Oral History of Frank Heart

Interviewed by:
Marc Weber and Gardner Hendrie

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Weber: I'm Marc Weber [joined by Gardner Hendrie, also of the Computer History Museum, who is identified later], and I'm here today on June 3, 2009 with Frank Heart, who's a major ARPANET pioneer. We're here at BBN [BBN Technologies; formerly Bolt, Beranek and Newman] where he did much of his work. So thank you for joining us.

Heart: You're welcome.

Weber: And I just want to start with a little bit of your early background—where you were born, grew up, and what led you toward computers?

Heart: Well, it's relatively straight forward. I was brought up in Westchester, New York and went to MIT as an undergraduate and had the enormous good fortune that when Gordon Welchman—a British person—first came to teach a computer course at MIT, I was able to take that course in the second term that he taught it. It was the first [digital] course in computers in the United States.

Weber: And why were you interested?

Heart: Well, it just seemed interesting. I didn't know much about it. It was an unusual course and I was a junior—halfway between junior and senior year. It just seemed interesting.

But of course, it's like catching a disease—once you catch the bug you're really hooked and Whirlwind, at that time, was a machine with 32 total registers and with toggle switches that you'd put things into those 32 registers. So I went and got involved in Whirlwind and got a master's degree while being a research assistant and began to program Whirlwind.

Weber: And what was your degree in?

Heart: Electrical engineering—both master's and a bachelor's degree. And Whirlwind, of course, was incredibly exciting. It had gone through difficult financial times for a while and then the Air Force got interested in air defense and began supporting Whirlwind as an experiment in tracking airplanes from radar and I got involved in that.

And that rather rapidly led to the group at Whirlwind joining [MIT] Lincoln Laboratory and so I then spent the next 15 years at Lincoln Laboratory connecting computers to everything in sight—seismic arrays, radars, sonar systems, etc. And the group that I was running became probably as knowledgeable as anyone in the world at connecting computers to real-time things, such as radar, seismic arrays, underwater acoustics, and so on. So it was a very exciting time at Lincoln, too, and I liked Lincoln Lab a lot. And it's amazing it's still running. It seems to be still okay all these years later.

So that was the beginning as to how one got into computers. It was like riding a rocket at that time.

Weber: And you ended up running a group relatively soon.

Heart: Yeah, relatively soon. The group, as I say, connected all kinds of computers to all kinds of real-time systems and it was a very unusual thing. Most computers in those days, everywhere in the world, were being used to do computation of one kind of another—whether it was business computation or scientific computation. So the notion of using them to connect to phone lines was very, very rare and Lincoln was one of the few places—maybe not the only place, but one of the few places in the world that that was happening.

Weber: And some of the early modem work was—

Heart: Yes, that was later, though. We're talking now really the '50's—the mid '50's—and there was stuff done with modems soon.

Weber: I thought there was some at the end of the '40's, the very first—

Heart: Connected to computers?

Weber: That were moving toward the modem.

Heart: Well, *je ne sais pas* [I don't know].

Weber: So you were connecting generally real-time systems, because you needed to acquire the real-time data.

Heart: Right.

Weber: And you were starting from scratch. How did you do that?

Heart: Well, I just think there was a strong group that we managed to collect that understood how to do the electronics and also how to do the programming. As I say, it was a very different kind of machine-language programming. Many people were involved in trying to use computers other ways, but to try to get a radar scan into the machine before the next radar scan came along with computers at that day was a tricky business. It took very fancy, real-time programming in machine language, in general, to accomplish that.

Weber: And you had an interface at the end of say the radar.

Heart: Yeah, the radar would sit on— for example, the first experiments with Whirlwind had a radar sitting on Cape Cod and a phone line to the Barta Building in Cambridge. Data was sent over that phone line to the computer and came in through an interface box that somebody else had worked on at that time. That was before I got to building things and computers. I was still a bare undergraduate going to Whirlwind.

But yes, it was a very, very unusual and exciting time. People at Whirlwind would, spend day and night there and go have a little food in the diner across the street and go back to work. The Air Force was very anxious to move forward. They were very worried about Russian bombers at that time. I doubt,, frankly if the air defense system that had gotten built would ever stop the Russian bombers, but that didn't stop the Air Force from trying.

Weber: And you felt that at the time.

Heart: We thought at the time it was wonderful idea, right. Oh, you mean—I worried that it wouldn't work then? No, no, I was too naïve to worry then that it wouldn't work.

Weber: You were confident that it would?

Heart: No, that's putting it too strong, but we worked on trying. It was the thing you were working on. So that was the beginning of my involvement, and as I said, I spent 15 years at Lincoln Labs, so I was very happy there. BBN had to put a lot of energy into trying to extract me, because I was fairly conservative and not very anxious to move, and Lincoln was pretty comfortable and so on. So it was hard to even make a change, but they eventually convinced me to move to BBN.

Weber: And describe the atmosphere at Lincoln.

Heart: I think the average age was under 30 and it was very, very collegial. People—you could almost stand on a street corner in Cambridge and hitch a ride to Lincoln by all the people that were living in Cambridge and going out to Lincoln. And it was a young group, because they didn't really know who could program computers. They basically said "oh, maybe mathematicians can, maybe musicians can." There was not a school anywhere that produced computer programmers.

Weber: So as an electrical engineer you were not the standard—you were just one of different types of people.

Heart: Right, right.

Weber: But a lot of people had gone back and forth with BBN and you knew people here.

Heart: Well, not really back and forth. There were people from Lincoln that went to BBN. There weren't very many that went in the reverse direction, to my knowledge.

Weber: So how did they convince you to come to BBN?

Heart: Well, that was an interesting story. Lincoln was primarily taking money from the Air Force. Its support was from the Air Force. And there were people at Lincoln who wanted to work on non-Air-Force problems. For example, there were people at Lincoln that wanted to work on medical problems or on healthcare problems. But Lincoln management wasn't comfortable with that, because they felt it was very important to keep their customer—the Aair Force—happy and diverting resources to something like healthcare was not so much in their interests. A number of people got interested in that class of problem and in fact left Lincoln to set up—there was one group in particular that did that—that left Lincoln to work on healthcare problems. I was also interested in that, and thought it was a worthwhile thing.

So one trick BBN managed was they had a project in trouble—a so-called Hospital Computer Project, which was a joint project with BBN and Mass [Massachusetts] General Hospital, supported by the National Institutes of Health. It was being run by someone that looked 12 years old. He was actually in his 20s—Paul Castleman, but he looked 12 years old, and the project was in trouble. It was not happy. There was a fellow at Mass General who wasn't too happy with BBN's performance on the project, so they wanted a new manager for this project. That was the bait, if you like. Also, at that time, I realized that I was never going to make any money at Lincoln Lab, although it was a fine place to work. So you know, BBN was able to attract me with a combination of it being a company and with a project that was in the healthcare world.

Weber: And it was a promotion?

Heart: Oh well, I don't know—I'm not sure how you'd describe it as a promotion. It was a change. It was—well, I probably ended up running more people at BBN than I did then at Lincoln. The group at Lincoln was relatively small.

Weber: How many roughly?

Heart: A dozen.

Weber: And what was your actual title?

Heart: I was an assistant group leader.

Weber: And the name of the group?

Heart: Uh-oh. You're giving me trouble now.

Weber: <laughter> The mandate of the group.

Heart: Well, it was a communications group. It was working on communication problems primarily.

Gardner Hendrie: I wanted to ask—was the project with Mass General the one that eventually ended up with the MUMPS [Multi-User Multi-Programming System] system, the information system?

Heart: No, no.

Hendrie: It was a different project?

Heart: It was an earlier project. In fact, I arrived at BBN and within about a year—even less than a year—I was officiating at the funeral of that project because it was in trouble and it was too early. It was a project that was before its time. It actually was the stimulus for many other projects around the country in that general, technical domain. But the project itself was in trouble. It was trying to use a PDP-1 at BBN over phone lines to Mass General with a very messy software system and nobody was terribly happy either at Mass General or at BBN with the project. But it was nevertheless a way to get me there. So I ended up running a small division at BBN upon walking in the door.

Weber: And that was for healthcare.

Heart: Well, it had other things in it. There was some education work—a group that was working on educational systems with Wally Feurzeig and some other people. There were some other small pieces of that division.

Weber: And over the 15 years at Lincoln, you had done Whirlwind, but also many other things.

Heart: Oh yeah, Whirlwind was—in some sense Whirlwind was coming to an end when the group moved to Lincoln. Whirlwind helped IBM get core memory and helped IBM become the company it ended up becoming. So pretty soon there was a SAGE [Semi-Automatic Ground Environment] system and big computers like the AN/FSQ-7, which is an enormous building-filling computer that was presumably to be used for air defense and so Whirlwind transitioned into other computers at Lincoln Lab—big IBM ones and some other little ones.

Weber: I remember SAGE was a huge project, but you also did other—

Heart: Oh yeah, I was only involved in SAGE for a while, because after a little while MITRE broke off from Lincoln and basically took control of the air defense projects, leaving Lincoln doing other things, primarily communications, radar antennas, radio antennas. In fact, one fascinating project at Lincoln was to build a huge thing called “Haystack,” a huge, huge radio and radar antenna in nearby areas. It was—I forget the suburb now—but it was north of Boston a ways. And that was again, a fascinating thing to be working on, because up until that time all radio astronomers would work the radar by turning two knobs—one knob made it go up and down and one knob made it go sideways. That's the way a radio astronomer controlled an antenna. Well, Millstone had a tiny, tiny beam width. It was built to have a very, very small beam width. So if, for example, the beam width on the moon you could scan the entire moon with the beam it was so narrow. To move that around with just two knobs was a little tricky. So we ended up building a computer system where you could type in the name of the object you wanted to look at, like the moon or some star or something, and it would automatically move the antenna to that place. Then you could ask it to scan around that place and so on. So it was a Univac 490 was used to drive the Haystack antenna. So there were some very interesting projects of that kind at Lincoln that had nothing to do with the SAGE system. [In the prior paragraph, Haystack Observatory and Millstone Hill Observatory were two systems at the same location in Westford, MA.]

Weber: Okay, you did a variety of industrial stuff and this was all basically—

Heart: Right, no—almost entirely with support from the government. Haystack actually got support from the radio astronomy community, in addition to the government, because it was a shared resource and many, many different astronomers used Haystack and still do. It's still a going concern. In fact, there's a plaque on the wall up there to memorialize the Univac 490, which of course has long since gone from there but…

Weber: And you were fairly young in a management role, but were you also hands on?

Heart: Well, really I would almost say no. By the time I moved to BBN, I was primarily managing things rather than programming or wiring anything. That's probably an error that I may have made, but that's how it goes.

Weber: So you went to BBN and it was a campaign to get you there?

Heart: Yeah, it was a bit of a campaign. Dick Bolt put a lot of energy into that, meeting me at Howard Johnsons on Route 2 a number of times to try to make that happen. I was hard to move, because I was a depression baby and I was sort of happy at Lincoln and I wasn't too energetic at moving but I did.

Weber: What finally—just a combination—

Heart: Oh I—just a combination of, you know, different things.

Weber: So you arrived at BBN. You were working on the healthcare.

Heart: Right, December 1966. And I was working on healthcare and education and a few other small different things and then—to the extent that you're interested in the ARPANET, that was sort of the next big thing that happened in 1968. That wasn't so much later than when I got there. I mean, December '66 to mid '68 was really not a great long time.

Weber: Yeah, 18 months or so. Because we are interested in not just ARPANET—the sort of broader area would be obviously computing in the broader sense. But networking and communication and then ARPANET.

Heart: And also the healthcare thing, I was very interested in that for a while. I mean, for a while I was the U.S. representative to the EIFA community in healthcare. So I was pretty interested in that. It turned out that for a variety of reasons it was very early. In fact, to the current day it may still be too early. The notion of trying to use computers for healthcare in this present time may be tough for Mr. Obama.

Weber: It's a bit like AI. It just keeps on receding.

Heart: Yeah, it just keeps on receding.

Weber: Okay, so then what was the first that you heard of the ARPANET project?

Heart: On the Boardwalk in Atlantic City at the Spring Joint Computer Conference in 1968. I had known Larry Roberts from Lincoln and he had gone to ARPA under circumstances that you probably are aware of. He was going around telling a variety of people at a variety of different companies and organizations that they were thinking of this network and that maybe one should think about it and ask for the RFP [request for proposal] if and when it came out. So that was my first knowledge that they were doing that.

Weber: Well, it was him that asked you to—

Heart: It was more—I think what he was doing—he'd gotten turned down by the big guys, okay. AT&T and IBM had told him "Gee, we don't think this will work and we're not interested anyway and the only computers we have are far too big and so go away." So then he began going to a whole bunch of other people and just telling them that ARPA was thinking of doing this. it wasn't so much requesting anything as mentioning it to people—giving them a heads-up that this was about to happen—"maybe they'd be interested," was, I think, the form of the conversation, rather than asking anything.

Weber: But at this point you were heading a healthcare group.

Heart: No, I think as I said, there were more than just healthcare. There was a variety of other things going on at BBN. Healthcare was certainly a major one but there was an education group as well and some other small activities.

Weber: But you personally at that time were more on the healthcare side—

Heart: Yes.

Heart: And so how much of a jump was that? How did you end up submitting the proposal?

Heart: Well, I think that when we realized that this was happening there were other people at BBN who'd become interested in the networking world—like Bob Kahn—who had been at BBN for some time. I had realized as had some other people working with me that we were uniquely knowledgeable about connecting computers to phone lines. There were people that had followed me from BBN and that were—

Weber: Who were some of the notables?

Heart: Well, Severo Ornstein was at BBN and Dave Walden followed me from BBN. [the preceding should be "from Lincoln to BBN"]

Weber: And Severo had also come from Lincoln, right?

Heart: Yes, so—well, Severo took a circuitous route to get there. Severo was one of the people that left Lincoln to go off and work on a healthcare issue at MIT and then at St. Louis and then eventually wanted to come back to the East Coast and came to work at BBN for me. He followed me from Lincoln by a circuitous route through MIT proper and St. Louis, but was there at the time. And Dave Walden specifically followed me from Lincoln. And so when we heard about this we became interested and looked into a little and eventually the RFP arrived and then there was a decision BBN had to make as to whether to bid on that and we ended up deciding to do that.

Weber: And did you need to get approval from upper management?

Heart: Well sure, it was a lot of money. BBN hadn't bid on something quite that size and you know—in many ways it was a surprising thing that happened, because BBN was a very small company to get that contract. The government hardly ever gives big messy contracts to little teeny companies and BBN in their view is a little tiny company compared to say Raytheon or DEC [Digital Equipment Corporation] or other things. But we did decide to bid on it and you know, in the space of a month or six weeks, produced a proposal. We were fortunate that we were able to attract one other person from Lincoln in that process—Will Crowther, and that made a big difference because he was a unique resource.

Weber: Describe him and his expertise.

Heart: Well, he was— there's a class of people who I guess I would describe as super programmers where their cleverness and productivity isn't just two or three times the norm but is ten or a hundred times the norm. He's such a person. Very, very inventive and very, very good at what he does.

Weber: And Severo had been a hardware guy also at Lincoln.

Heart: Well, actually Severo started out as a geologist. He came to Lincoln and did—

Weber: Hardware of a sorts.

Heart: —did various things and then got interested in computer hardware and software and went to work with Wes Clark at Lincoln and became a hardware guy. He didn't start out being trained that way in school, that's for sure.

Weber: And Dave Walden?

Heart: Dave Walden was a young programmer—again, incredibly energetic young programmer.

Weber: And how many were in your team at BBN?

Heart: When the proposal got written?

Weber: Well, there were four for the proposal but on your total team—

Heart: Well, there were five. There was a—the press—there was a key group. The A group, if you like, was five people. Myself, Crowther, Walden, Ornstein, and Kahn—that was the core group. Then there was a second group of another half-dozen people: Bernie Cosell, Marty Thrope, Ben Barker, Truett Thatch. They were another half a dozen people—Hawley Rising, who had followed me from MITRE. So the group consisted of a key group of five and then a follow along group of another maybe eight, roughly. Small, relatively small group.

Weber: And they were all within your group.

Heart: Yes.

Weber: And these were all obviously the people with communication interests or background.

Heart: Yes, but some of them had actually worked at Lincoln and had done all this connection work. [The following is true for Crowther but not for Walden]Walden and Crowther had written programs for connecting computers to phone lines for a decade. So this—and I had Ornstein. And Ornstein's—the interim period with Ornstein, he worked on a thing called "The Link" with Wes Clark and helped develop that and helped do software and hardware for it.

Weber: Which building were you all in at this point?

Heart: This one probably.

Weber: Right, this floor?

Heart: Well, it was down at the very end, just after you come over the bridge on the left.

Weber: Over the bridge from the entrance.

Heart: Over the bridge from the other building.

Weber: But then that would be around here, isn't it?

Heart: Yeah, but not this far over. In other words, we can walk over and look at it <laughs>.

Weber: Yeah, I'd like to actually. And then so you're putting together the RFP was putting the proposal—

Heart: Yeah, the proposal was an extremely tough thing to do. And the proposal basically stated that we thought this was going to be kind of hard but that we thought we knew how. We were pleasantly surprised to have won come January 1.

Weber: And this took a lot of people off what they were doing. If you guys got it, it would be a lot of internal rearranging.

Heart: Well, it never got to be a big group. The set of people that I described was the set of people that mostly worked on the project. There were not a lot of other people. There was probably some of the people. There were Honeywell people, Bill Bartell from Honeywell. There were some other people—even Gardner [Hendrie] spent probably a moment or two on this <laughs>.

Hendrie: <laughs> Maybe, probably not.

Weber: Well, you went over there and talked to them, right?

Heart: Oh yeah, and—you see, it was actually tough on Honeywell, too because at that time there were only a very small number of machines that made any conceivable sense for this task. ARPA had originally assumed it would end up being a DEC machine. They had in their head the PDP-8 or some similar machine. But when we analyzed that problem and we—and some of the other bidders also analyzed that problem to figure out that it was pretty critical to have a very, very competent interrupt system in the machine. It turns out that the 516—the Honeywell 516—had a uniquely good system of that kind compared to the DEC machines, for example. It was perhaps the single factor that primarily influenced the choice. Now, in addition, Honeywell was making a hardened version of that machine and I was a nut about reliability, so the fact that Honeywell had a hardened version—it wasn't really a mil-spec [machine built to military specifications] machine, but it was a hardened machine. The fact that that was available made a big difference in the choice as well. And the other bidders also discovered—they're not stupid either—and so therefore, Honeywell found itself in the position of having to satisfy several bidders simultaneously who were all bidding on the same thing using the Honeywell machine. That was not so easy on Honeywell at the time. They actually had to struggle a bit to keep—you know, they didn't want to cross connect the bidders and yet they needed to satisfy each of the people that wanted to use their machine in the contract.

Hendrie: Afterwards you, of course, found out who some of the other bidders were.

Heart: Yeah. Well, I guess I don't know exactly who used the machine in the bid. I think Raytheon was the finalist that we ended up—I think it came down to two eventually and I think Raytheon was the one that was left with us at the end. DEC also bid and bid with somebody—in cooperation with somebody else.

Hendrie: Okay. Do you have any insight as to, you know, any of the factors that made your bid the winning bid? Was there ever a debriefing by Larry who sort of said "Well, you know, why we ended up choosing you besides this was you took this approach to this problem," or something like that?

Heart: I'll tell you, it's a complicated question and I'm going to be a little careful now, because I really can't speak for what went on at ARPA. I think that one factor was clearly that we weren't a big company. That is, there wasn't a seven-layer-of-management structure. There was me and the rest of the group. You know, there really was almost no structure and so that was one factor. Furthermore, he knew many of the people. He had known many of the people earlier even if only casually and had known them by reputation. So I think part of it was the thin layer of the management, which appealed to him, since he could talk to everybody easily. And secondly, I think we just wrote a better proposal. I think we knew more. As I think I said earlier, there were not groups around who'd connected computer to phone lines much. It was a very unusual set of talents that—while we weren't unique at Lincoln it was darn near unique. It was right next to unique. And so I think it was those two factors certainly and then as I said, we wrote a very smashing proposal. Crowther had actually written the interloop code to handle packets before the proposal got sent in. He—because of his—

Weber: On his own for fun?

Heart: No, no, no. In other words, the question was how fast could you handle packets and the RFP had one number in it, BBN's proposal offered to do it ten times faster.

Weber: Do you remember the numbers?

Heart: No, of course not <laughs>. And so Crowther had written the interloop to make that comp[utation]—we had to say how fast it was going to work. Well, how do you know that? You write the code and you see how many instructions it takes to handle the packet and—

Hendrie: Well, if you have a Crowther you write the code.

Heart: If you have a Crowther, you do that, yes, yes.

Weber: By the way, I should formally identify us. Gardner Hendrie is the other interviewer.

Hendrie: Interloper <laughs>.

Weber: No, interviewer.

Heart: So anyway, the proposal was very, very persuasive, because we knew more.

Hendrie: You'd done more.

Heart: We'd done more basically.

Weber: And they knew you had done more.

Heart: And they knew that. And furthermore, as I say, the other factor was—we thought the smallness might weigh against us because, you know, it was a big project, relatively. As it turned out, the smallness was probably at least even, in the sense that while it was a negative for performance, it was a positive in terms of ARPA's ability to interact with all the people in the group. Larry Roberts kept talking to Kahn, in addition to talking to me. He was able to talk to the group easily.

Hendrie: It was a big project. Could you quantify how much your original bid was?

Heart: I really don't remember the numbers, but it was a nine month contract to produce four IMPs [Interface Message Processors] and put them in the field and it was not a big contract, really. It kept getting bigger over time when they went on to many more nodes but I can take considerable pride in saying it was on time and on budget, which for a government project is not so bad.

Weber: Or common, yeah <laughs>. So once you got the contract who did you put to work doing what and what were some of the—

Heart: Well, I think—

Weber: Say at a technical level.

Heart: Yes. I think there were a lot of very serious problems. They were all what I would describe as "engineering problems." In other words, this was not like inventing the double helix. This was not a question of having some incredible breakthrough. It was a set of very difficult engineering problems.

An example is the routing problem. I mean, if you imagine a network of nodes connected by lines, where do you send the packet? Well, the computer has to figure that out in real time and it furthermore, has to adjust when a line is down. It has to adjust when there's a lot of traffic going in one direction and not another. It has to be able to figure out all on its own—each node has to be able to figure out where to send things. So that's one example of a kind of problem.

Another problem is, and this was a critical, early problem: special hardware had to get built both by Honeywell—BBN didn't have any hardware design or construction capability as we had no factory, where Honeywell had a factory. Now unfortunately, computer companies that have a factory normally want to use that factory to make their next multiple money-making computer, not to make you one of a kind interface. So Honeywell had to agree—which again was very tough on Honeywell—had to agree to make special interfaces of our design to connect to host computers and to connect to phone lines. There were two completely separate special interfaces that had to get designed and constructed. Worse than that, the host interface—not only did there have to be special hardware in the IMP to connect to the host, there had to be special hardware and software in the host to connect to the IMP. And so a critical problem was to tell the hosts what they had to build.

Now, if you think about the timing, the contract started in January 1, the delivery was basically in September—there had to be time not only for us and Honeywell to build hardware and software, but we had to design the interface and then the hosts had to have time to build the hardware and software that they needed, so that when the machine arrived it would connect. That was a race against time, because every day we didn't get that interface spec [specification] out was one day the hosts didn't have to build hardware and software and some of the hosts had a lot of trouble with that. That is, the spec eventually came out—Lenny Kleinrock once made the comment that no one would ever forget the number 1822, which was the spec number that BBN eventually managed to get out which defined how the hosts and the

IMP would mate—what hardware had to be at each end and what software had to be at each end. And that came out, you know, a few months after the ARPA contract was signed. It was a critical, critical deadline, because without the time, the hosts couldn't—in fact, when the hosts, the hosts had some funny experiences. I mean, the first machine at UCLA was an SDS [Scientific Data Systems] something or other. They went to SDS and said "Would you please design the hardware for us for this connection?" SDS said "Sure, we can probably do that. We'll start in a few months and maybe in a year and a half we'll get that for you." So in other words, they had a terrible time. They eventually assigned a graduate student to build the hardware—Mike Wingfield—who eventually built the hardware in time and got it connected. But it was not easy on the hosts, in addition to it being not easy on either BBN or Honeywell to meet that deadline.

So another problem was the spec. How do you mate the hosts and the IMP and how do you connect the IMPs to the phone lines?

Weber: And who wrote that spec?

Heart: Well, it was—there's two questions. It's a question of who designed it and it's a question of who wrote it. The design was done by Ornstein and Crowther and Walden. Kahn—one of his tremendous benefits was he was a fabulous writer and he worked around the clock. So in terms of actually who put that spec on paper, Kahn was probably the most involved in the actually getting it on paper. Kahn ended up being a major contact to the host organizations, in addition. Because even once the spec got written, there were questions. It was not a trivial matter for the hosts to cope with that.

Weber: And how many different kinds of hosts in the first instant?

Heart: Four.

Weber: So there were four different ones then.

Heart: I think there were four different ones, yeah.

Hendrie: Can we just stop for a minute?

Heart: Sure.

Hendrie: We have to change tapes.

Heart: Okay, sure. How are we doing on time?

END TAPE 1

START TAPE 2

Weber: So I was asking—prior to this, connecting computers was more rare than connecting computers to devices. But you were saying there had been some—

Heart: I think that what was rare was connecting computers in real time to something. That was what was rare. Connecting a computer to something wasn't so rare as long as there was no time constraint. I mean, you know, people connected computers to displays of various kinds. People connected computers to adding machines. I mean, they did strange things one-on-one in various places. But what they weren't doing was doing it quickly, because it didn't matter whether it got done in a microsecond or a millisecond or a second, whereas if you're talking about data on a phone line or from a host, you have to take it and get rid of it before the next little thing comes along.

Now, in terms of connecting computers together, a fascinating thing that took place in the very first months of the contract had got to do with connecting computers together. The original RFP asks for the IMP to be connected to a multiplicity of phone lines—a small multiplicity—and one host. Okay, that was the spec. The minute the contract was issued, several of the host organizations said, "Wait, wait! We've got several computers we're going to want to connect to this IMP." Well, it was a cost-plus, fixed-fee contract and ARPA came to BBN and said, "How about modifying it so that you can connect to several computers, please?" Well, that became an amazing thing, because it ended up solving a problem we'd never intended to solve, which was connecting computers at one site to each other—which no one had been able to do very easily. I mean, if you imagine two computers of a diverse sort trying to connect, that's a tough problem.

Weber: Had it been done before?

Heart: Very little, very little. I don't know the answer, actually, but put this way, if it had it was tough each time and there weren't many.

Weber: It is accurate to say this is the beginning of LANs in a sense.

Heart: Yes, absolutely. Absolutely. But you know, again, I don't want to claim that I know of every conceivable case where there was a one-on-one connection. But what happened was the IMP connection to the host became a standard. So if you have three hosts at a site, they would just connect through the IMP. I mean, it's just as easy to connect through the IMP as it is to connect to a computer across the country. And so that became a standard way to connect computers at an individual site.

Weber: Do you agree that then the IMP was the first router, in a sense?

Heart: Oh, yeah, absolutely. Sure. Absolutely.

Weber: And what was the name for the IMPs with multiple connections?

Heart: No, if you're talking about IMPs connecting to multiple hosts, it was still just an IMP.

Weber: Oh, but the Pluribus IMP was later.

Heart: That's much later. That's a whole different story. Much later.

Weber: And the terminal IMPs and all.

Heart: Yeah, different story. So anyway, you asked what some of the problems were. Routing was a problem. Getting a spec to connect to the host and a spec to connect to the phone line, and having them built on time and delivered on time was a tremendous problem. There was a problem for ARPA getting phone lines put in on time. Fortunately, that wasn't our problem at BBN. Larry Roberts got the phone lines through some military organization at someplace and ordered them himself. And he was in charge of beating on AT&T, which was not trivial either, but we didn't have to do it. And so that was a problem. And there were a whole bunch of others.

I think that we ended up inventing what I believe was one of the very first instances of any action at a distance with computers. I mean, we could debug computers over the phone lines from BBN. We could put new programs into the computers over phone lines from BBN. We could look into the active memory of the machine as it was working and find out how many packets it was processing and what else it was doing. And that action at a distance involvement, I think, was unique at that time.

Weber: And who was most responsible for...

Heart: The crew of people, Cosell, Walden, Crowther. There was nobody else. I mean, there was only just a small group there—

Weber: Well, was there someone that—because that was a relatively new idea as well.

Heart: It was, very new idea.

Weber: Was that kind of a light bulb or it just sort of evolved?

Heart: I think it just evolved. Well, let me say it differently. I was extremely concerned about reliability. I mean, I wanted to make it really hard for the graduate students at UCLA to futz with my IMP. I wanted to make it really tough for anybody to touch it. You know, there was originally pressure from the host site, so couldn't they use it for some other things since it was just sitting there most of the time? I wanted the answer to that to be a large, capitalized NO. And so the question was, "How did you debug it? How did you find out what was going on? If you didn't want anybody at the site to touch it under penalty of death, how did you do anything? And then there was also the fact that ARPA wanted information as to how their network was working, so they'd given a separate contract to UCLA to run a measurement center. Well, it had to measure something. There had to be something in the IMPs collecting that data to send that they could measure. So the IMPs ended up being very—a lot of energy went into the whole idea of action at a distance on the IMPs.

**{from editor Dave Walden: The ability to debug, collect statistics, etc., across the network fell out of the need (discussed earlier in the interview) for there to be more than one host on an IMP at an IMP site. Originally, I wrote the host code to handle one host as the RFQ called for. Then we needed to handle multiple hosts, so I rewrote the code to have a parameter for which host it was dealing with. As soon as the code could handle multiple hosts, it was trivial to have "fake hosts" inside the IMP code, i.e., stats, trace, debug in and out, parameters change, etc., and this was what easily allow all that cross-net control and monitoring stuff. We settled on up to four real hosts on an IMP (a limitation of how many host hardware interfaces could be attached to the computer, and thus with one more bit we could specify any of four real and four fake hosts. Not only we, but people at host sites (e.g., Len Kleinrock's network measurement center at UCLA) could communicate with an IMP's fake hosts (e.g., to turn on statistics taking). With the ability to tell an IMP what to do at a distance, we could tell it to reload itself from a neighboring IMP; this allowed distributing new releases over the network.}

Again, if you imagine a network and somebody somewhere presses a key on their little terminal and they expect an answer from some distant host and nothing happens, how do you find out what went wrong? It was a very difficult problem and that problem evolved through a decade of the ARPANET. Not only did we work on it very much at the very beginning, but it kept being worked on for the next decade very hard, because it was a difficult problem. We could, for example, crosspatch phone lines at a distant IMP from the control center at BBN. We could connect the interface back to itself to find out if the interface was working when somebody had a problem, to separate it from what was happening in the host at that site. And there was a lot of that kind of effort going into debugging and control and improving the program remotely without having to go to these places or to have local help.

And how do you correct when something really goes wrong? There was a crazy thing in the Honeywell machine called a watchdog timer. You could set it so that if it didn't get poked periodically, it would force the program to reload from a distant—it would reload from the next neighbor. You could actually force it to do that if something went completely crazy in the program, which we knew would happen sometimes.

So those were some of the problems, and there were a bunch of others. The problem with phone lines is they make errors, so a big technical problem was, what kind of error control do you use on the phone lines? And Kahn actually was an expert in that particular technology. And so basically an error-detecting, an error-correcting kind of code was built into the messages[should be “packets”]. And that had to be implemented in hardware, because the software wasn’t fast enough for that. In other words, as the packet came in, you had to grab a piece of it and do a code conversion to compare with the piece that came in. And that the software couldn’t do. You know, we constantly had the problem: What should be done in hardware and what should be done in software? There was a mix of both things happening, and the error control stuff was too tough for the software—had to be done too quickly. So that was again a piece that had to get built into the interface and was hard to design and wasn’t so easy for Honeywell to build.

Weber: So you would basically send them [Honeywell] the hardware spec and then...

Heart: Yes. Ornstein would send them the hardware spec and they’d try to build it. And when they built it wrong, we’d beat them on the head and they’d try to fix it. It was hard.

Weber: And with all of the host companies, it was sort of a similar...

Heart: Each host company had the same problem of building their mating interface, yes.

Weber: But you were sending them a spec and spec—

Heart: We sent them a document called 1822, which was a spec for the hardware they had to construct in order to mate to the IMP. Yes.

Weber: And you’ve talked about technical problems. Were there any sort of changes of direction, things that didn’t work—

Heart: Well, the one change in direction I mentioned to you was the change from one host to more than one host per site. That was a big change. There were no other big changes. There were obviously little things that may have happened. For example, we wanted to have AT&T put in a voice circuit, so that in the early network we could have somebody at the end of both things and just be able to talk to each other. There were other things that were little changes that took place as we went along, but nothing else major from the original spec.

Weber: Describe when they were first hooked up and worked.

Heart: Well, the first one, there was nothing to hook up to. I mean, one machine went out to UCLA to mate to the SDS and it talked to itself. The first connection was one computer to the IMP. Then the next connection was to a machine in the San Francisco area.

Weber: SRI, yeah.

Heart: Yeah.

Weber: And would you consider that the beginning of the ARPANET, when the first two machines—

Heart: Kleinrock would certainly claim that when the first machine showed up at UCLA, that was beginning of the ARPANET.

Weber: Yeah.

Heart: All right, so it would depend who you asked, when the ARPANET—

Weber: What would you say?

Heart: I don't—it's not—it's an uninteresting question.

Weber: <laughs> So then what was the next—well, I take it it was gratifying that it worked...

Heart: Well, yeah. Many things then began to change. I think the first thing that happened was that they—ARPA wanted—now that it worked, they wanted more. And so there were many more nodes starting to come into being. And then it became clear that there would be some people that wanted to get on the ARPANET that didn't have a big computer. And so that led to the development of the Terminal Interface Message Processor [TIP], which allowed people to access the ARPANET and access some of the computers on the ARPANET without having their own computer to contribute. That was a big change, and that impacted a number of the military sites. It began to involve people who weren't just research organizations at universities. I mean, the first group of people were all university research groups. But after a while, it began to involve other kinds of users, and the TIP was a way for some of those people who didn't have their own big computer to still experiment with the network and use computers that were on the network.

Weber: How long did it take for that to—roughly?

Heart: Probably within the first 18 months, that began to be an issue.

Weber: And you guys did all that? Same team?

Heart: Yeah, same team. The team never got very big. I mean, it really didn't.

Weber: And the Pluribus IMPs?

Heart: Well, yeah. That was a—

Weber: Wasn't that eight connections?

Heart: Pardon me?

Weber: That was eight connections?

Heart: That was just a much, much faster machine. There, the idea was to be able to handle other kinds of data besides just data from individuals or from computers. The Pluribus IMP was partly developed because of wanting to handle seismic data and to be able to have just a much faster machine. We wanted to build a Pluribus IMP, because it was a very fascinating multiprocessor project. At that time, Kahn was at ARPA, and he was interested in that too, really, as a—you know, the government's supposed to only work on government problems, and the Defense Department's only supposed to work on defense problems, but we all know that isn't completely true. ARPA in particular often put money into things that were, what I would call, joint-use. That is, obviously, both of use to the Defense Department, but also of use to lots of other things. And the idea of developing a multiprocessor was certainly in the category of things that had broad other potential uses, besides uses for the ARPANET. So I don't think that the Pluribus IMP was intended because the ARPANET so much needed as it was a research project that had a use in the ARPANET for certain classes of users. And it was a way to support an interesting multiprocessor project.

Hendrie: Before you got to the Pluribus and the TIP—

Heart: Well, the TIP was much earlier than Pluribus.

Hendrie: Much earlier, yes. I was trying to get some timeframe. Were there iterations in the IMP?

Heart: Oh, sure. All the time. The IMP software changed steadily. We would issue new software in months. There would be many—just a few months go by and we would resend an entire new software package to all the IMPs. Before there was a cross-country connection, we did that with paper tape. But the minute there was a cross-country connection, we began to do it over the network itself. And we'd reload IMPs with new software. People would find glitches of one kind or another or imperfections, and they'd want to fix them. As long as they could fix them without driving the network to distraction, that was done.

Hendrie: How long did you use the original hardware and the 516? When did you do a hardware—

Heart: Yeah. Well, I've really forgotten, Gardner, when that was. It was 40 years ago, Gardner.

Hendrie: I know.

Heart: I really can't remember.

Hendrie: It was after a few years.

Heart: It was after a small number of years, and ARPA properly noticed that they were paying 20 percent more for this hardened machine. And Honeywell had come out with the 316, which was a follow-on machine. Therefore, why not downgrade slightly, give up a little of this hardening for a cheaper, smaller machine? And that was what happened. But I've forgotten the exact timing.

Hendrie: Yeah. And did you redo the interface at the same time or...?

Heart: Well, yeah. The interface had to be adjusted for the 316.

Hendrie: Yeah, sure. Okay.

Weber: One thing we're trying to figure out is what copies exist of the IMP software? Any leads? Okay. <laughter> But would there be paper tape versions, except for the first, or then it was—I presume... no...

Heart: I don't know where—the IMP you have doesn't have the software in it? How would it have gotten rid of it?

Hendrie: That's true. <laughter> It's a core memory. You're right.

Weber: I think you solved the problem.

Hendrie: The binaries may be a little hard to read, but, hey...

Heart: I don't know. I have no idea where the software is.

Hendrie: You could reverse compilers. Yeah.

Heart: Does BBN have a copy?

Weber: We're asking.

Heart: You're asking. I really don't—I have no idea.

Weber: And tell a little bit about—what was a typical day like, working here, say, early in the period.

Heart: I think it was really just a very, very tough time for people, and they put in very, very long hours. I'm not sure Kahn ever slept. I mean, other people probably occasionally ate and slept, but it was very tough.

Weber: So you were...

Heart: And people felt very strongly about trying to meet the deadline.

Weber: You might arrive in the morning and find guys who had worked all night.

Heart: You certainly would find some people. You'd find Cosell still around or something—find some people. There were a lot of other things to do besides work on the IMP software. For example, the very first software work was done in machine language on the IMP itself. But as soon as people like Cosell showed up, they wanted that compiler on the PDP-1 so that they could write in a little easier terms than machine language for the 516 and compile on the PDP-1. So there were all kinds of tools that had to get built over time. The very beginning, we didn't do that, but soon afterward there were tools: debugging tools, compiling tools, listing tools. Tools for making listings of—and it was a lot of extra work that had to go on around a project like this. But the team never grew very much.

Weber: And most of these guys are working on paper. Some had terminals or what was...

Heart: Well, yes. Most of them were working on paper. After a while, they worked on the PD—as I said, they used the PDP-1 as a compiler after a while.

Weber: But would they have—if they walked through the offices, you would have seen mostly people writing on paper. **{ from editor Dave Walden: This discussion is misleading. We were soon were inputing and editing code on TTY terminals hooked to the PDP-1d based time-sharing system. TECO was our editor, and we used the macro assembler for the PDP-1 modified to understand 516 instruction codes. }

Heart: Yeah.

Weber: A few people sitting at terminals.

Heart: Well, they'd be sitting—or they'd be sitting at terminals of one kind or another. Sure, there were terminals. There were teletypes. There were other terminals.

Weber: And they each had their own office?

Heart: Yeah, in general.

Weber: And you would have meetings a few times a week?

Heart: In a little conference room called the Weiner Room, which may still exist, for all I know.

Weber: And why was it called the Weiner Room?

Heart: I've forgotten. <laughter>

Weber: Sounds like a very compatible group. You all knew each other very well.

Heart: I think that's right. One of the benefits of a very small, very, very strong group is that you-everybody knew what everybody else was doing. All the software guys knew about hardware and all the hardware guys could program. I mean, this was not a group that was separated by boundaries of one kind or another. It was a very small group.

Weber: And what were—were people—were they dressed like hippies, with pocket protectors, like...

Heart: It varied. I dressed, but a lot of them didn't. Crowther never put on anything but sneakers in his life. People dressed differently. Bernie Cosell played music occasionally in his office. It was a pretty relaxed group.

Weber: You would wear a jacket or suit?

Heart: I would tend to—not a suit but usually a jacket and tie. Yeah, I tended to be one of those types.

Weber: And Kahn?

Heart: Well, yeah. Not particular—everybody was pretty relaxed. I don't think there was much in the way of dress code worry.

Weber: And did people hang out together. Did they know each other's personal lives? There was more...

Heart: Well, some certainly did. I mean, you know, Severo and I were always friends, and Walden at that time was certainly a friend. Crowther spent more time on his own—rock climbing and crawling through caves and so forth. But it wasn't a social group. I mean, in the sense that if you asked, did they see other on weekends, probably either they were working or they didn't. But they were friends.

Weber: What was the acronym for the Pluribus IMPs?

Heart: Pluribus IMP, I think was—I don't know, maybe just the Pluribus IMP. I don't know.

Weber: Okay. And did you have much to do with the NIC [Network Information Center] at SRI?

Heart: Very little. In fact, the other hosts that had contracts with ARPA—in my view—they were partly simply ARPA's way of keeping those people interested in the net and staying involved. They really were not things that, in my view, made a huge difference in what happened to the network. If you asked, did the Network Measurement Center make a huge difference in the success of the Internet, I would say, "Gee, probably not." That's not to say they didn't do some good things, but it wasn't on the main path.

They had to have a contract to do something, because otherwise they wouldn't even cooperate in the network. And the NIC, again, you wanted that to happen. You wanted those things to get done, but if they hadn't gotten done or if they were a month late… It was a little different with the BBN group and with trying to get, you know…

For example, Howie Frank ran this group in New York that was worried about network topology. And again, it's nice to have that, but most of the network got chosen where it went by Larry Roberts scratching on a piece of paper and saying, "Let's put it there." Or "this is the next military organization that I have to convince to get interested. Let's put one there." So all the analysis of where you would optimally want to put your network, it was a little bit off the point. Not bad or not—it contributed—but it wasn't sort of in the main path.

Weber: And the main path was you guys and DARPA...

Heart: And DARPA, yes.

Weber: Anyone else? Not really?

Heart: Not really. I mean, that was the main path. Well, wait a minute now. I need to be careful. The next problem that had to get worked on—and which people like Crocker and the Network Working Group worked on—it was none of the things we were doing. None of the things that involved the connection of the IMP to either host or phone lines solved the problem "what the hell the hosts were going to do with the network?" So there was a whole other layer of problem. And that actually didn't go well. It was years before the network working group came up with software which really allowed any resource sharing. Larry's original idea—when Larry first thought about the network, he imagined that one site and its computer would use software in some other site, so they didn't have to construct it again in their own site. There'd be resource sharing across the network. Well, for years there was zilch of that. I mean, it just plain didn't happen, because there was a whole other layer of software required in the host computers. The mere fact that you can call France on your telephone in the corner doesn't mean you can speak French. That's a whole separate problem. Even if the phone connection is perfect, if you can't speak French you don't do so well calling France. Likewise, the host software problem with a much longer, drawn-out, difficult thing, which never—in my view—satisfied the original intent. Email made a much bigger difference than ever did the idea of resource-sharing.

Weber: That's still for the future.

Heart: Right, still true. I got to that discussion was when you said, "What was the main line?" Another main line was the host software. People like Crocker and the Network Working Group and many, many other people—people at BBN and people at many other places—worked on that problem. And it was a very big, distributed problem, which really, in some ways, has not had really good solutions to this day.

Weber: But your group was not involved?

Heart: Well, no. That's not fair. We were involved, but peripherally.

Weber: Right.

Heart: In other words, people like Alex McKenzie in our group became our representative to the Network Working Group. He was also a person who could write incredibly well. He followed in Kahn's footsteps. So we actually were involved in a nontrivial way, because we put up one very, very strong person who went to these things and helped. But it wasn't our project. We had no responsibility for making that happen.

Weber: So as time went on, you remained with mostly IMP and hardware aspects.

Heart: Hardware and software of the IMP.

Weber: Right. But you did stay at BBN into the early '80s, right?

Heart: No, I stayed at BBN until 1994.

Weber: Okay. But you were involved—sorry—specifically in the IMP until the early '80s.

Heart: Yes.

Weber: So what went on in the later years?

Heart: Well, it gets harder and harder for me to answer that, because so many different things were going on.

Weber: I mean for your group.

Heart: I understand. I think you've already alluded to questions like the Pluribus IMP, and there was work on satellite networks—the IMP was used to connect to satellite networks as well and connect to other networks. There began to be Internetting—

Weber: Right—

Heart: Which began to happen. But I was less personally involved in that. I mean, I was not a driving force for any of those other projects.

Weber: Because I've interviewed, well, a number of people involved with the Internetting effort—with Ginny [Virginia Strazisar] Travers, who brought us here. But that was something that you saw but you were not—

Heart: I didn't have a responsible job in that area. The group was involved because, in many cases, it required adjusting what was happening. In some cases, the IMP was changed slightly to connect to radio networks or something. But those were relatively major other efforts that were not always even run at Bolt, Beranek, and Newman [BBN]. There were things that were happening. Norman Abramson came up with the ALOHA System [or ALOHAnet] in Hawaii. We knew all about that and we were good friends, but it wasn't our project.

Weber: And what Ginny was doing with the gateways...

Heart: Again, it was much later.

Weber: Right. '77…

Heart: Yeah, much later.

Weber: So in explaining the IMP to the ordinary person—a typical museum-goer—what would you say? Why is it important and...

Heart: I think that it was necessary to have a set of phone lines so that there was multiple connections between sites. The IMP allowed a host computer to connect not just to one route to some other host, but over a network. It was a routing device. It took information from a host and was able to send it to some other host via a whole variety of paths. It could pick the right one at any given moment that, A, wasn't broken and, B, had available capacity and, C, was quick enough. The IMP was a device which could transduce between a host wanting to send something to someplace and figuring out how it gets there over a multiplicity of phone lines. The IMP typically connected to three or four phone lines [probably almost never 4], and the host would send information to the IMP, and the IMP would figure out where to send it so that it had the best chance of getting there. It would also make sure it got there, because it had error control. So if it got sent over a phone line and broke—if the message broke—the IMP knew enough to send it again. It was, therefore, a reliable route to get from one place to another via a network.

Weber: Now, IMP, obviously, is a literal meaning of Interface Message Processor. But did you—why did you choose the name? For the acronym as well?

Heart: No. I think that—I certainly have forgotten how we first came up with that name. I think that it certainly is an interface that processes messages. So it was named essentially correctly.

Weber: What were the two or three most important goals for the IMP—why you did it this way?

Heart: I think one critical goal was to be able to be fast enough that a person sitting at one host computer could touch a key and—even if the message had to go through three IMPs to some far away host, through the host and back through three other IMPs—it would still get back there fast enough so that the person would think it was a local computer. It had to be quick enough so that it felt like it was local, even though it went all the way across country through six IMPs and a host somewhere else. It had to feel like the host was in the room. That was very important; otherwise, people would kick the machine and not use it.

Weber: And this is a very military-hardened machine. Say something about that.

Heart: Well, I think the goal was to try—in every possible way—to make it reliable. I think that—I grew up in an environment at Whirlwind, this is now going way back, but Jay Forrester was another person who believed incredibly strongly in reliability. And Whirlwind even had a thing called “marginal checking,” where you could go into the control the room and you could change the supply voltages in all the tubes, so that the ones that were about to fail would fail while you were checking them, rather than while it was doing a computation. So I grew up in an environment where reliability had been a very, very important thing. And likewise, at Lincoln—people wanted their antennas to point to the right place and not accidentally go zipping off some other place. I was really a nut on reliability, and I wanted not only to have the machine itself be very reliable, but to have the software be very reliable and have nobody touch it. So the idea of getting a hardened machine was to increase the chances that it would keep working in the face of student populations at various universities.

Weber: And what did you envision them doing? <laughs>

Heart: I didn't want them doing anything.

Weber: And you've said that you were a Depression baby in this—generally, your security is a concern...

Heart: Reliability.

Weber: ...for you, is an important thing.

Heart: Yes.

Weber: So how much is the IMP kind of an outgrowth of your personality and your goals?

Heart: No, no. That's going too far. That's going too far. It's just that I viewed reliability as very important. And so there were, both physically in the program, and in the way of doing debugging and in the way of reloading and in the way of cross patching lines—a lot of energy was put into trying to make it reliable, because I was certain that if it wasn't reliable it wouldn't succeed.

Weber: And I presume that DARPA knew this. I mean, they knew you, and do you think this was a factor in choosing you?

Heart: Well, yes. I think the proposal had considerable data on attempts to make it reliable—the choice of the machine itself and so on. Sure, yes.

Weber: And what do you think the IMP's legacy is?

Heart: Well, I think it's the Internet. I think the IMP is the—the ARPANET is the progenitor of the Internet.

Weber: But also the IMP in many ways may be the first LAN?

Heart: Well, it's the first router.

Weber: First router.

Heart: The first router.

Weber: Which gives birth to the first LAN...

Heart: Right.

Weber: You've mentioned a number as we've talked, but any other kind of human interest stories or anecdotes that spring to mind?

Heart: Well, no. I guess, asked that way, I can't come up with anything very exciting.

Weber: It's a tough way to ask. Yeah. Gardner, do you have any...

Hendrie: Yeah, one of the things I am always interested in is your view of what you would tell youngsters who are interested in science. Do you have any advice as to how they ought to proceed and what things you would advise them to go do?

Heart: Well, do you remember how, in *The Graduate*, the person said, "Plastics, plastics, plastics"? I'd probably these days say, "Biology, biology, biology."

Hendrie: All right. <laughter>

Heart: No, quite seriously. I think that the last century was an engineering, scientific century. I think the coming century is going to be a biology century.

Hendrie: Good. All right.

Heart: <laughs>

Weber: Do you remember when you first got interested in computers before going to college? Did you think about them? Did you know about—

Heart: No, I didn't know such a thing existed.

Hendrie: We have just a little bit more time. One thing I'm always interested in is when you were growing up, what, you know...

Heart: I wanted to be an engineer.

Hendrie: Yeah. Why did you—what...

Heart: My father was an engineer.

Hendrie: That's a good—see, we didn't know that. That's a very good reason. What did he do?

Heart: He worked at Otis Elevator for his whole career, building, essentially, computers out of relays. I mean, an elevator controller in those days was a relay computer, for all practical purposes.

Weber: And did you see what he did—

Heart: Oh, yeah. Yeah, but the word "computer" never entered either of our minds. I mean, it was what he did. He built relay things and they controlled elevators. But they were essentially relay computers.

Hendrie: Okay. So he was the biggest influence and you decided you wanted to be an engineer.

Heart: Oh...

Hendrie: And did you do well in the courses, science, and math in high school?

Heart: Oh, sure. Sure, I won the Rensselaer Math Medal in high school.

Hendrie: Really? And you didn't go to Rensselaer?

Heart: No.

Weber: Did you build things as a child or teenager?

Heart: Not a lot. I wasn't—you know, some. Some gadgetry for controlling lights in my room and so on. But no, not a lot. I wasn't really a person that did that all the time, no.

Weber: But you were more attracted to electrical than mechanic? Or both?

Heart: Oh, yeah. Yeah, yeah. I was going to be a power engineer. I worked two terms as a co-op student at MIT on major, big-power transformers and on aircraft jet engines at General Electric Company. So yeah, I was going to be a power engineer until Gordon Welshman showed up with his course on computers.

Hendrie: My goodness! So all way through the first two years, you were...

Heart: Oh, yeah.

Hendrie: You were headed toward power engineer.

Heart: Power, power. Yeah.

Weber: And you just knew when you saw a computer.

Heart: Well, it was very, very new and exciting. I mean, it was like seeing another world and. Yes. I dropped out of the co-op program, to the very great annoyance of the General Electric Company, since no had ever done that before.

Hendrie: Okay. <laughs>

Weber: So there was a risk involved too. No?

Heart: Well, no. I was offered a research assistantship to replace it. I mean, no risk. Just a new, very, very new and very exciting thing.

Weber: What are your hobbies?

Heart: I don't—I'm not a hobby person. I'm okay. It's been—retirement's been quiet for me. I think we're done. When you're getting to my hobbies, it's time to quit, probably. <laughter>

Hendrie: All right.

Heart: Okay?

Weber: Good. Well, thank you so much.

END OF THE INTERVIEW

