dollars)

	Thousands of Units, 1996	Thousands of Units, 1997	1996	1997	Rank 1997	Rank 1996
S3	28,910	37,705	460	427	1	1
ATI	10,000	15,580	190	240	2	3
Matrox	2,950	9,500	85	220	3	5
Cirrus	14,750	7,500	207	89	4	2
Trident	10,580	8,539	137	81	5	4
Nvidia	25	901	25	23	6	7
3Dlabs	70	970	2	20	7	NR
Rendition	150	650	4	13	8	15
SIS	900	1,853	12	10	9	11
Ark	1,800	1,150	22	10	10	9
Others	6,580	5,125	94	72	-	-
Total	**76,715**	**89,473**	**1,236**	**1,204**	-	-

NR = Not ranked
Source: Dataquest (June 1998)

Figure 4-5
Deskbound PC Graphics Controller Revenue



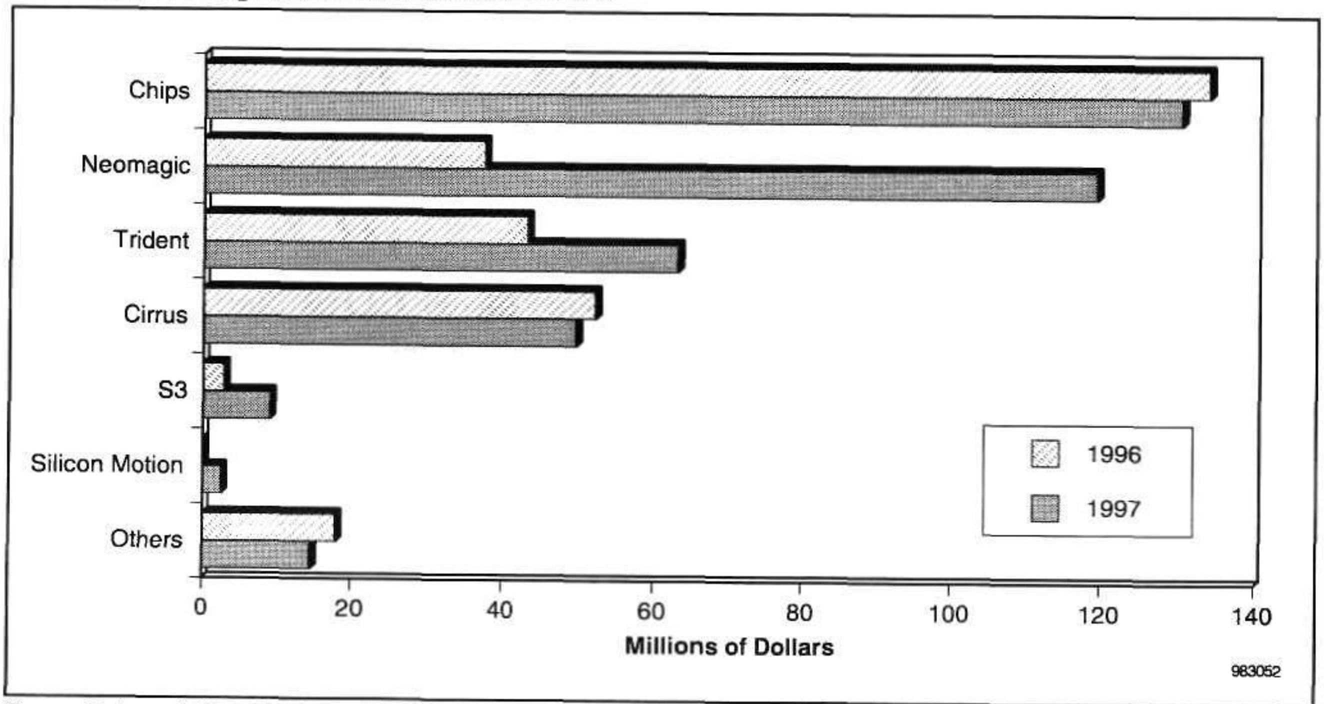
Source: Dataquest (June 1998)

Table 4-4
Mobile PC Graphics Controller Market Share Statistics (Millions of Dollars)

	Thousands of Units, 1996	Thousands of Units, 1997	1996	1997	Rank 1997	Rank 1996
Chips	6,380	5,400	134	131	1	1
Neomagic	900	3,100	38	120	2	4
Trident	2,170	2,818	43	63	3	3
Cirrus	2,500	2,700	53	50	4	2
S3	128	480	3	9	5	6
Silicon Motion	0	125	0	3	6	-
Others	931	623	18	15	-	-
Total	**13,008**	**15,246**	**288**	**390**	-	-

Source: Dataquest (June 1998)

Figure 4-6
Mobile PC Graphics Controller Revenue



Source: Dataquest (June 1998)

Table 4-5
Worldwide PC Graphics Controller Revenue Forecast (Millions of Dollars)

		1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Desktop	2-D Accel	692.1	829.0	759.5	148.4	13.4	0	0	0	0	0	-100.0
	2-D Accel with Video	1.2	49.5	405.7	809.6	280.5	30.6	29.2	0	0	0	-100.0
	2-D, 3-D, and Video Accel	0	0	2.3	236.0	532.6	716.0	503.8	85.6	0	0	-100.0
	2-D, 3-D, Video, and TV	0	0	0	41.4	355.0	612.0	962.1	1,549.3	1,904.9	2,292.0	45.2
	Advanced Programmable	0	0	0	0.3	22.4	70.4	214.6	535.6	730.2	836.7	106.3
Desktop	Total Revenue	693.2	878.5	1,167.4	1,235.6	1,203.9	1,428.9	1,709.6	2,170.6	2,635.0	3,128.7	21.0
	Growth Year-to-Year		26.7	32.9	5.8	-2.6	18.7	19.6	27.0	21.4	18.7	-
Mobile	2-D Accel	155.0	201.1	181.3	107.6	21.7	0	0	0	0	0	-100.0
	2-D Accel with Video	0	0	39.2	180.6	277.1	92.7	17.2	0	0	0	-100.0
	2-D, 3-D, and Video Accel	0	0	0	0	64.0	303.6	284.0	128.1	96.0	108.8	11.2
	2-D, 3-D, Video, and TV	-	-	0	0	26.7	111.4	344.3	771.3	918.6	1,058.1	108.8
Mobile	Total Revenue	155.0	201.1	220.6	288.2	389.6	507.7	645.5	899.4	1,014.6	1,166.9	24.5
	Growth Year-to-Year		29.7	9.7	30.7	35.2	30.3	27.1	39.3	12.8	15.0	-15.7
Total	2-D Accel	847.1	1,030.0	940.8	256.0	35.1	0	0	0	0	0	-100.0
Total	2-D Accel with Video	1.2	49.5	445.0	990.3	557.6	123.3	46.4	0	0	0	-100.0
Total	2-D, 3-D, and Video Accel	0	0	2.3	236.0	596.6	1,019.6	787.8	213.7	96.0	108.8	-28.9
Total	2-D, 3-D, Video, and TV	0	0	0	41.4	381.7	723.4	1,306.3	2,320.6	2,823.4	3,350.0	54.4
Total	Advanced Programmable	0	0	0	0.3	22.4	70.4	214.6	535.6	730.2	836.7	106.3
	Total Revenue	**848.2**	**1,079.5**	**1,388.1**	**1,524.0**	**1,593.4**	**1,936.7**	**2,355.1**	**3,070.0**	**3,649.6**	**4,295.6**	**21.9**
	Growth Year-to-Year	**-**	**27.3**	**28.6**	**9.8**	**4.6**	**21.5**	**21.6**	**30.4**	**18.9**	**17.7**	**31.2**

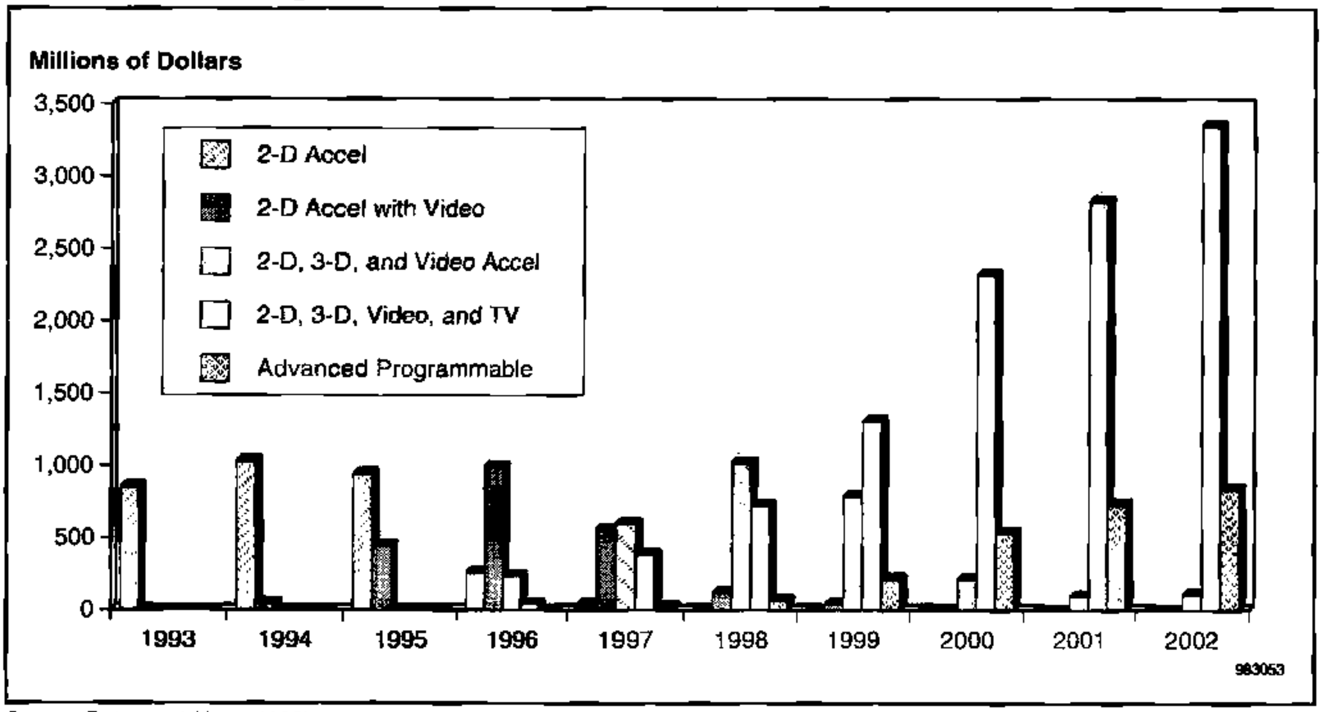
Source: Dataquest (June 1998)

Table 4-6
Worldwide PC Graphics Controller Unit Forecast (Shipments in Thousands)

		1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Desktop	2-D Accel	39,006	49,161	48,999	16,486	2,416	0	0	0	0	0	-100
Desktop	2-D Accel with Video	44	1,650	17,753	49,865	29,526	5,100	5,831	0	0	0	-100
Desktop	2-D, 3-D, and Video Accel	0	0	55	8,822	36,058	53,037	37,317	6,849	0	0	-100
Desktop	2-D, 3-D, Video, and TV	0	0	0	1,534	20,579	40,798	64,138	106,851	126,990	145,522	48
Desktop	Advanced Programmable	-	-	-	8	895	3,060	9,329	23,288	31,748	36,380	110
Desktop	Total Units	39,050	50,811	66,807	76,715	89,473	101,994	116,615	136,988	158,738	181,902	15
	Growth Year-to-Year	-	-	-	-	-	13.7	14.3	17.5	15.9	14.6	-
Mobile	2-D Accel	6,010	8,029	9,925	5,854	1,525	0	0	0	0	0	-100
Mobile	2-D Accel with Video	0	0	1,353	7,154	11,130	4,873	1,133	0	0	0	-100
Mobile	2-D, 3-D, and Video Accel	0	0	0	0	1,830	10,120	10,199	4,003	3,047	3,509	14
Mobile	2-D, 3-D, Video, and TV	0	0	0	0	762	3,748	11,332	22,685	27,421	31,584	111
Mobile	Total Units	6,010	8,029	11,278	13,008	15,246	18,741	22,664	26,688	30,467	35,093	18
	Growth Year-to-Year	-	-	-	-	-	22.9	20.9	17.8	14.2	15.2	-
Total	2-D Accel	45,016	57,190	58,923	22,340	3,941	0	0	0	0	0	-100
Total	2-D Accel with Video	44	1,650	19,106	57,019	40,656	9,972	6,964	0	0	0	-100
Total	2-D, 3-D, and Video Accel	0	0	55	8,822	37,887	63,157	47,516	10,853	3,047	3,509	14
Total	2-D, 3-D, Video, and TV	0	0	0	1,534	21,341	44,546	75,471	129,535	154,411	177,106	111
Total	Advanced Programmable	0	0	0	8	895	3,060	9,329	23,288	31,748	36,380	18
Total	Graphics Controller Units	45,060	58,840	78,085	89,723	104,719	120,735	139,280	163,676	189,205	216,995	16
	Growth Year-to-Year	-	30.6	32.7	14.9	17.0	15.0	15.4	17.5	15.6	14.7	-

Source: Dataquest (June 1998)

Figure 4-7
Worldwide PC Graphics Controller Revenue Forecast



Source: Dataquest (June 1998)

Chapter 5

Dataquest Perspective

The markets for PC peripheral chips are both competitive and under pressure from OEMs striving for profitability as PC system prices fall. Nowhere is this more obvious than the PC graphics and PC audio chip markets. The changes to the market dynamics of the PC market necessitate changes to the PC peripheral chip markets too.

The shift of PC manufacturing to greater reliance on build-to-order manufacturing practices reduces the forward visibility of add-in board vendors and in turn reduces forward visibility for the chip vendors. Add-in board vendors can manufacture product as quickly as needed, but chip vendors cannot. The fundamental mismatch between chips and boards for manufacturing lead time will ultimately have the greatest impact on the chip vendors because much of the risk will be shuffled to them. Fabless chip vendors may be able to foist some of that risk on the foundries they use, but only so far as foundry wafer supply exceeds demand. As supply tightens relative to demand, foundries will want to book wafer starts as far ahead of time as they can to minimize their own risk. Again, the fabless chip vendor must shoulder the greater burden of risk.

Declining PC prices and the new segmentation of the PC market will also require changes in the way chip vendors define their products and position them in the market. New graphics and audio products will increasingly be targeted at specific segments of the PC market. The old segments were simple: deskbound and mobile. The new segments include sub-$1,000 deskbound PCs and companion notebooks that have different sets of requirements compared to the traditional deskbound and mobile segments.

At the same time that some market forces are squeezing peripheral chip vendors, new opportunities arise. The future convergence of computing and consumer electronics is a potential boon for PC chip vendors. PC architecture will compete for design wins in new convergence equipment as it evolves, and PC chip vendors could enjoy significant market growth from this new market if they are aligned with the winning OEMs. It is too early to divine with confidence whether or not PC OEMs will fare better than consumer electronics OEMs. The two industries may effectively split the market, but it is likely one of the two will gain the upper hand and leverage that position. Chip vendors are advised to work with both sets of OEMs as a hedge against picking the "losing" side. If PC OEMs market convergence devices like PCs instead of like consumer electronics, they are likely to fail. Chip vendors that play both sides of the court can limit their risk.

Graphics and audio chips will compete at the low end with integrated solutions in 1999 and must be positioned properly against those low-cost solutions. Yesterday's chip at a bargain price is not a winning strategy for the future. New products tailored for each market segment are the key to success.

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