COSATI ORGANIZATION

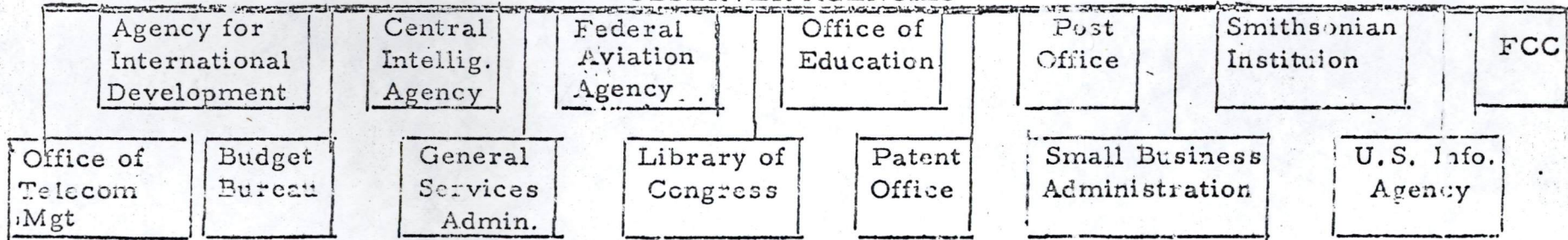| Office of Science and Technology (OST) | - - - | Federal Council for Science and Technology (F C S T) | - - - - - | BOB |

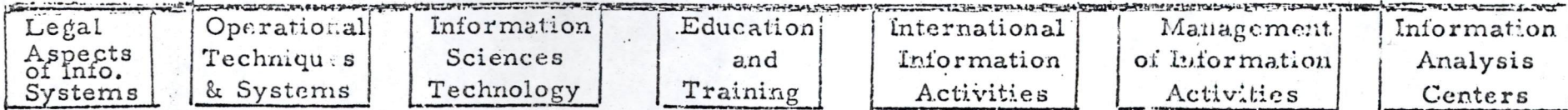| Committee on Scientific & Technical Information (COSATI) | - - - - - - - - | Committee on Scientific & Technical Communication SATCOM - - - (NAS/NAE) |

MEMBER AGENCIES

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| Office of Telecom Mgt | Budget Bureau | General Services Admin. | Library of Congress | Patent Office | Small Business Administration | U.S. Info. Agency |

PANELS

| Legal Aspects of Info. Systems | Operational Techniques & Systems | Information Sciences Technology | Education and Training | International Information Activities | Management of Information Activities | Information Analysis Centers |

TASK GROUPS

| Dissemination of Info | Steering Group | National Systems | Library Programs | Technology Utilization |

April 10, 1968

For background and information

COSATI ORGANIZATION

| Office of Science and Technology (OST) | - - - | Federal Council for Science and Technology (FCST) | - - - - - | BOB |

| Committee on Scientific & Technical Information (COSATI) | - - - - - - - | Committee on Scientific & Technical Communication SATCOM - - - (NAS/NAE) |

MEMBER AGENCIES

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TASK GROUPS

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April 10, 1968

PRIVATE SECTOR AREA

GOVERNMENT SECTOR AREA

OFFICE OF
COMBINED
STUDIES

PRIVATE SECTOR SUPPORT BUREAU (PSSB)

GOVERNMENT SECTOR SUPPORT BUREAU (GSSB)

Office of Foreign Computer Activities	Office of Domestic Activities	Office of Special Projects	OFFICE OF NAT'L POLICY STUDIES FOR CS&T	OFFICE OF PROJECT STUDIES FOR CS&T	OFFICE OF INFOR-MATION SUPPORT FOR CS&T
--Study of Market Trends in W. Europe** --Study of Market Trends in E. Europe** --Study of Recent Developments in Japanese Computer Industry** Study of Computer Applications & Requirements in USSR** --Technical Evaluation of Foreign Computer Technology Trends**	--Study of Rates & Directions of US Computer Technologies*** --Comparative Analysis of US & Selected Foreign Computer Industries*** --Assessment of Importance & role of Computer Technology in US-World Technology balance***	--Study of Computer Technology Transfer-ability, Factors affecting same*** --Study of Impact of Computers on Military/Civilian Organizations**	--Information Systems Panel (CLR) --CS&T Nat'l Priorities Study for '70's (OST) --Privacy Inquiry-70-1 (Russell Sage) --Nat'l Program Panels "A" - "B". (Board Initiative) --CS&E Standards Panel (Board) --Technology Assessment Program** --Technology Transfer Program* --Non-Technological Impact Study* --Study of R&D in Computer Science Field*	--Summer Conference on Comptrs. & Education - (NSF) --Survey of Computer Industry Support of Computing Activities in colleges & universities (NSF) --Interconnections Study (FCC) --Computer Export Panel (DoD, State, OST)	--Research Program for college/univ. activities & developments related to computer science* --Data Collection regarding computer related activities International area* --Special support to Nat'l Policy & Project Studies.

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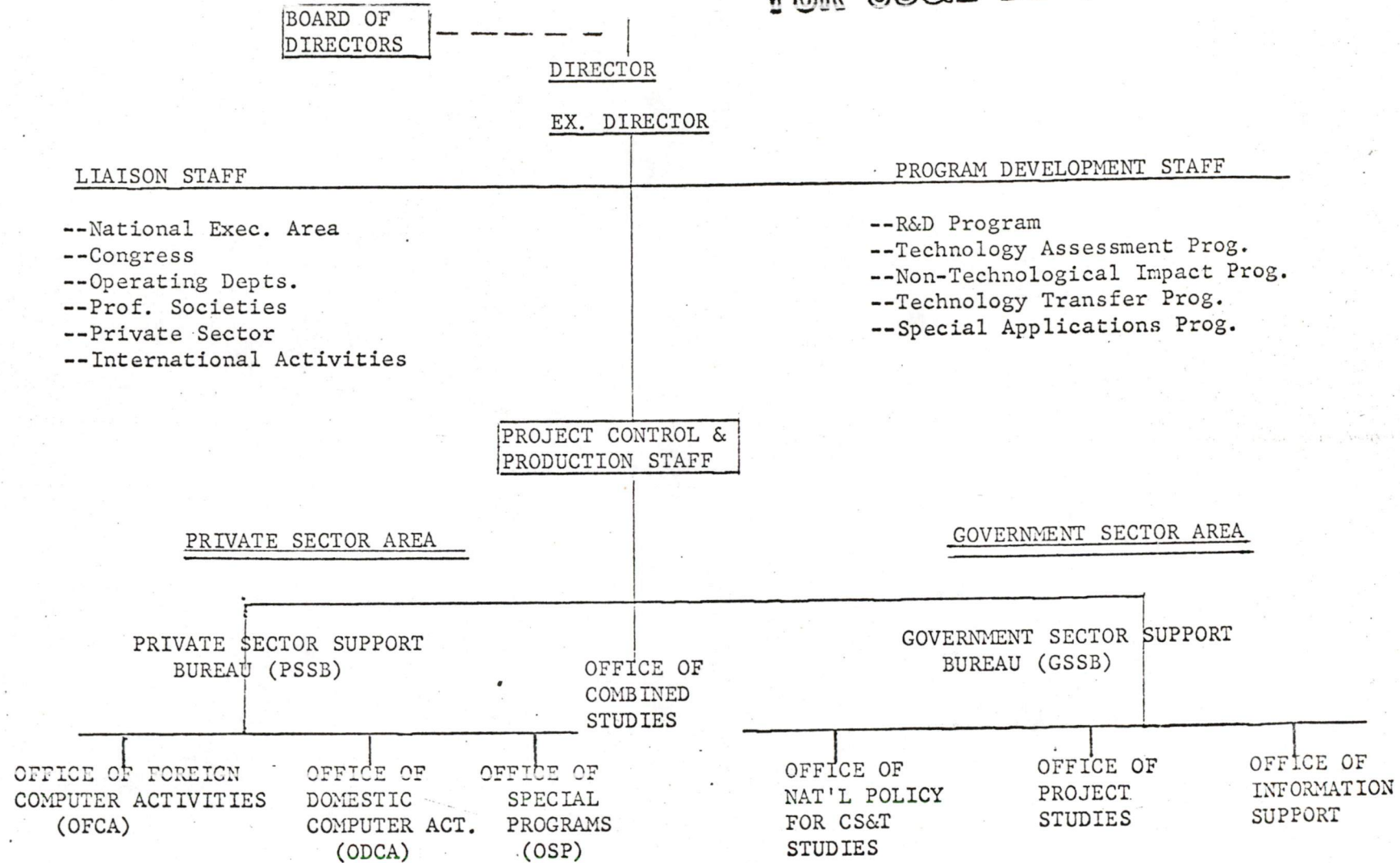*ILLUSTRATIVE

--ACTIVE, SPONSORED
*PLANNED OR SCHEDULED

NATIONAL CENTER FOR COMPUTER
SCIENCE & TECHNOLOGY

(NCCS&T)

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BOARD OF     ┐ _ _ _ _ _ ┐
DIRECTORS    ┘           |
                   DIRECTOR

                   EX. DIRECTOR
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LIAISON STAFF   PROGRAM DEVELOPMENT STAFF

--National Exec. Area   --R&D Program
--Congress   --Technology Assessment Prog.
--Operating Depts.   --Non-Technological Impact Prog.
--Prof. Societies   --Technology Transfer Prog.
--Private Sector   --Special Applications Prog.
--International Activities

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                          │PROJECT CONTROL & │
                          │PRODUCTION STAFF  │
                          └─────────────────┘
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PRIVATE SECTOR AREA   GOVERNMENT SECTOR AREA

PRIVATE SECTOR SUPPORT   OFFICE OF   GOVERNMENT SECTOR SUPPORT
BUREAU (PSSB)   COMBINED   BUREAU (GSSB)
                                    STUDIES

OFFICE OF FOREIGN   OFFICE OF   OFFICE OF   OFFICE OF   OFFICE OF   OFFICE OF
COMPUTER ACTIVITIES   DOMESTIC   SPECIAL   NAT'L POLICY   PROJECT   INFORMATION
(OFCA)   COMPUTER ACT. PROGRAMS   FOR CS&T   STUDIES   SUPPORT
                       (ODCA)   (OSP)   STUDIES

COMPUTER

INDUSTRY

PROFILE

Prepared for: Data Base Panel
Computer Science and
Engineering Board
National Academy of Sciences
Washington, D C 20418

By: Patrick J. McGovern
International Data Corp.
60 Austin Street
Newton, Massachusetts 02160

TABLE I   ESTIMATED AND PROJECTED ANNUAL VALUE OF COMPUTER EQUIPMENT SHIPPED BY AMERICAN MANUFACTURERS
AND THE ANNUAL SIZE OF THE RELATED PERIPHERAL EQUIPMENT, SOFTWARE, AND SERVICES MARKET
(Values in $Millions; Equipment values calculated as purchase price of systems when shipped)

Year	General Purpose Digital Computers	Special Purpose Computers	Independent* Peripheral Equipment	Contract and Packaged Software	Computing and Data Processing Services	Data Processing Supplies	Total
1955	$ 75	$ 80	$ 14	$ 15		$ 155	$ 339
1956	140	210	25	20		175	570
1957	240	350	35	25		195	845
1958	460	450	50	40		230	1230
1959	600	650	75	90		270	1685
1960	720	900	105	125		370	2220
1961	1100	1100	110	180		485	2975
1962	1400	1300	130	220		530	3580
1963	1800	1300	145	$ 5	$ 265	595	4110
1964	2200	1200	170	20	300	630	4520
1965	2400	1250	175	50	400	660	4935
1966	3660	1400	185	100	500	740	6585
1967	5900	1610	225	175	600	850	9360
1968	7200	1850	300	270	720	960	11,300
1969	8200-8400	2050-2150	375-425	350-450	800-900	1050-1150	12,825-13,475
1971	10,500-11,100	2400-2600	625-725	600-800	1000-1200	1200-1350	16,325-17,775
1973	14,900-15,900	3000-3200	900-1100	1000-1200	1350-1650	1300-1500	22,450-24,550
1975	19,400-20,400	3850-4150	1400-1600	1500-2000	1800-2200	1500-1700	29,450-32,050

* Part of this equipment is sold to computer manufacturers.

WORLDWIDE SHIPMENTS OF COMPUTER EQUIPMENT
BY AMERICAN MANUFACTURERS*

Company	Shipments in $ millions	Percentage
International Business Machines	$5200	72.2%
Univac	380	5.3
Honeywell	340	4.7
Control Data Corporation	305	4.2
General Electric	280	3.9
Radio Corporation of America	225	3.1
Burroughs	170	2.4
National Cash Register	170	2.4
Scientific Data Systems	75	1.0
Digital Equipment Corporation	35	0.5
Others	20	0.3
	$7200	100.0

*Includes equipment produced or assembled
in plants outside the United States.

INTERNATIONAL DATA CORPORATION

TABLE III   GENERAL-PURPOSE DIGITAL COMPUTERS, MADE BY U.S. FIRMS, INSTALLED WITHIN THE U.S.
(Values, in $ Millions, calculated as purchase price of systems when shipped)

Year	No. of Systems Shipped	Cumulative Net Systems Installed (Yearend)	Value of Computer Equipment Shipped	Cumulative Net Value Installed (Yearend)	Cumulative Customer Installation Sites (Yearend)
1955	145	244	$ 63	$ 177	$ 185
1956	550	746	156	324	533
1957	850	1500	240	547	930
1958	1180	2550	395	923	1575
1959	1395	3810	495	1390	2380
1960	1790	5400	590	1937	3210
1961	2700	7550	880	2715	4195
1962	3470	9900	1090	3620	5590
1963	4200	12,850	1300	4720	7050
1964	5600	18,200	1670	6105	9875
1965	5350	23,200	1770	7655	12,275
1966	7250	29,800	2640	10,030	15,650
1967	11,200	40,100	3900	13,600	18,400
1968	9100	47,100	4800	17,350	20,400
1969	9100-9800	53,000-54,000	5270-5370	21,100-21,850	22,500-23,300
1970	10,500-11,200	60,300-61,800	5700-5850	25,200-26,300	25,000-26,200

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INTERNATIONAL DATA CORPORATION.

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TABLE V FUTURE DISTRIBUTION OF GENERAL-PURPOSE DIGITAL COMPUTERS MADE BY U.S. FIRMS
(Values, in $ Millions, calculated as purchase price of systems when shipped)

Year	Value of Computer Equipment Shipped			Cumulative Net Value Installed (Yearend)		
	U.S.	Outside U.S.	Worldwide	U.S.	Outside U.S.	Worldwide
1969	$ 5270-5370	$ 2930-3030	$ 8200-8400	$21,100-21,850	$ 9400-9650	$30,500-31,500
1971	6390-6770	4110-4330	10,500-11,100	29,500-30,800	15,900-16,600	45,400-47,400
1973	9040-9600	5860-6300	14,900-15,900	39,800-41,300	25,200-26,700	65,000-68,000
1975	10,400-10,600	9000-9800	19,400-20,400	54,000-54,400	38,000-42,000	92,000-96,400

Chart I   ESTIMATED DISTRIBUTION OF INSTALLED COMPUTERS BY CLASS
(Shown as percent of value installed worldwide, by year)

I II III   I II III   I II III   I II III   I II III
   1967   1969   1971   1973   1975
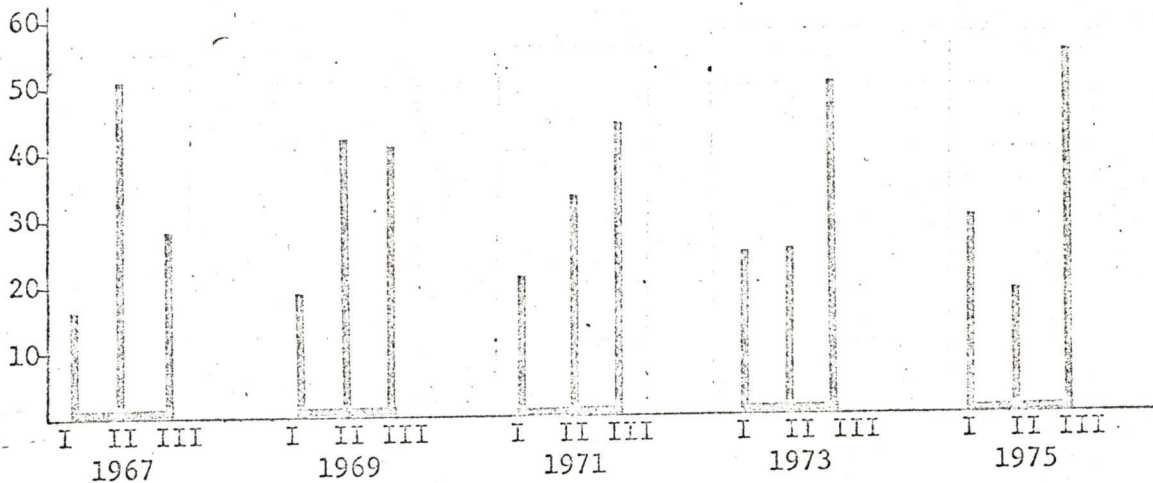
Class I -- Monthly rental of $500 - $5,000
Class II -- Monthly rental of $5,000 - $20,000
Class III -- Monthly rental of $20,000 and up

Chart II DISTRIBUTION OF COMPUTER SHIPMENT VALUE BY MAJOR SYSTEM COMPONENT
(Shown as percent of worldwide shipments, by year)

67 69 71 73 75   67 69 71 73 75   67 69 71 73 75   67 69 71 73 75
   Central   CPU-Coupled   External   Remote
   Processor   Input/Output   Memory   Terminals
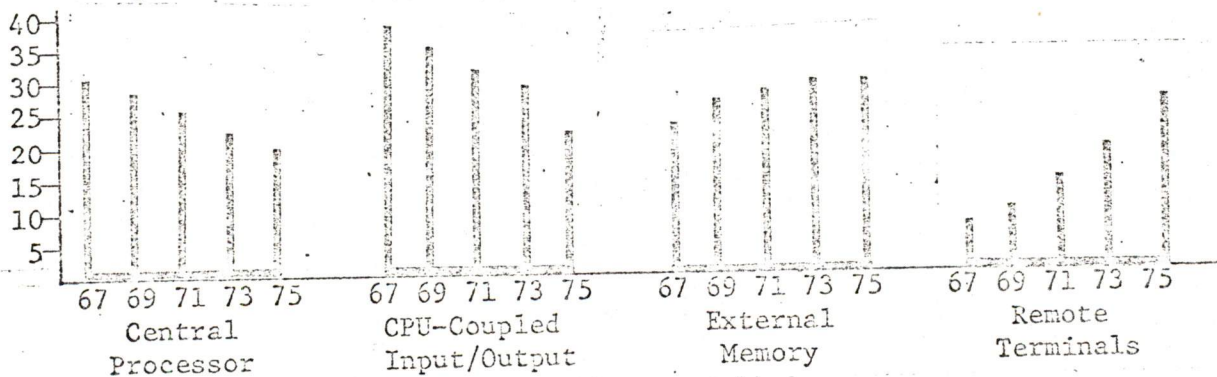
Expenditures by Organizations
in United States
for Use of
General Purpose Digital Computers
(all figures in millions of dollars)

	Hardware Rentals & Purchases	Salary Costs for Professional Computer Personnel	Outside Consultants, DP Services, & Software	Supplies & Other Facility Expenses	Total
1960	$ 430	$ 300	$ 50	$ 380	$ 1160
1965	1780	1490	225	695	4190
1968	4030	3810	595	1040	9475
1970	6190	6175	1125	1290	14780
1975	15360	12250	3187	1920	32717

Professional Computer Personnel
in the United States
as of December 30, 1968

Title	Employer	Number of Persons
Systems Analysts	Computer Users	80,000
	Computer Manufacturers	9,200
	Independents	3,800
	Total	93,000
Systems and Application Programmers	Computer Users	140,000
	Computer Manufacturers	15,000
	Independents	5,400
	Total	160,400
Computer Operators		50,000
Computer Installation Managers		30,000

PRODUCTION AND TRADE OF
BUSINESS MACHINES
IN PRINCIPAL WORLD MARKETS

U.S. DEPARTMENT OF COMMERCE / BUSINESS AND DEFENSE SERVICES ADMINISTRATION

BDSA
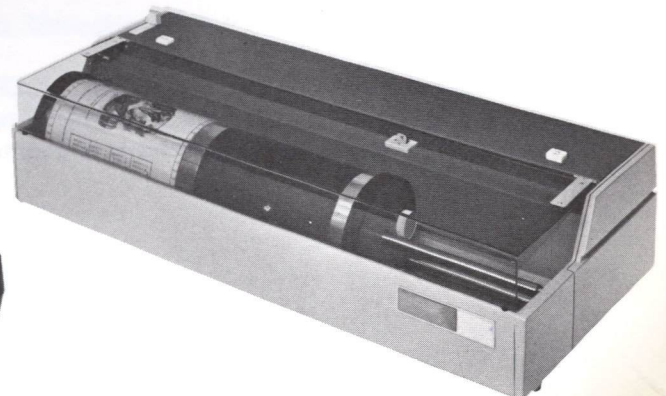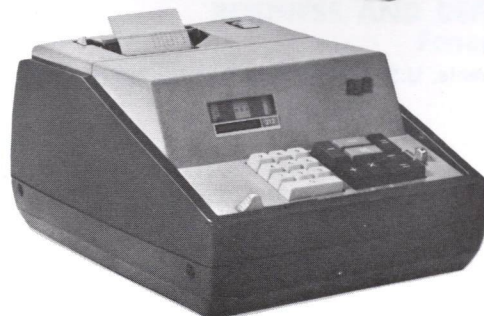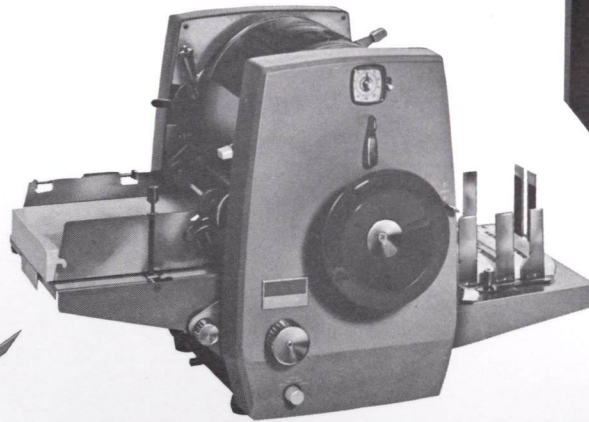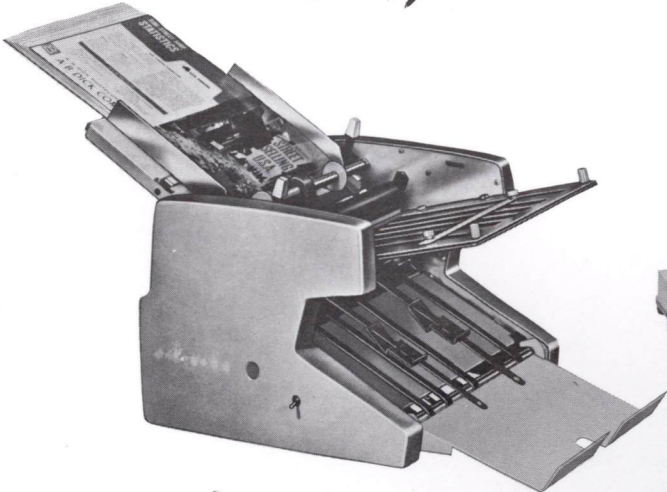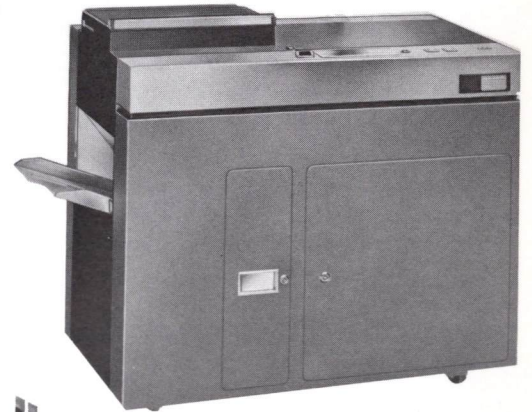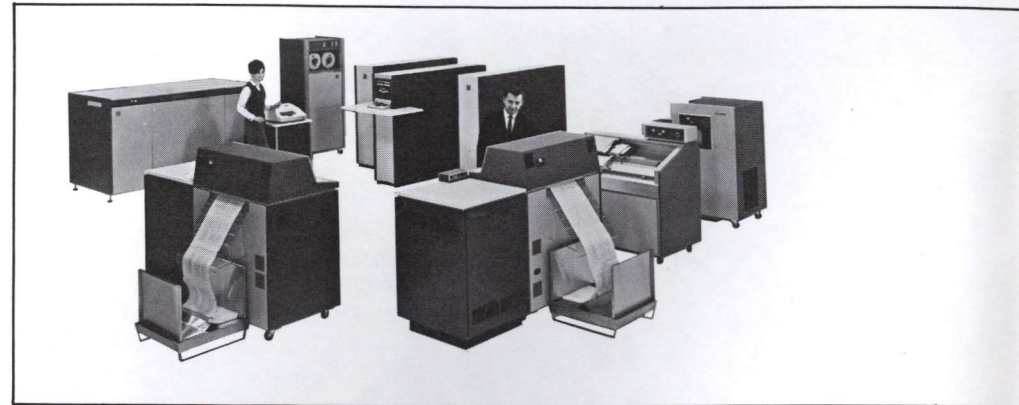
PRODUCTION AND TRADE OF

BUSINESS MACHINES

IN PRINCIPAL WORLD MARKETS

20 COUNTRIES   Exports / Imports / Production / Population / Gross National Product / Market Highlights

U.S. DEPARTMENT OF COMMERCE

Maurice H. Stans, Secretary

Rocco C. Siciliano
Under Secretary

K. N. Davis, Jr.
Assistant Secretary
for Domestic and International Business

BUSINESS AND DEFENSE SERVICES ADMINISTRATION
Forrest D. Hockersmith, Acting Administrator

Washington, D. C.
July 1969

FOREWORD

The business machines industry is one of the more dynamic industries in the world today. Shipments by the United States industry have increased 126 percent between 1965-1968. Demand exists in every country for business machines. Production facilities and markets are spread throughout the world.

This publication presents information on recent trends in the business machines industries in 20 representative countries. For each of the countries, it also includes statistical tables showing values of imports and exports of business machines.

The Scientific and Business Equipment Division, under its Director, Saul Padwo, is responsible for the overall planning and preparation of this study. Text and statistical materials were prepared by James N. Carr and Stephen T. McClellan.

Charley Denton
Assistant Administrator
for Industry Operations
Edward G. Smith, Director
Office of Producer Goods

CONTENTS

INTRODUCTION

The 20 representative countries detailed in this study are arranged geographically by continent: North America, South America, Europe, and Asia. Export and import statistics for each country are classified under the Standard International Trade Classification (SITC) No. 714 which represents business machines.

The export and import figures appear by economic class (EC CL I, II, and III), monetary area (Sterling), trading area (Common Market, EFTA), geographic area, and country. All the export and import figures have been converted into U.S. dollars.

Export and import statistics were compiled from the **United Nations Commodity Trade Statistics, 1967.** Gross national product (GNP) and population were taken from the **United Nations Monthly Bulletin of Statistics, September, 1968.** Production totals are based on the **Engineering Industry in North America—Europe—Japan, 1967** and U.S. Embassy airgrams. The text is based on U.S. Embassy airgrams as well as other information on file in the Scientific and Business Equipment Division of BDSA. All statistics are for the year 1967, the latest year for which United Nations data is available, unless otherwise noted.

The following is a key to the export-import group abbreviations:

CHINA MX: China (mainland), North Korea, North Viet-Nam, Mongolia

COMN MARKET: Belgium, France, Federal Republic of Germany, Italy, Luxembourg, Netherlands

E EUROPE: USSR, Albania, Bulgaria, Czechoslovakia, Eastern Germany, Hungary, Poland, Romania, Eastern Europe n.e.s.

EC CL I: Economic Class I comprising: United States, Canada, Western Europe, Australia, New Zealand, South Africa, Japan

EC CL II: Economic Class II comprising the world less both EC CL I and EC CL III

EC CL III: Economic Class III comprising Eastern Europe plus China MX

EFTA: European Free Trade Association comprising: United Kingdom, Denmark, Norway, Sweden, Austria, Portugal, Switzerland

LAT AM RPS: Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Uruguay, Venezuela, Latin America n.e.s.

MID EAST: Aden, Bahrein, Kuwait, Qatar, Sterling Arabia n.e.s., Jordan, Cyprus, Libya, Israel, Iran, Iraq, Saudi Arabia, Yemen, Lebanon, Other Arabia, Syria, UAR, Sudan, Ethiopia, Somalia, Fr. Somaliland, Middle East n.e.s.

AUS NZ SAF: Australia, New Zealand, South Africa

OTH AFRICA: East Africa, Gambia, Ghana, Mauritius, Nigeria, Federation of Rhodesia and Nyasaland, Sierra Leone, Zanzibar and Pemba, Other Sterling Africa, Dahomey, Ivory Coast, Mali Rep., Senegal, Mauritania, Niger, Upper Volta, Guinea, Central African Rep., Chad, Congo (Brazzaville), Gabon, Cameroun, Madagascar, Reunion, Togo, Congo (Leopoldville), Ruanda-Urundi, Angola, Mozambique, Other Portuguese West Africa, Spanish Central Africa, Liberia, Algeria, Morocco, Tunisia, Africa n.e.s.

OTHER ASIA: Burma, Ceylon, India, Pakistan, Federation of Malaya, Singapore, Sarawak, Brunei, N. Borneo, Hong Kong, Sterling Asia n.e.s., Afghanistan, China (Taiwan), Cambodia, Laos, Viet-Nam Rep., Indonesia, Korea Rep., Philippines, Thailand, Nepal, Ryukyu Isles, Portuguese Asia, other Asia n.e.s.

OTH C NES: Jamaica, Trinidad and Tobago, Bahamas, Barbados, Bermuda, Br. Guiana, Sterling America n.e.s., Netherlands Antilles, Surinam, Guadeloupe, Martinique, Panama Canal Zone, America n.e.s., Fiji, Papua, Australian New Guinea, Other Sterling Europe, Other Sterling Oceania, Caledonia, Guam, Oceania n.e.s.

OTH W EUR: Iceland, Ireland, Greece, Turkey, Spain, Finland, Yugoslavia, Western Europe n.e.s.
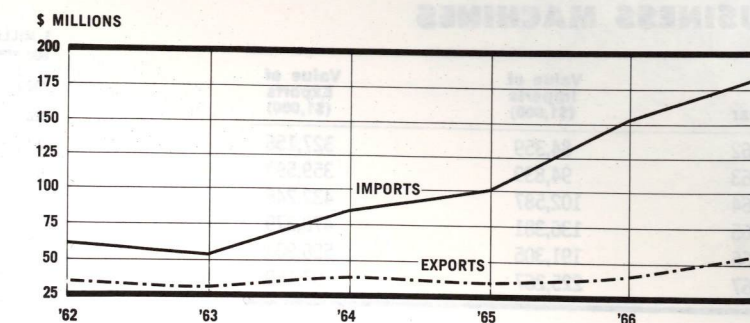
STERL AREA: Sterling Area

W EUROPE: Western Europe comprising: Common Market, EFTA, Other Western Europe

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CANADA

BUSINESS MACHINES

Year	Value of Imports ($1,000)	Value of Exports ($1,000)
1962	59,673	33,024
1963	54,318	29,525
1964	84,558	36,465
1965	100,624	32,647
1966	157,040	39,867
1967	187,970	55,253

MARKET HIGHLIGHTS

Canadian production of business machines in 1966 was valued at $150.5 million, up significantly from the $113 million in 1965. Total sales of all classes of business equipment have been increasing by 12-14% annually. Duplicators have been gaining 20% per year in sales recently. Computer manufacturers expect 15-20% growth in dollar volume in 1968 and succeeding years. This rapid growth rate is expected to continue.

Computers are one of the fastest growing capital goods markets in Canada. As of 1968, the total number of computer installations was approximately 1,800. This number includes 500 units installed during 1968, valued at $100-150 million. By the end of 1968, the value of computer installations was expected to total about $510 million.

At present there is little research and development or manufacturing in the computer industry in Canada. However, in view of the prospect of 3,000 computer installations valued at $1 billion by 1970, the Canadian government has taken steps to encourage domestic manufacturing. To counter its $115 million in imports in 1967, mostly from the United States, the Canadian government has persuaded IBM, Honeywell Controls Ltd., NCR Company of Canada Ltd., and Honeywell, to start domestic production.

Computer research and development is important to Canada because of the number of basic scientific disciplines it employs and the number of possible spin-off industries that can develop as a result. With the rapid development of and interest in scientific research, the lack of a computer industry leads to the loss of scientific talent to other countries.

In the late 1950's, Ferranti developed a Canadian computer but has since sold its design to International Computers, Ltd. of Britain. Northern Electric Co. Ltd., a subsidiary of Bell Telephone Co. of Canada, though it does not yet manufacture computers, is involved in the computer terminal market (banking and time-sharing) and possesses the necessary capability for producing them.

In 1967, Canadian imports of business machines were over three times the value of business machine exports. This gap should begin to close as more domestic manufacturing develops. Of the total $188 million imported that year, $142 million were from the United States and $41 million from Western Europe. Canadian exports totaled $55 million in 1967. The United States received $28 million of this amount and western European countries, $12 million.

VALUE OF IMPORTS
OF BUSINESS MACHINES, 1967

Country or Area of Origin	Value ($1,000)	Country or Area of Origin	Value ($1,000)
Total	**187,970**	Netherlands	2,355
EC CL I	187,234	EFTA	16,690
EC CL II	434	U.K.	13,110
EC CL III	303	Denmark	241
Sterling Area	13,319	Sweden	2,405
U.S.	141,966	Switzerland	850
Lat. Am. Rps.	216	Other W. Europe	191
Argentina	185	Spain	191
W. Europe	41,025	E. Europe	302
Common Market	24,143	Czechoslovakia	220
France	7,859		
W. Germany	5,447	Japan	4,239
Italy	8,475	Other Asia	217
		India	195

VALUE OF EXPORTS
OF BUSINESS MACHINES, 1967

Country or Area of Destination	Value ($1,000)	Country or Area of Destination	Value ($1,000)
Total	**55,253**	Italy	662
EC CL I	48,365	Netherlands	320
EC CL II	6,886	EFTA	7,416
Sterling Area	7,632	U.K.	6,459
Africa	120	Denmark	192
U.S.	27,728	Sweden	381
Lat. Am. Rps.	5,326	Switzerland	225
Argentina	593	Other W. Europe	483
Brazil	1,861	Spain	306
Colombia	355	Aus.-N.Z.-SAF	599
Costa Rica	107	Australia	429
Mexico	449	N. Zealand	127
Panama	141	Japan	7,754
Peru	719	Other Asia	1,054
Venezuela	951	India	182
W. Europe	12,284	China Taiwan	227
Common Market	4,385	Philippines	558
Belg.-Lux.	376	Other C NES	360
France	1,404	Bermuda	115
W. Germany	1,624		

UNITED STATES

Population: 199,118,000
Gross National Product: $765.9 billion
Business Machine Production: $5.0 billion

BUSINESS MACHINES

Year	Value of Imports ($1,000)	Value of Exports ($1,000)
1962	84,359	327,156
1963	94,839	359,592
1964	102,587	432,246
1965	136,381	470,379
1966	191,305	556,904
1967	225,267	707,150

MARKET HIGHLIGHTS

Total production of business machines in the United States amounted to approximately $5 billion in 1967. Computing machines and parts totaled $4.2 billion (electronic computers $3.6 billion); typewriters and parts, $487 million; and other business machines (addressing, dictating, duplicating and other machines and parts), $353 million.

The computing machines industry (adding, calculating, bookkeeping and accounting machines, electronic computers, cash registers, punched card and coded media machines) manufactures 94% of all the computing machines produced in the country. Within this segment of the business machines industry, the eight largest firms account for 80% of the value of shipments. The industry has extensive and modern plants and equipment, highly skilled personnel, strong research and development programs, and aggressive marketing, which make it one of the most progressive industries in the United States.

Demand for U.S. computer equipment continues to grow both in the domestic and overseas markets. A 20% growth rate is expected in overseas orders until the mid-1970's. A recent trend is the increased interest in small computers as these machines become faster and cheaper. New computer applications are creating a backlog of future demand for computers and EDP equipment.

It was estimated that as of January 1, 1969, U.S. manufacturers had installed a total of 48,900 computers in the United States and 23,800 computers overseas. Unfilled orders totaled 21,500.

The U.S. typewriter industry consists of six major standard typewriter manufacturers and four specialized manufacturers. The eight leading firms in this industry, based on value of shipments, account for 99% of total production. Total value of shipments of typewriters and parts in 1967 increased 12.6% over 1966 shipments. About 45% of standard and 85% of electric typewriters produced in the United States are sold through manufacturers' branch sales offices. Portables, however, are distributed almost entirely through retail dealers.
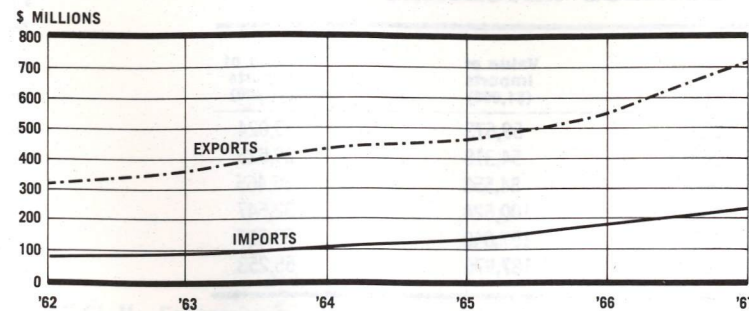
Other business machines (addressing, dictating, duplicating, etc.) are produced by eight major firms making up 71% of the market. Total value of shipments in this category decreased 10.4% in 1967 compared to 1966.

U.S. exports of business machines totaled $707 million in 1967. An additional $58 million of photocopying equipment and parts and $28 million in dictating machines and parts (not classified as business machines in the United Nations statistical reports) were also exported. The total reflects a 29% rise over 1966.

Electronic computers and parts accounted for 55% of all exports ($433 million). Bookkeeping and accounting machines and parts accounted for 11% ($87 million). Next in total value was photocopying equipment and parts, 7% ($58 million), followed by statistical machines with 5% ($44 million). Typewriters also comprised 5% ($41 million) of the exports. The leading customers for U.S. business machines were Canada ($131 million), United Kingdom ($100 million), West Germany and France ($89 million each), and Japan ($78 million).

Imports of business machines totaled $225 million in 1967, reflecting an 18% increase over 1966. The leading import was typewriters and parts ($62 million), which comprised 28% of the total. The leading suppliers to the U.S. business machine market were West Germany ($43 million), Italy ($39 million), Japan ($25 million), and the United Kingdom ($24 million).

UNITED STATES (Continued)

VALUE OF IMPORTS
OF BUSINESS MACHINES, 1967

Country or Area Of Origin	Value ($1,000)	Country or Area Of Origin	Value ($1,000)
Total	225,267	U.K.	23,840
EC CL I	218,486	Denmark	2,670
EC CL II	6,115	Norway	141
EC CL III	666	Sweden	19,444
Sterling Area	24,995	Austria	191
Canada	20,596	Switzerland	4,984
Lat. Am. Rps.	5,924	Other W. Europe	5,312
Argentina	4,517	Ireland	779
Mexico	1,307	Spain	4,443
W. Europe	172,796	E. Europe	666
Com. Market	116,157	Czechoslovakia	564
Belg.-Lux.	4,432	Aus.-N.Z.-SAF	194
France	11,498	Australia	193
W. Germany	43,025	Japan	24,901
Italy	38,629	Other Asia	161
Netherlands	18,573	Hong Kong	160
EFTA	51,326		

VALUE OF EXPORTS
OF BUSINESS MACHINES, 1967

Country or Area of Destination	Value ($1,000)	Country or Area Of Destination	Value ($1,000)	Country or Area Of Destination	Value ($1,000)	Country or Area Of Destination	Value ($1,000)	Country or Area Of Destination	Value ($1,000)
Total	707,150	Honduras	530	Austria	3,530	Saudi Arabia	942	India	2,286
EC CL I	622,087	Mexico	11,813	Portugal	496	Lebanon	554	Pakistan	374
EC CL II	78,573	Nicaragua	447	Switzerland	12,606	UAR Egypt	261	Malaysia	416
EC CL III	6,490	Panama	797	Other W. Europe	12,338	Ethiopia	276	Singapore	595
Sterling Area	144,571	Paraguay	128	Ireland	232	Aus.-N.Z.-SAF	25,735	Hong Kong	11,134
Africa	11,657	Peru	1,840	Greece	469	Australia	14,801	China Taiwan	1,578
Non-Afr. ME	5,875	Uruguay	191	Turkey	634	N. Zealand	2,415	Laos	113
Canada	131,926	Venezuela	4,407	Spain	7,604	South Africa	8,519	Viet Nam Rep.	1,871
Lat. Am. Rps.	41,311	W. Europe	385,943	Finland	1,942	Other Africa	2,322	Indonesia	271
Argentina	3,798	Com. Market	234,384	Yugoslavia	1,435	Kenya	360	Korea Rep.	903
Bolivia	359	Belg.-Lux.	7,873	E. Europe	6,490	Ghana	128	Philippines	2,596
Brazil	9,573	France	89,293	U.S.S.R.	1,130	Nigeria	145	Thailand	981
Chile	3,271	W. Germany	89,445	Czechoslovakia	3,582	Zambia	214	Ryukyu Isl.	2,194
Colombia	1,477	Italy	20,557	E. Germany	1,288	Congo Leo	148	Other C NES	2,842
Costa Rica	500	Netherlands	27,217	Hungary	425	Mozambique	280	Jamaica	461
Dominican Rep.	531	EFTA	139,221	Mid-East	6,691	Liberia	222	Trinidad T	273
Ecuador	372	U.K.	99,918	Kuwait	208	Morocco	132	Bahamas	904
El Salvador	480	Denmark	5,431	Libya	259	Tunisia	275	Barbados	169
Guatemala	778	Norway	2,834	Israel	1,671	Japan	78,483	Bermuda	253
		Sweden	14,404	Iran	2,290	Other Asia	25,406	Neth. Antilles	455

ARGENTINA

BUSINESS MACHINES

Year	Value of Imports ($1,000)	Value of Exports $(1,000)
1962	14,924	None
1963	8,752	984
1964	10,857	7,145
1965	11,197	6,415
1966	14,092	7,595
1967	N.A.	N.A.

MARKET HIGHLIGHTS

There are no official statistics on Argentine production of business equipment. Estimated production of $14.2 million in 1967 is based on the assumption that about 80 percent of all production is exported. According to industry sources, production and sales continued to increase in 1966 and 1967. A survey conducted by the U.S. Embassy in Buenos Aires of the leading companies indicates great optimism for future production growth.

Eight companies account for the major portion of manufacturing in Argentina. These include Esveco S.A. (Facit), Gestetner S.A., IBM, Lamson Paragon S.A., Miguel Keszler S.A., Olivetti Argentina S.A., Remington Sudamericana S.A., and Ultra S.A. Domestic production adequately satisfies domestic demand for conventional machines.

Electronic computers are almost entirely imported; the low tariff of 20% serves as an inducement. Government programs initiated in the past to expand the use of computers are no longer being pursued. As in Mexico, efforts to place modern computers in universities were abandoned in 1966.

The government is the major customer for statistical machines. IBM, the only domestic producer of these machines, exports 80% of its production.

In September 1967, magnetic coding of checks became obligatory for all banks using the Central Bank's clearing facilities. Burroughs and IBM computers are used in this operation. A Bull-GE computer is used by the state-owned petroleum enterprise and by the Buenos Aires electrical companies. Industry sources indicate favorable prospects for continued expansion in the sale and leasing of EDP equipment in the private and public sectors. There is concern, however, for the difficulty some organizations will have in adjusting to the computer after using conventional operation methods.

Another possibility is oversupply in computer time available on machines in place in the future.

Major business machine imports into Argentina are manual typewriters, four-operation calculators, accounting machines, and electronic statistical equipment. Brazil is the leading supplier of typewriters. Italy provides most of the calculators and accounting machines, and the United States is the leading supplier of statistical equipment. Brunning and Xerox now import copiers into Argentina. Copiers are not manufactured domestically.

Leading Argentine business machine exports are calculators and electronic statistical equipment. The United States is the major customer in both cases. Olivetti shipped about 70,000 Argentine-made calculators to the United States in 1967. Chile and Brazil are also important markets for Argentine business equipment.
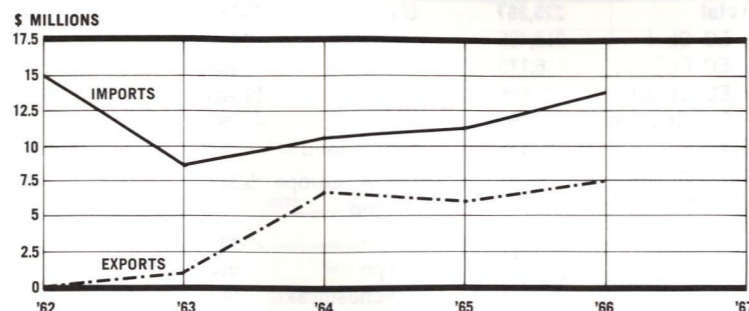
VALUE OF IMPORTS
OF BUSINESS MACHINES, 1966

Country or Area of Origin	Value ($1,000)	Country or Area Of Origin	Value ($1,000)
Total	**13,776**	Italy	3,143
Canada	210	Netherlands	32
United States	3,256	Norway	31
Lat. Am. Rps.	1,967	Portugal	1
Brazil	1,895	Spain	2
Colombia	63	Sweden	197
Chile	1	Switzerland	212
Panama	1	United Kingdom	1,306
Peru	5	West Germany	1,640
Uruguay	2		
Europe	7,843	Israel	1
Austria	2	USSR	33
Belgium	4	Australia	2
Denmark	1	Japan	315
Finland	1	Others	149
France	1,271		

VALUE OF EXPORTS
OF BUSINESS MACHINES, 1966

Country or Area of Destination	Value ($1,000)	Country or Area of Destination	Value ($1,000)
Total	**7,565**	France	231
United States	1,364	Netherlands	11
Lat. Am. Rps.	3,981	Portugal	70
Brazil	2,453	Spain	69
Chile	1,099	Sweden	86
Mexico	321	West Germany	722
Paraguay	6	United Kingdom	16
Peru	70	India	7
Uruguay	32	Australia	1
W. Europe	1,252	Others	960
Belgium	47		

Source: Comercio Exterior, International Trade Statistics, Argentina, 1966

BRAZIL

BUSINESS MACHINES

Year	Value of Imports ($1,000)	Value of Exports ($1,000)
1962	16,281	None
1963	16,891	383
1964	14,814	855
1965	15,941	2,895
1966	23,025	6,379
1967	31,060	13,160

MARKET HIGHLIGHTS

The Brazilian business machine industry, consisting largely of branches or subsidiaries of international producers, has expanded steadily in recent years. The value of production, however, is not available. In 1966, output included the manufacture (over 50% Brazilian parts) of 166,200 manual typewriters, 19,200 electric adding machines, 8,370 calculating machines, and 5,576 cash registers. The industry assembled (less than 50% Brazilian parts) 49,896 electric and manual adding machines and 2,100 electric calculating machines. Other production was of less significance. The 1967 production estimate is based on the above.

Most orders are for new equipment, not for replacement or modernization of existing equipment, to meet the larger volume of paper work now required as the result of much new federal regulatory legislation affecting business and industry. A significant development is the trend toward production of the more advanced accounting and calculating machines. Inca-Industria Nacional de Calculadores began production of calculators in 1967, the parts of which are 100% Brazilian made.

There were less than 100 computers in Brazil in 1967, but their use is growing steadily. Various foreign manufacturers are considering future production in Brazil. Burroughs is locating two such plants in Sao Paulo where it will manufacture accounting machines and magnetic memory cores for computers. Xerox has a subsidiary in Brazil which leases and services its copiers and is planning to eventually assemble its machines there. Manufacturing plants are operated by IBM, UNIVAC, NCR, Remington Rand, Addressograph-Multigraph, Friden, Olivetti, and Facit.

The federal government is attempting to limit price increases by awarding tax reductions if a company minimizes its price increases and by imposing fines if prices are raised extensively. Price increases in 1967 did not adversely affect sales.

Brazil's imports are increasing. The upward trend is strongest in adding and calculating machines. Electronic computers and data processing equipment and accessories, and statistical machines are also growing rapidly. Local subsidiaries of foreign companies are the largest importers bringing in mostly parts. The United States is the major supplier of business equipment to Brazil.

Exports are rising rapidly. Most shipments are to other Latin Free Trade Association (LAFTA) countries, particularly Argentina. Principal exports include typewriters, adding machines, cash registers, and ADP equipment.
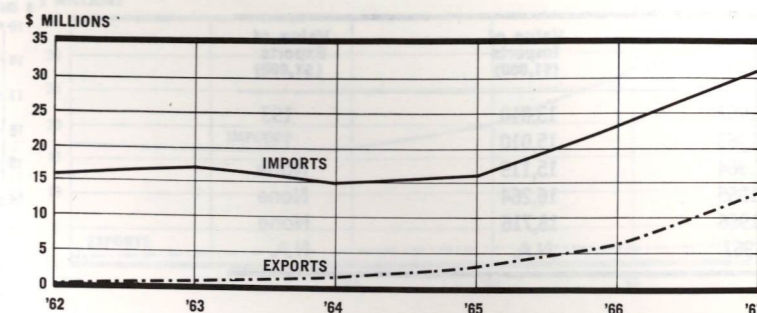
VALUE OF IMPORTS
OF BUSINESS MACHINES, 1967

Country or Area of Origin	Value ($1,000)	Country or Area of Origin	Value ($1,000)
Total	**31,060**	W. Germany	1,700
EC CL I	28,027	Italy	3,507
EC CL II	2,456	Netherlands	855
EC CL III	577	EFTA	7,863
Sterling Area	3,800	U.K.	3,799
U.S.	8,381	Sweden	3,458
Canada	1,688	Switzerland	514
Lat. Am. Rps.	2,455	Other W. Europe	477
Argentina	2,388	Spain	477
W. Europe	15,358	E. Europe	577
Common Market	7,018	E. Germany	521
France	956	Japan	2,599

VALUE OF EXPORTS
OF BUSINESS MACHINES, 1967

Country or Area of Destination	Value ($1,000)	Country or Area of Destination	Value ($1,000)
Total	**13,160**	Venezuela	297
EC CL I	7,239	W. Europe	6,943
EC CL II	5,919	Common Market	6,468
U.S.	279	Belg.-Lux.	386
Lat. Am. Rps.	5,795	France	1,750
Argentina	3173	W. Germany	2,750
Chile	865	Italy	902
Mexico	859	Netherlands	680
Peru	241	EFTA	460
Uruguay	163	Austria	359

MEXICO

BUSINESS MACHINES

Year	Value of Imports ($1,000)	Value of Exports ($1,000)
1962	13,810	193
1963	15,010	137
1964	15,119	None
1965	16,264	None
1966	18,716	None
1967	N.A.	N.A.

$ MILLIONS — IMPORTS — EXPORTS NOT AVAILABLE

MARKET HIGHLIGHTS

Mexican production figures for business machines are not available. Several U.S. and foreign firms are in Mexico but their business equipment production is uneconomical. There are few exports, mainly portable typewriters, ADP equipment and business machine parts. Mexican business machines to date have been unable to compete in the world market. The Mexican Government encouraged some foreign companies to establish domestic production facilities in order to develop Mexican technology. In order to retain their share of the import market the foreign companies have started production operations in addition to their import market operations. The firms include NCR, Burroughs, Underwood-Olivetti, A.B. Dick, IBM, Remington Rand, Xerox, Control Data, Facit, and Bull-GE.

There is no production of electronic computers in Mexico. A low tariff rate of 20%, and no tariff in the case of government purchases, encourages imports of this commodity. IBM does manufacture ADP equipment domestically and exports over 80% of this equipment. The Mexican government is the major user of computers but banks, insurance companies, utilities, and large industrial organizations also own or rent some EDP equipment. The market demand for computers is not increasing as rapidly as might be expected. Government programs to expand the use of computers domestically are not being pursued. An effort to place modern computers in Mexican universities was abandoned in 1966.

Mexico imports mainly accounting and computing machines. Many statistical machines including electronic computers are also imported. The companies listed above are the leading importers of business equipment into Mexico.

VALUE OF IMPORTS
OF BUSINESS MACHINES, 1967

Country or Area of Origin	Value ($1,000)	Country or Area of Origin	Value ($1,000)
	Not Available		

VALUE OF EXPORTS
OF BUSINESS MACHINES, 1967

Country or Area of Destination	Value ($1,000)	Country or Area of Origin	Value ($1,000)
	Not Available		

AUSTRIA

BUSINESS MACHINES

Year	Value of Imports ($1,000)	Value of Exports ($1,000)
1962	16,820	703
1963	16,479	982
1964	16,526	1,458
1965	20,377	1,720
1966	27,148	1,643
1967	32,860	2,334

$ MILLIONS — IMPORTS — EXPORTS
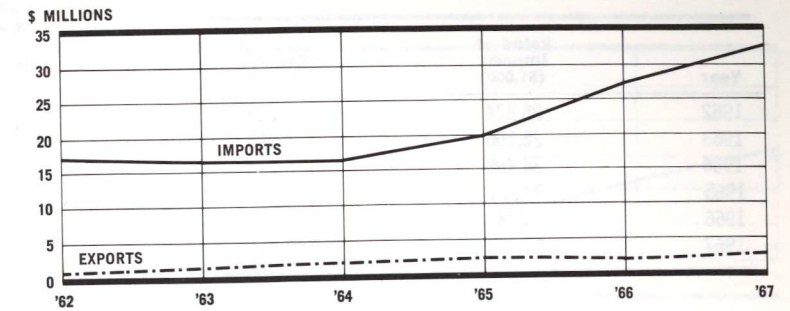
MARKET HIGHLIGHTS

Business machine production in Austria amounted to less than $1 million in 1967. The little production which did take place was almost solely by the German Anker Datentechnik Ges m.b.h. which assembles one-counter cash registers. A Dutch subsidiary assembles dictating machines in Austria but production figures are not available. A recent effort by the Federal Chamber of Commerce to attract foreign manufacturers into Austria was unsuccessful. This was due to the small local market and lack of qualified, experienced, technical personnel.

Although Austria is a small market, the EDP sector is far from developed. In 1968 there were 274 computer installations with 330 other existing firms as potential buyers. During 1967, data processing equipment valued at $7.6 million was imported, $2.3 million of which came from the United States. Presently there are about 80 units on order to be installed in the near future. A 25% growth rate for large and medium-sized computers is forecast through 1972 while that for small EDP units should be about 30%.

West Germany is the major supplier of business machines to Austria (42%). The U.S. share (31%) totaled $4.3 million in 1967. Austria is closely associated with neighboring eastern European countries and conducts business in these markets. Industry sources believe that the potential of the Eastern European market has barely been tapped.

Foreign business machine imports are subject to certain Austrian border taxes which were raised in 1968. This barrier has not been a significant factor however in recent years. Austria's only business machine exports are dictating machines and one-counter cash registers. The Netherlands receives 63% of the dictating machines manufactured in Austria. The leading recipient of Austrian business machines is West Germany (52% in 1967).

VALUE OF IMPORTS
OF BUSINESS MACHINES, 1967

Country or Area Of Origin	Value ($1,000)	Country or Area Of Origin	Value ($1,000)
Total	32,860	France	5,208
		W. Germany	13,648
EC CL I	32,327	Italy	5,203
EC CL II	277	Netherlands	313
EC CL III	256	EFTA	3,287
Sterling Area	1,894	U.K.	1,886
U.S.	4,253	Sweden	546
Lat. Am. Rps.	269	Switzerland	728
Brazil	187	E. Europe	256
W. Europe	27,719	E. Germany	191
Common Market	24,423	Japan	257

VALUE OF EXPORTS
OF BUSINESS MACHINES, 1967

Country or Area of Destination	Value ($1,000)	Country or Area of Destination	Value ($1,000)
Total	2,334	W. Europe	1,804
		Common Market	1,566
EC CL I	1,863	W. Germany	1,065
EC CL II	164	Italy	351
EC CL III	307	EFTA	168
Lat. Am. Rps.	101	E. Europe	307

BELGIUM-LUXEMBOURG

Population: 9,916,000
Gross National Product: $19.3 billion
Business Machine Production: N.A.

BUSINESS MACHINES

Year	Value of Imports ($1,000)	Value of Exports ($1,000)
1962	25,874	3,213
1963	28,196	4,018
1964	34,889	6,208
1965	33,261	8,616
1966	44,383	7,470
1967	54,470	12,340
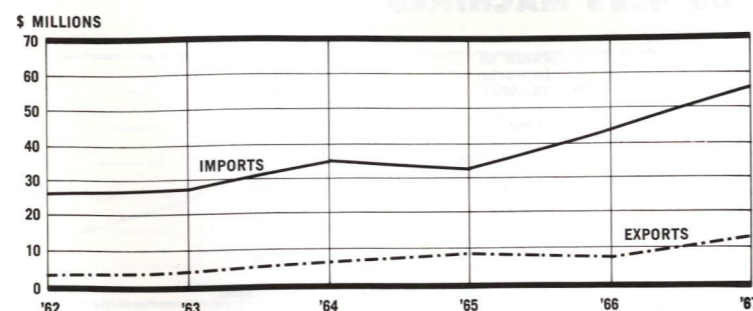
MARKET HIGHLIGHTS

There is little domestic production of business machines in Belgium and none in Luxembourg. Some foreign subsidiaries, however, are producing or plan to produce business machines in Belgium. International Business Machines dedicated a technical center in Brussels in 1967 and Burroughs opened a manufacturing plant the same year to produce electronic accounting machines. Friden has been producing adding and calculating machines in Mechelen since 1962. Dictating machines are manufactured by domestic firms in Brussels and Charleroi; most of this production is exported.

Foreign firms supply almost all business machines to Belgium. Although electronic computers are by far the largest imported business machine in terms of value, typewriters, adding, and calculating machines are also significant imports. The leading suppliers of computers and data processing machines are IBM, Bull-GE, Univac,

and NCR, respectively. In early 1967, there were 300 computer installations with another 150 units on order. Growth in this market is expected to continue. Many firms have just begun to automate and many mergers are taking place. Such corporate expansion into larger organizations is necessitating efficient control and distribution of information.

Belgium's exports of business machines amounted to only $12 million in 1967. Most of these were accounting, adding and calculating machines. The United States was the leading customer ($4.7 million).

Total imports by Belgium-Luxembourg totaled $54 million in 1967, $26 million of which were statistical machines and electronic computers. The largest share of imports came from West Germany ($15 million). France was the second largest supplier ($11 million) and the United States was third ($9 million).

VALUE OF IMPORTS
OF BUSINESS MACHINES, 1967

Country or Area of Origin	Value ($1,000)	Country or Area of Origin	Value ($1,000)
Total	54,470	France	11,236
		W. Germany	15,206
EC CL I	53,661	Italy	8,540
EC CL II	560	Netherlands	1,911
EC CL III	249	EFTA	6,841
Sterling Area	4,085	U.K.	4,084
U.S.	8,819	Sweden	1,182
Canada	771	Switzerland	1,402
Lat. Am. Rps.	446	E. Europe	242
Argentina	116	E. Germany	205
Brazil	330	Mid-East	112
W. Europe	43,799	Israel	112
Common Market	36,893	Japan	272

VALUE OF EXPORTS
OF BUSINESS MACHINES, 1967

Country or Area of Destination	Value ($1,000)	Country or Area of Destination	Value ($1,000)
Total	12,340	Italy	258
		Netherlands	1,362
EC CL I	11,437	EFTA	1,215
EC CL II	284	U.K.	595
EC CL III	620	Denmark	196
Sterling Area	686	Sweden	137
Africa	134	Switzerland	192
U.S.	4,702	Other W. Europe	346
W. Europe	6,673	Spain	288
Common Market	5,112	E. Europe	620
France	1,696	Bulgaria	579
W. Germany	1,797		

DENMARK

Population: 4,839,000
Gross National Product: $11.5 billion
Business Machine Production (1965): $8.7 million

BUSINESS MACHINES

Year	Value of Imports ($1,000)	Value of Exports ($1,000)
1962	17,520	6,245
1963	20,601	6,852
1964	24,683	7,818
1965	22,484	9,600
1966	32,586	10,582
1967	41,779	13,083
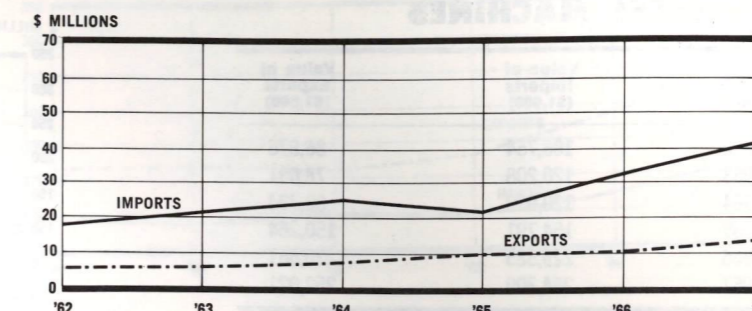
MARKET HIGHLIGHTS

Production of business machines in Denmark amounted to $8.7 million in 1965, according to the latest figures available from the American Embassy in Copenhagen. This reflects an increase in production of all types of business machines. Adding and calculating machines rose 60% over the previous year from $1.3 million to over $2.1 million. The production of miscellaneous business machines, of which duplicating machines is the largest production item in terms of value, rose 21% over 1964, from $4.7 million to $5.7 million. A single manufacturer, the Zeuthen & Aagaard Company, produces all Danish duplicators.

The use of electronic data processing equipment in Denmark is burgeoning. This emphasis on rapid information processing is due to the modernization of Danish plants

and business procedures. In addition, there is a continuous labor shortage. Rising costs of operations are causing banks, insurance companies, and merchandising firms to utilize electronic data processing equipment to cut costs. Most of this EDP equipment is imported. American computer and business equipment companies are well represented in Denmark. Leading firms include Addressograph-Multigraph, Bull-GE, Burroughs, Control Data, Honeywell, IBM, and UNIVAC.

In terms of value, Denmark's imports of business machines are more than three times its exports. The Common Market countries supply over 50% of these machines. West Germany and the United States are the leading individual suppliers. Imports of punch card machines have increased the

fastest in recent years. The United States supplied 18% of the typewriters and 11% of the calculators, adding, and bookkeeping and accounting machines imported into Denmark in 1966.

The value of exports exceeds production in Denmark because of the substantial use of imported parts in business machine production, many of which are not specified in the trade statistics as parts for business machines. Duplicating machines have been the most important export item in the last few years. The United States, Denmark's leading customer for business machines in 1966, received 29% of the duplicating machines exported from Denmark. The United States also bought 27% of the Danish produced calculating, adding, and accounting and bookkeeping machines.

VALUE OF IMPORTS
OF BUSINESS MACHINES, 1967

Country or Area of Origin	Value ($1,000)	Country or Area of Origin	Value ($1,000)
Total	41,779	Italy	4,340
		Netherlands	1,184
EC CL I	41,271	EFTA	9,061
EC CL III	442	U.K.	3,809
Sterling Area	3,840	Norway	444
U.S.	7,703	Sweden	3,578
Canada	345	Switzerland	1,162
W. Europe	32,341	Other W. Europe	110
Common Market	23,170	E. Europe	433
Belg.-Lux.	127	Czechoslovakia	136
France	6,764	E. Germany	270
W. Germany	10,755	Japan	883

VALUE OF EXPORTS
OF BUSINESS MACHINES, 1967

Country or Area of Destination	Value ($1,000)	Country or Area of Destination	Value ($1,000)
Total	13,083	Norway	462
EC CL I	10,220	Sweden	710
EC CL II	1,072	Switzerland	247
EC CL III	1,791	Other W. Europe	613
Sterling Area	1,064	Turkey	108
Africa	305	Spain	270
Non-Afr. ME	184	Finland	175
U.S.	2,784	E. Europe	1,789
Canada	271	U.S.S.R.	677
Lat. Am. Rps.	436	Bulgaria	338
Mexico	144	Czechoslovakia	362
W. Europe	4,768	Hungary	144
Common Market	2,162	Poland	241
France	583	Mid-East	212
W. Germany	1,066	Aus.-N.Z.-SAF	381
Italy	195	Australia	246
Netherlands	250	South Africa	116
EFTA	1,992	Other Africa	161
U.K.	439	Japan	2,016
		Other Asia	233

FRANCE

BUSINESS MACHINES

Year	Value of Imports ($1,000)	Value of Exports ($1,000)
1962	106,754	86,876
1963	120,208	78,091
1964	120,929	82,794
1965	154,791	150,264
1966	229,585	220,661
1967	284,309	252,021
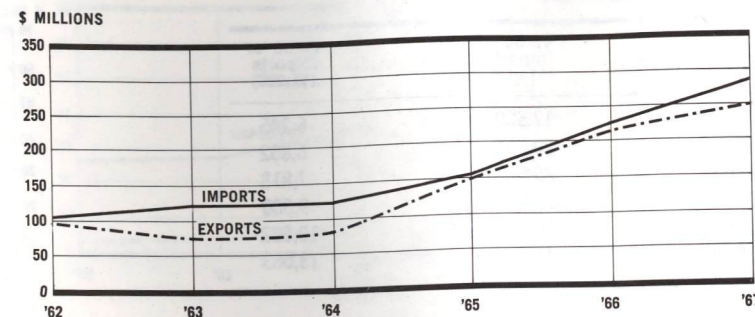
MARKET HIGHLIGHTS

Total production of business machines in France in 1967 amounted to $586 million. Electronic computers and associated data processing equipment made up $545 million of this figure. The total reflects a 95% increase in computer production over 1966 and no increase in conventional business machine output.

Conventional business machine production in France is stagnant. Domestic companies are small and cannot compete successfully with foreign firms. Imports, therefore, should continue to increase. Typewriters are the leading domestically produced item ($17.4 million in 1966), and are manufactured solely by Japy. Accounting and calculating machines are second in value ($8.1 million).

The French data processing and computer market is a dynamic one. Very rapid growth has attracted many foreign subsidiary firms into France and they control the market. It is estimated that IBM has 62% of the market, Bull-GE 20%, Control Data 5%, and Societe d'Electronique et d'Automatisme (S.E.A.) 3%. The French Government's Plan Calcul, initiated in late 1966, is a program to build up domestic computer manufacturing capability. It involves financial assistance to local companies and requires the government and nationalized firms to buy French peripheral equipment. However, this stimuli to purchase domestically produced computers had not cut into the United States share of the French market as of the end of 1968.

French imports reached a new high in 1967. West Germany was the main supplier ($87 million); the United States was second ($82 million). Italy and the United Kingdom also ship significant amounts to France. Major imported products include data processing equipment, statistical machines, computer components, accounting machines and dictating machines.

Exports totaled $252 million in 1967. The major customers were the Common Market countries (especially West Germany—$76 million; and Italy—$37 million) which received 52% of all exports. The United Kingdom ($33 million) and the United States ($11 million) are also important customers. Leading products exported in 1967 were data processing equipment and components, statistical machines and components, and punching and checking equipment for punched-card machines.

VALUE OF IMPORTS
OF BUSINESS MACHINES, 1967

Country or Area of Origin	Value ($1,000)	Country or Area of Origin	Value ($1,000)
Total	**284,309**	W. Germany	86,819
EC CL I	279,880	Italy	44,552
EC CL II	2,595	Netherlands	8,545
EC CL III	1,833	EFTA	50,397
Sterling Area	24,752	U.K.	24,606
U.S.	81,997	Denmark	662
Canada	2,587	Norway	310
Lat. Am. Rps.	2,404	Sweden	20,066
Argentina	806	Switzerland	4,666
Brazil	1,591	E. Europe	1,829
W. Europe	192,050	E. Germany	1,686
Common Market	141,595	Japan	3,243
Belg.-Lux.	1,678	Other Asia	104

VALUE OF EXPORTS
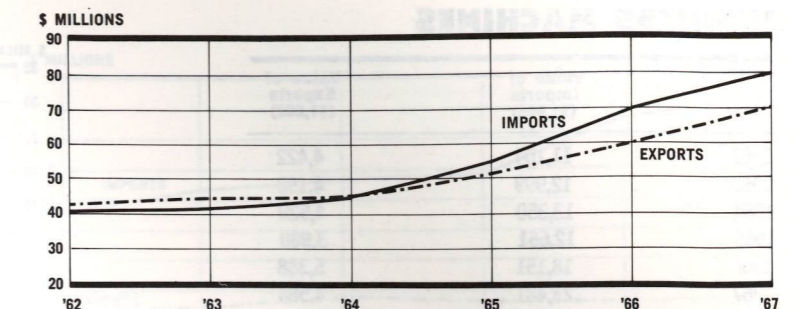### OF BUSINESS MACHINES, 1967

Country or Area of Destination	Value ($1,000)	Country or Area of Destination	Value ($1,000)	Country or Area of Destination	Value ($1,000)	Country or Area of Destination	Value ($1,000)
Total	**252,021**	W. Europe	204,246	Finland	2,469	Ivory Coast	189
EC CL I	233,720	Com. Market	132,390	Yugoslavia	846	Senegal	583
EC CL II	13,942	Belg.-Lux.	8,715	E. Europe	4,252	Congo Bra.	100
EC CL III	4,359	W. Germany	76,202	Czechoslovakia	1,437	Cameroon	158
Sterling Area	39,258	Italy	37,257	E. Germany	1,389	Madagascar	134
Africa	7,793	Netherlands	10,216	Hungary	372	Reunion	140
Non-Afr. ME	736	EFTA	62,789	Poland	274	Algeria	2,003
U.S.	11,489	U.K.	33,435	Romania	648	Morocco	343
Canada	6,262	Denmark	2,442	Mid-East	975	Tunisia	496
Lat. Am. Rps.	6,679	Norway	2,391	Libya	197	China M X	106
Argentina	1,550	Sweden	16,444	Israel	404	China MNLD	106
Brazil	884	Austria	2,966	Iran	266	Japan	7,256
Chile	128	Portugal	447	Aus.-N.Z.-SAF	4,466	Other Asia	483
Mexico	2,790	Switzerland	4,664	Australia	1,488	India	188
Peru	108	Other W. Europe	9,068	N. Zealand	570	Oth. C NES	660
Uruguay	125	Ireland	162	South Africa	2,408	Martinique	177
Venezuela	903	Greece	161	Oth. Africa	5,146	Caledonia	120
		Spain	5,335	Zambia	499		

ITALY

BUSINESS MACHINES

Year	Value of Imports ($1,000)	Value of Exports ($1,000)
1962	43,532	116,507
1963	40,990	119,104
1964	49,470	114,036
1965	45,840	135,733
1966	78,701	195,680
1967	120,202	243,114
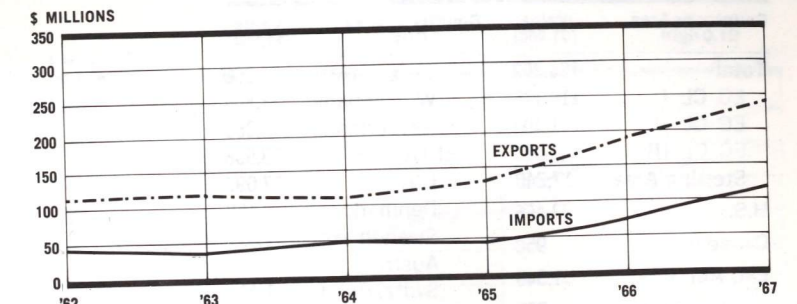
MARKET HIGHLIGHTS

Italian production of conventional business machines reached record levels in 1967. The sizeable increase in production was prompted by the rising demand of Italian consumers and the low output in 1966 due to strikes. In terms of units, typewriters were up 21.4% and calculating machines (of the three-and-four operation type) increased 14.6%. Production figures on business machines by value are not published.

A trend toward more sophisticated and costly calculators may be starting. New and improved models of bookkeeping and accounting machines have entered the market, principally those of Olivetti. Although there is no rush toward sophisticated models, NCR is marketing such machines with some success. Italy manufactures almost no cash registers domestically. Most units are supplied by Anker-Riv S.P.A. of Milan from factories in West Germany and NCR's European plants. Litton Italia is expanding in this area. Foreign manufacturers supply close to 90% of all copying equipment sold in the Italian market. Imports from the United States account for most of this total. An Olivetti affiliate has just introduced a new desk-top copier which is expected to give new impetus to domestic production in this area.

The computer market is growing rapidly in Italy. There were over 1600 installations at the end of 1967; this number is expected to increase to 2800 by 1970. United States firms dominate this area. The Italian government, however, is seriously considering entering the field through a joint venture between a government industrial group (IRI) and various private corporations. In 1967, the market shares were as follows: IBM, 60%; Olivetti-GE, 27.5%; Univac, 8%; Honeywell, 3%; and other, 2%. NCR entered the field in 1968.

Olivetti remains the dominant force in Italy's business machine market. The firm accounted for 68% of the portable typewriter market in 1967, and 80% of the market for standard typewriters and calculators. The Italian business machine industry is weak, however, in electrostatic copiers, cash registers, sophisticated calculating and accounting machines, and EDP equipment. Cost is a major factor considered by Italians when purchasing business equipment as they are less concerned with sophisticated cost analysis and long-term savings. Thus, generally, short-term savings in the form of low-priced equipment are of major interest.

A new development in Italy is the establishment of the first time-sharing computer service by Olivetti-GE. The same firm has introduced a faster and larger computer. Growing sophistication is leading to the use of the computer as a management tool in banking, transportation, production, and process control. The best growth areas in this regard are the manufacturing industries, public administration, and wholesale and retail trade. Small and medium-sized computers can be utilized in these fields and thus the growing sales trend is expected to continue. It is estimated that 2800 computers will be functioning in Italy by 1970.

Continuing strong Italian demand while the rest of Europe underwent an economic recession resulted in a 20% increase in imports in 1967. Imports were nonetheless significantly lower than exports, a condition which is expected to continue in the near future. The slowdown in exports in 1967 was attributed to the European recession.

Italian business machine manufacturers are optimistic regarding domestic demand. Some concern is expressed, however, for the increasing imports of business machines from Japan, particularly typewriters and calculators. This inroad is not presently a significant problem.

ITALY (Continued)

VALUE OF IMPORTS
OF BUSINESS MACHINES, 1967

Country or Area Of Origin	Value ($1,000)	Country or Area Of Origin	Value ($1,000)
Total	120,202	Belg.-Lux.	300
EC CL I	118,175	W. Germany	28,504
EC CL II	1,496	Netherlands	2,065
EC CL III	530	EFTA	23,558
Sterling Area	17,240	U.K.	17,097
U.S.	23,466	Denmark	159
Canada	950	Sweden	4,475
Lat. Am. Rps.	1,348	Austria	322
Argentina	359	Switzerland	1,421
Brazil	920	E. Europe	530
W. Europe	92,945	E. Germany	524
Common Market	69,296	Japan	813
France	38,426	Other Asia	136
		India	129

VALUE OF EXPORTS
OF BUSINESS MACHINES, 1967

Country or Area Of Destination	Value ($1,000)	Country or Area Of Destination	Value ($1,000)	Country or Area Of Destination	Value ($1,000)	Country or Area Of Destination	Value ($1,000)	Country or Area Of Destination	Value ($1,000)
Total	243,114	Guatemala	199	Oth. W. Europe	15,926	Iran	765	Algeria	638
		Mexico	5,196	Iceland	172	Saudi Arabia	182	Morocco	299
EC CL I	206,205	Nicaragua	105	Ireland	318	Lebanon	162	Tunisia	331
EC CL II	31,585	Peru	855	Greece	661	Ethiopia	292	China M X	188
EC CL III	5,278	Uruguay	261	Turkey	591			Viet Nam N	118
Sterling Area	27,242	Venezuela	2,177	Spain	10,679	Aus.-N.Z.-SAF	7,581	Japan	6,988
Africa	9,865	W. Europe	147,763	Finland	1,645	Australia	2,260	Other Asia	4,471
Non-Afr. ME	2,040	Com. Market	94,539	Yugoslavia	1,860	N. Zealand	814	India	113
U.S.	38,776	Belg.-Lux.	7,246			South Africa	4,506	Pakistan	106
Canada	5,097	France	38,510	E. Europe	5,089	Oth. Africa	4,490	Malaysia	280
Lat. Am. Rps.	18,834	W. Germany	40,783	U.S.S.R.	2,018	Kenya	510	Singapore	736
Argentina	3,780	Netherlands	8,000	Czechoslovakia	670	Ghana	256	Hong Kong	469
Bolivia	114	EFTA	37,298	Hungary	1,391	Nigeria	238	Cambodia	157
Brazil	4,202	U.K.	14,538	Poland	275	Zambia	511	Indonesia	728
Chile	329	Denmark	2,773	Romania	587	Ivory Coast	198	Philippines	764
Colombia	505	Norway	1,865	Mid-East	2,909	Cameroon	167	Thailand	757
Costa Rica	118	Sweden	6,424	Kuwait	101	Madagascar	212	Other C NES	881
Dominican Rep.	247	Austria	4,991	Cyprus	114	Congo Leo	131	Jamaica	235
Ecuador	335	Portugal	1,403	Libya	403	Angola	247	Caledonia	107
El Salvador	139	Switzerland	5,304	Israel	585	Mozambique	116		

NETHERLANDS

Population: 12,597,000
Gross National Product: $21.9 billion
Business Machine Production (1966): $55.2 million

BUSINESS MACHINES

Year	Value of Imports ($1,000)	Value of Exports ($1,000)
1962	40,425	42,571
1963	41,765	43,582
1964	45,218	44,886
1965	55,258	50,957
1966	70,304	59,569
1967	81,446	69,741

MARKET HIGHLIGHTS

Production of business machines in the Netherlands during 1966 amounted to $55 million. About 75% of this production is exported. Imports of business machines, however, outpace exports.

Electronic desk calculators are growing in popularity. Initially introduced by Anita of Great Britain, more recent entrants include Friden, Diehl, and several Japanese companies. Electrostatic photocopiers are also experiencing large-scale rapid growth. Addressograph-Multigraph got a fast start in this area as did Rank Xerox, the market leader. Gevaert-Agfa is entering this field also. Sales of bookkeeping and accounting machines have grown steadily and these products are large import items. About 70% of this market belongs to NCR and Burroughs which import their equipment from the United Kingdom and Europe.

In other developments, Philip's plans to market an entire line of business machines instead of just components. In early 1967 IBM, Remington Rand, and Royal McBee were the exclusive producers of typewriters which at that time accounted for 50% of all Dutch business machine production and exports.

The most dynamic business machine market in the Netherlands is the computer. At the beginning of 1967 there were 284 Dutch installations and another 284 on order. The computer market is expected to double between 1967 and 1968. American firms and their foreign subsidiaries supply about 80% of this market, IBM alone accounting for approximately 50%. Dutch production is very small, Philips Electrologica is the only manufacturer.

The Netherlands' imports of business machines exceeded exports in 1967. The imports were purchased mainly from West Germany ($20.7 million) and the United States ($17.2 million). Dutch exports of business machines consist mostly of typewriters. The United States ($18.8 million) was the leading recipient of Dutch exports in 1967 and West Germany was next ($11.0 million).

VALUE OF IMPORTS
OF BUSINESS MACHINES, 1967

Country or Area of Origin	Value ($1,000)	Country or Area of Origin	Value ($1,000)
Total	81,446	France	16,466
EC CL I	79,874	W. Germany	20,745
EC CL II	989	Italy	11,012
EC CL III	583	EFTA	11,702
Sterling Area	7,423	U.K.	7,375
U.S.	17,231	Denmark	285
Canada	460	Sweden	2,348
Lat. Am. Rps.	768	Switzerland	1,514
Argentina	175	E. Europe	568
Brazil	593	E. Germany	496
W. Europe	61,129	Japan	1,044
Common Market	49,389	Other Asia	201
Belg.-Lux.	1,166	China Taiwan	175

VALUE OF EXPORTS
OF BUSINESS MACHINES, 1967

Country or Area of Destination	Value ($1,000)	Country or Area of Destination	Value ($1,000)	Country or Area of Destination	Value ($1,000)
Total	69,741	W. Europe	40,855	Finland	411
EC CL I	64,474	Common Market	24,108	E. Europe	772
EC CL II	4,495	Belg.-Lux.	2,350	Czechoslovakia	384
EC CL III	772	France	9,158	E. Germany	201
Sterling Area	10,551	W. Germany	11,022	Mid-East	302
Africa	926	Italy	1,579	Israel	166
Non-Afr. ME	284	EFTA	15,361	Aus.-N.Z.-SAF	2,138
U.S.	18,872	U.K.	7,701	Australia	1,388
Canada	2,008	Denmark	1,402	Sou. Africa	722
Lat. Am. Rps.	3,108	Norway	766	Other Africa	186
Argentina	244	Sweden	2,610	Japan	601
Brazil	738	Austria	485	Other Asia	773
Colombia	126	Portugal	145	Singapore	140
Mexico	985	Switzerland	2,252	China Taiwan	178
Peru	436	Other W. Europe	1,385	Philippines	103
Venezuela	331	Ireland	150	Other C NES	126
		Spain	635		

NORWAY

BUSINESS MACHINES

Year	Value of Imports ($1,000)	Value of Exports ($1,000)
1962	11,104	4,422
1963	12,999	4,190
1964	13,350	4,529
1965	12,661	3,980
1966	18,151	5,388
1967	23,481	4,584
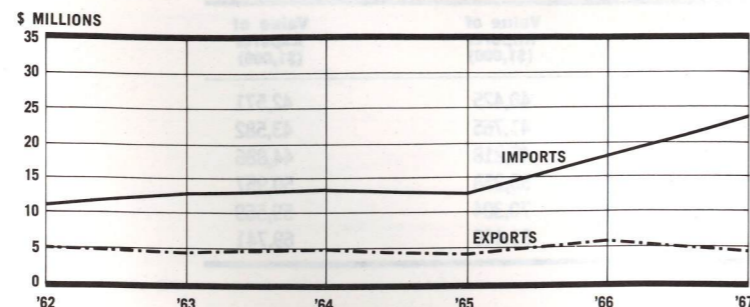
MARKET HIGHLIGHTS

There is almost no production of conventional business machines in Norway; therefore, Norway must import to satisfy demand. One firm, however, Nordata A/S, does manufacture small computers in the $70,000 range. Imports of business machines totaled $23 million in 1967.

The market for compact computers, now coming into use in Norway, is ripe for development. EDP equipment is coming into demand by government, universities, insurance companies, power plants, shipbuilders, and other industries. Norway regards the United States as a leader in these fields and, thus, equipment related to electronic data processing either manufactured in the United States or by American-owned European subsidiaries holds the major share of the market.

In 1967 Norway's imports of computing and accounting machines amounted to $8.3 million. Norway also imported $8.3 million in statistical machines, including electronic computers, and $2.6 million in typewriters. West Germany was the leading supplier and France was second.

The only significant exports are accounting and computing machines, $3.8 million of which were exported in 1967. West Germany was the leading recipient.

VALUE OF IMPORTS
OF BUSINESS MACHINES, 1967

Country or Area of Origin	Value ($1,000)	Country or Area of Origin	Value ($1,000)
Total	**23,481**	Italy	3,157
EC CL I	23,210	Netherlands	888
EC CL III	243	EFTA	6,909
Sterling Area	2,832	U.K.	2,832
U.S.	3,467	Denmark	494
Canada	117	Sweden	3,087
W. Europe	19,493	Switzerland	486
Common Market	12,584	E. Europe	243
France	3,860	E. Germany	195
W. Germany	4,659	Japan	133

VALUE OF EXPORTS
OF BUSINESS MACHINES, 1967

Country or Area of Destination	Value ($1,000)	Country or Area of Destination	Value ($1,000)
Total	**4,584**	France	210
		W. Germany	676
EC CL I	4,103	EFTA	1,379
EC CL II	464	U.K.	630
Sterling Area	916	Denmark	367
U.S.	161	Sweden	280
Lat. Am. Rps.	437	Other W. Europe	881
Argentina	107	Spain	719
Mexico	324	Aus.-N.Z.-SAF	263
W. Europe	3,329	Australia	130
Common Market	1,069	Japan	282

PORTUGAL

BUSINESS MACHINES

Year	Value of Imports ($1,000)	Value of Exports ($1,000)
1962	3,721	267
1963	4,352	432
1964	4,775	763
1965	4,860	607
1966	6,783	550
1967	7,252	726
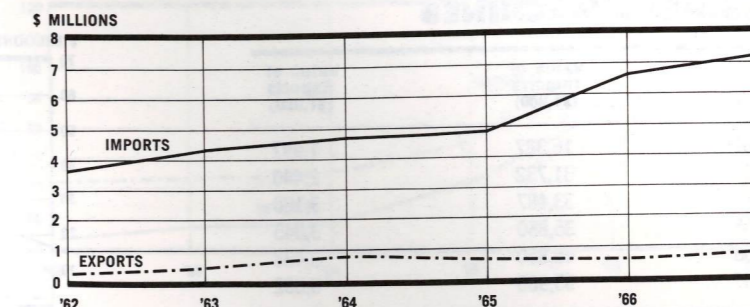
MARKET HIGHLIGHTS

Business machine production in Portugal is almost non-existent. Only a limited number of typewriters are assembled by Maquinas de Escrever SARL (MESSA) in its plant at Mem Martins near Lisbon. The company produces under a license agreement with a German firm. Actual production figures are unavailable; however, typewriters were the sole business machine export in 1967, totaling $700,000.

Portugal imported $7 million in business machines in 1967. Accounting and computing machines accounted for almost half of these imports; statistical machines, including electronic computers, made up about one-third. The major suppliers of business equipment to Portugal in 1967 were West Germany, $1.9 million, and Italy, $1.3 million.

VALUE OF IMPORTS
OF BUSINESS MACHINES, 1967

Country or Area of Origin	Value ($1,000)	Country or Area of Origin	Value ($1,000)
Total	**7,252**	W. Germany	1,904
EC CL I	7,094	Italy	1,289
		Netherlands	160
Sterling Area	979	EFTA	2,227
U.S.	562	U.K.	978
W. Europe	6,525	Sweden	916
Common Market	4,256	Switzerland	283
France	885		

VALUE OF EXPORTS
OF BUSINESS MACHINES, 1967

Country or Area of Destination	Value ($1,000)	Country or Area of Destination	Value ($1,000)
Total	**726**	U.S.	119
		W. Europe	215
EC CL I	350	Other Africa	283
EC CL II	376	Angola	129
Africa	288	Mozambique	131

SPAIN

BUSINESS MACHINES

Year	Value of Imports ($1,000)	Value of Exports ($1,000)
1962	16,327	1,997
1963	31,732	2,440
1964	33,487	3,180
1965	35,860	3,045
1966	46,850	3,438
1967	55,985	6,062
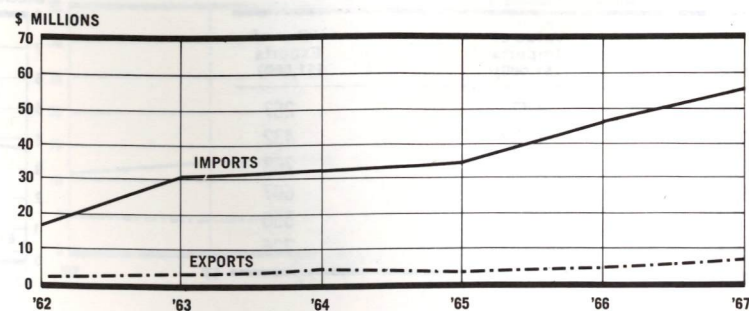
MARKET HIGHLIGHTS

Spanish business machine production in 1967 totaled $16 million, according to the Industrial Production Statistics of Spain. Typewriters accounted for about three-fourths of this total. Typewriter manufacturing is the only significant business machine production in Spain. A very limited number of manual adding machines and electric calculators are also produced.

In 1967, Spanish exports of business machines totaled $6 million, most of which represented typewriters. The United States received over half of these exports.

Spanish imports of business machines totaled $56 million in 1967. These imports were comprised of 43% accounting and computing machines, 37% statistical machines (including electronic computers) and the remaining 20%, typewriters. West Germany and Italy are the leading suppliers to the Spanish business machine market. They provided $14.1 million and $12.2 million, respectively, in 1967. The United States shipped $8.5 million in business machines to Spain in 1967.

VALUE OF IMPORTS
OF BUSINESS MACHINES, 1967

Country or Area of Origin	Value ($1,000)	Country or Area of Origin	Value ($1,000)
Total	**55,985**	Italy	12,157
EC CL I	54,396	Netherlands	579
EC CL II	125	EFTA	11,486
EC CL III	1,464	U.K.	5,415
Sterling Area	5,461	Denmark	225
U.S.	8,541	Norway	720
Canada	405	Sweden	3,935
W. Europe	45,158	Switzerland	1,191
Common Market	33,667	E. Europe	1,464
Belg.-Lux.	556	Czechoslovakia	154
France	6,233	E. Germany	1,310
W. Germany	14,143	Japan	292

VALUE OF EXPORTS
OF BUSINESS MACHINES, 1967

Country or Area of Destination	Value ($1,000)	Country or Area of Destination	Value ($1,000)
Total	**6,062**	Mexico	596
EC CL I	4,809	W. Europe	673
EC CL II	1,245	Common Market	460
Sterling Area	243	France	223
Africa	120	W. Germany	154
U.S.	3,857	EFTA	179
Canada	160	U.K.	117
Lat. Am. Rps.	1,215	Aus.-N.Z.-SAF	118
Brazil	485	South Africa	114

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SWEDEN

BUSINESS MACHINES

Year	Value of Imports ($1,000)	Value of Exports ($1,000)
1962	44,191	62,058
1963	48,462	64,358
1964	48,934	66,553
1965	61,232	74,710
1966	84,740	105,277
1967	108,042	112,359
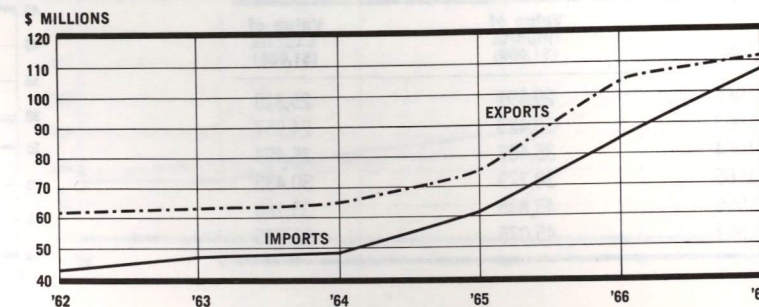
MARKET HIGHLIGHTS

Business machine production in Sweden is estimated at $145 million in 1968. This increase over 1967 is due to the improved European economic conditions, especially in West Germany, the principal market for Swedish machines. The economic slowdown of 1967 did not affect computers which make up 25% of total business machine production. Most of Sweden's conventional machines, except cash registers, are manufactured by the Facit Group. The firm's competitive position is being affected by the lack of Common Market advantages and the currency devaluations abroad in 1967. However, Facit has recently opened a new calculator plant to add to its 17 other domestic plants.

Photocopiers were the only conventional machines unaffected by the general business slowdown. For all other machines, sales in 1967 were the poorest in a decade. Improvement is now seen for 1968 and 1969, but the record level of 1965 is not likely to be reached. Sales of photocopiers are growing rapidly as a result of the switch from carbon copies to photocopies by many Swedish firms. Business and commercial establishments are also changing over to electric typewriters from standard models, which is reflected in the prodution figures. Production of accounting machines is highlighted by the American firms, including Burroughs, NCR, and Friden, which have 20% of the market. In the more recently established electronic desk calculator market Burroughs, Remington Rand, and Friden are active.

In the last few years, there has been a strong increase (25% per year) in the demand for electronic computers and peripheral equipment in Sweden. This market is dominated by U.S. subsidiaries, Swedish SAAB, and the Facit Group. Sweden, as of September 1968, had 550 computer installations and 250 more on order. It is estimated that by 1975 there will be 1200 installations. Sales of EDP equipment are expected to total $100 million in 1968. U.S. suppliers, with IBM in the lead, are expected to account for 70% of the business. The Swedish computer market looks exceptionally promising in the years ahead in the areas of manufacturing, process control, wholesale and retail distribution, and transportation.

Sweden's exports are a major factor in her economy. About 80% of Sweden's business machine production is exported to more than 100 countries. West Germany, the United States and France are the principal customers. In 1968, the industry's shipments increased markedly to both EFTA and EEC countries, notably Czechoslovakia. Imports into Sweden show a trend toward increased volume in electronic computers and statistical machines which accounted for over half of total imports in the first half of 1968. These as well as other sophisticated accounting machines are supplied for the most part by the United States, U.S. subsidiaries in Europe (IBM and others), and by France (Bull-GE).

VALUE OF IMPORTS
OF BUSINESS MACHINES, 1967

Country or Area Of Origin	Value ($1,000)	Country or Area Of Origin	Value ($1,000)
Total	**108,042**	France	32,632
		W. Germany	25,204
EC CL I	107,796	Italy	10,486
EC CL II	126	Netherlands	2,530
EC CL III	120	EFTA	16,225
Sterling Area	11,444	U.K.	11,406
U.S.	19,361	Denmark	587
Canada	649	Norway	155
W. Europe	87,281	Switzerland	4,070
Com. Market	71,013	E. Europe	118
Belg.-Lux.	161	Japan	505

VALUE OF EXPORTS
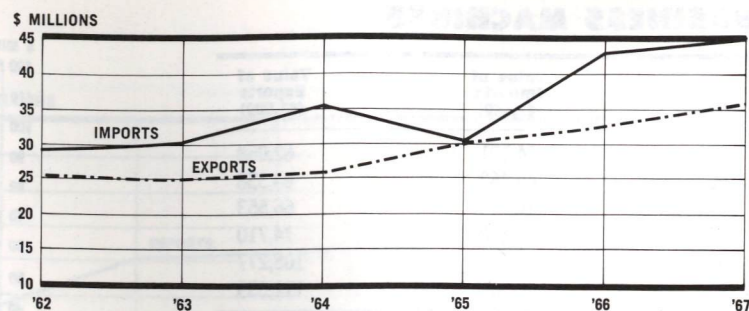OF BUSINESS MACHINES, 1967

Country or Area Of Destination	Value ($1,000)	Country or Area Of Destination	Value ($1,000)	Country or Area Of Destination	Value ($1,000)	Country or Area Of Destination	Value ($1,000)
Total	**112,359**	Mexico	1,811	Oth. Europe	8,723	Aus.-N.Z.-SAF	2,875
EC CL I	95,440	Panama	100	Iceland	107	Australia	1,220
EC CL II	13,570	Peru	449	Greece	224	New Zealand	815
EC CL III	3,348	Venezuela	1,092	Turkey	966	Sou. Africa	840
Sterling Area	12,808	W. Europe	66,373	Spain	2,463	Other Africa	1,240
Africa	2,219	Com. Market	39,776	Finland	3,116	Kenya	206
Non-Afr. ME	1,096	Belg.-Lux.	1,160	Yugoslavia	1,751	Angola	133
U.S.	19,139	France	12,098	E. Europe	3,346	Algeria	203
Canada	2,148	W. Germany	22,197	U.S.S.R.	468	Japan	4,905
Lat. Am. Rps.	9,267	Italy	2,262	Czecho-slovakia	920	Other Asia	1,517
Argentina	392	Netherlands	2,059	E. Germany	250	India	253
Bolivia	168	EFTA	17,873	Hungary	1,170	Pakistan	125
Brazil	4,112	U.K.	7,993	Poland	425	Singapore	142
Chile	320	Denmark	3,454	Mid-East	1,235	Hong Kong	323
Colombia	261	Norway	2,915	Israel	111	Viet Nam Rep.	132
Ecuador	150	Austria	496	Iran	636	Thailand	169
Guatemala	129	Portugal	879	Lebanon	145	Other C NES	311
		Switzerland	2,136				

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SWITZERLAND

BUSINESS MACHINES

Year	Value of Imports ($1,000)	Value of Exports ($1,000)
1962	29,491	25,328
1963	30,423	24,957
1964	35,407	25,494
1965	30,779	30,435
1966	43,835	33,180
1967	45,075	35,835

MARKET HIGHLIGHTS

The Swiss government does not publish production figures. Thus, the estimate of $55-60 million for business machine production in 1967 is based on the assumption that 60-65% of all production is exported. The continuing shortage of labor, the ceilings established on the labor force of individual companies, and the trend toward shorter work days in Switzerland have resulted in a rising demand for business machines, particularly labor-saving office equipment.

The Swiss business machine market is thoroughly developed. It has the highest consumption rate per capita of all Europe. In recent years there has been an increase in the demand for sophisticated business machines which have been supplied primarily by West Germany and the United States. The main items produced domestically are typewriters, adding and calculating machines, and cash registers.

The EDP equipment market in Switzerland is fully developed. The leading participants are IBM, Univac, Bull-GE, Control Data, NCR, and Honeywell. Most equipment sold by these suppliers is built in Europe. Computer application is progressing to overall planning, real time, and teleprocessing applications. As of June 1967, there were about 500 EDP systems installed in the country. As of a few years ago, most computer equipment was purchased outright although the suppliers also offered advantageous leasing terms. Government investment restrictions cause no real problems.

Switzerland imports mostly from West Germany ($14 million in 1967) and the United States ($10 million). It exports mainly to the United States ($5 million); France ($4.7 million); and West Germany ($4.6 million). Many U.S. firms are selling in the Swiss business machine market. Much of this United States equipment is manufactured by subsidiaries in Europe. U.S. companies in recent years have dominated the market in photocopiers, duplicators, bookkeeping and accounting machines, electric typewriters, and electronic computers.

VALUE OF IMPORTS
OF BUSINESS MACHINES, 1967

Country or Area Of Origin	Value ($1,000)	Country or Area Of Origin	Value ($1,000)
Total	45,075	France	4,725
EC CL I	44,729	W. Germany	14,382
EC CL II	185	Italy	5,234
EC CL III	161	Netherlands	1,784
Sterling Area	4,879	EFTA	6,982
U.S.	10,138	U.K.	4,868
Canada	248	Denmark	289
Lat. Am. Rps.	175	Sweden	1,709
W. Europe	33,246	E. Europe	161
Common Market	26,256	E. Germany	153
Belg.-Lux.	131	Japan	1,098

VALUE OF EXPORTS
OF BUSINESS MACHINES, 1967

Country or Area of Destination	Value ($1,000)	Country or Area of Destination	Value ($1,000)
Total	35,835	EFTA	6,772
EC CL I	31,836	U.K.	1,936
EC CL II	3,660	Denmark	1,089
EC CL III	339	Norway	385
Sterling Area	3,503	Sweden	2,351
Africa	1,027	Austria	727
Non-Afr. ME	303	Portugal	284
U.S.	5,241	Other W. Europe	1,694
Canada	665	Greece	101
Lat. Am. Rps.	2,123	Spain	1,129
Argentina	414	Finland	183
Brazil	545	Yugoslavia	190
Chile	385	E. Europe	301
Mexico	209	U.S.S.R.	152
Peru	112	Mid-East	323
Venezuela	137	Israel	130
W. Europe	21,855	Aus.-N.Z.-SAF	1,053
Common Market	13,389	Australia	349
Belg.-Lux.	901	New Zealand	245
France	4,677	South Africa	460
W. Germany	4,619	Other Africa	547
Italy	1,722	Japan	3,023
Netherlands	1,470	Other Asia	511
		Other C NES	156

UNITED KINGDOM

BUSINESS MACHINES

Year	Value of Imports ($1,000)	Value of Exports ($1,000)
1962	82,074	93,497
1963	86,072	110,664
1964	128,010	112,263
1965	148,707	124,500
1966	237,054	215,789
1967	262,344	216,595
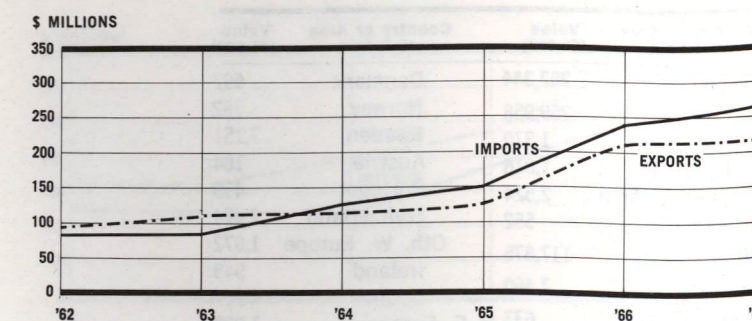
MARKET HIGHLIGHTS

Production of business machines in the United Kingdom totaled $466 million in 1967. The manufacture of conventional machines continues at a high level although there has been little growth in this segment of the industry since 1963.

In 1966, accounting machines comprised the largest share of the conventional business machines production. Duplicating machines were second in dollar value and typewriters were third. Intense competition which is still increasing has led to widespread price cutting in business machines; thus profit margins are thin. Philips of The Netherlands is entering the British market. Burroughs and NCR are already in the market.

Olivetti and various U.S. firms produce typewriters in the United Kingdom. Formidable competition here is evidenced by the two-thirds share held by European and Japanese firms in the U.K. typewriter market.

British firms supply over one-half of the domestic computer market. The United Kingdom is the only free-world country besides Japan in which IBM shares less than half of the market. The principal British firms which make up the major portion of the large, modern computer industry are International Computers Ltd. (ICL) and Elliott Automation. The former is the result of a merger of International Computers and Tabulators (ICT) and English Electric-Leo Marconi (EELM) in March of 1968. The British government is backing the domestic computer industry with financial participation in the form of R and D grants and loans. Other government aid is enabling these firms to offer longer payment terms in the international computer rental market. Thus, the British are becoming more competitive with the U.S. computer firms in the United Kingdom.

Domestic production of computers totaled $253 million in 1967. This was a 23% increase over 1966 production. As of December 1966, there were 1,700 digital computer installations in the United Kingdom. These installations are by the four major U.S. computer firms in the United Kingdom (IBM, Honeywell, Burroughs, and NCR) as well as by domestic companies.

Business machine imports into the United Kingdom in 1967 amounted to $262 million as compared to $217 million in exports. The United States was the leading supplier, with West Germany second. Statistical machines (including computers) were the leading import, amounting to $92 million in 1967. Accounting machines and typewriters ranked second and third, respectively. The leading customer for British business machines is West Germany, followed by France. Miscellaneous office machines (duplicating, addressing, dictating, check and mail handling machines, etc.) were the major export group in 1967. Second were accounting and computing machines and third were statistical machines, including electronic computers.

UNITED KINGDOM (Continued)
VALUE OF IMPORTS
OF BUSINESS MACHINES, 1967

Country or Area of Origin	Value ($1,000)	Country or Area of Origin	Value ($1,000)
Total	**262,344**	Denmark	697
EC CL I	259,958	Norway	782
EC CL II	1,370	Sweden	7,151
EC CL III	1,016	Austria	164
Sterling Area	2,524	Portugal	439
Africa	552	Switzerland	2,474
U.S.	117,875	Oth. W. Europe	1,072
Canada	7,460	Ireland	949
Lat. Am. Rps.	633	Spain	107
Argentina	619	E. Europe	1,003
W. Europe	131,246	Czechoslovakia	287
Com. Market	118,467	E. Germany	288
Belg.-Lux.	708	Hungary	323
W. Germany	50,543	Aus.-N.Z.-SAF	854
France	39,782	Australia	317
Italy	18,293	South Africa	515
Netherlands	9,142	Japan	2,523
EFTA	11,708	Other Asia	653
		Hong Kong	541

VALUE OF EXPORTS
OF BUSINESS MACHINES, 1967

Country or Area Of Origin	Value ($1,000)	Country or Area Of Origin	Value ($1,000)	Country or Area Of Destination	Value ($1,000)	Country or Area Of Destination	Value ($1,000)	Country or Area Of Destination	Value ($1,000)
Total	**216,595**	Venezuela	1,152	Spain	5,138	Lebanon	295	Japan	8,240
EC CL I	179,100	W. Europe	112,742	Finland	1,116	UAR Egypt	337	Other Asia	6,078
EC CL II	26,954	Com. Market	79,903	Yugoslavia	448	Sudan	127	Burma	207
EC CL III	10,541	Belg.-Lux.	3,622			Aus.-N.Z.-SAF	23,949	Ceylon	513
Sterling Area	38,329	France	24,790	E. Europe	8,924	Australia	10,041	India	896
Africa	13,812	W. Germany	33,502	U.S.S.R.	223	New Zealand	5,317	Pakistan	574
Non-Afr. ME	2,829	Italy	10,174	Bulgaria	457	South Africa	8,591	Malaysia	1,194
U.S.	23,486	Netherlands	7,815	Czechoslovakia	3,551	Other Africa	4,423	Singapore	397
Canada	10,683	EFTA	21,312	E. Germany	318	Kenya	838	Brunei	163
Lat. Am. Rps.	11,454	Denmark	2,810	Hungary	1,955	Ghana	333	Hong Kong	655
Argentina	1,341	Norway	1,892	Poland	1,452	Mauritius	156	China Taiwan	109
Bolivia	108	Sweden	8,412	Romania	968	Nigeria	954	Indonesia	118
Brazil	5,314	Austria	2,039			Zambia	929	Philippines	572
Chile	282	Portugal	1,602	Mid-East	3,627	Malawi	175	Thailand	625
Colombia	503	Switzerland	4,558	Kuwait	150	Senegal	102	Other C NES	1,372
Ecuador	133	Oth. W. Europe	11,527	St Arab NS	182	Angola	135	Jamaica	455
Mexico	1,638	Ireland	4,092	Libya	268	Mozambique	107	Trinidad T	134
Panama	176	Greece	329	Israel	732	Morocco	105	Barbados	104
Peru	320	Turkey	357	Iran	856	China M X	1,617	AM ST NES	169
				Iraq	152	China MNLD.	1,617	O S Europe	136
				Saudia Arabia	183				

WEST GERMANY

BUSINESS MACHINES

Year	Value of Imports ($1,000)	Value of Exports ($1,000)
1962	124,385	165,362
1963	119,858	164,031
1964	116,597	197,261
1965	186,456	243,029
1966	247,353	340,607
1967	286,445	336,999
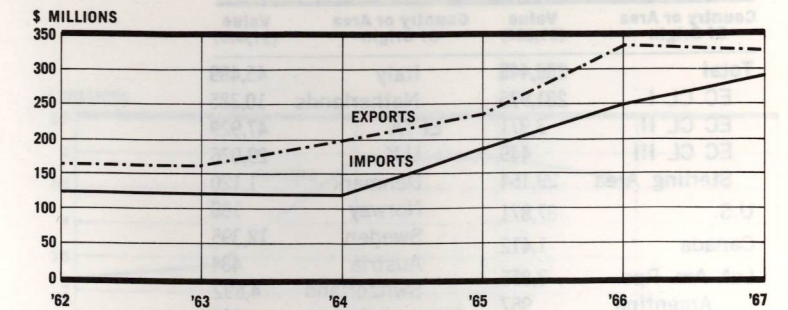
MARKET HIGHLIGHTS

Production of business machines in West Germany reached $846.4 million 1966, a 28% increase over the previous year. Computers led in dollar volume with punch card and special office machines second, and typewriters, third.

The typewriter production, 50% of which is electric, is dominated (80%) by two German firms, Olympia Werke AG and the Grundig group—Triumph and Adler (now part of Litton Industries). An NCR subsidiary holds 50% of the cash register market and 67% of the accounting machine market. Olympia Werke AG holds two-thirds of the adding machine market. A 3M Company subsidiary has a strong position in duplicating equipment and Rank-Xerox accounts for the majority of copiers sold in West Germany.

Domestic production is presently concentrated on unsophisticated, standard business equipment which is meeting increased foreign competition due to high domestic labor costs. Future success will depend on the production of newer, complex, more advanced equipment.

Computer installations in West Germany are second in number only to the United States. The 2,962 installations in 1967 are expected to double by 1970. Presently, commercial and industrial firms, scientific institutions, and universities provide the strongest demand for electronic data processing equipment. One-fourth of the computers in West Germany are installed in the metal industries.

Small computers comprise 50% of the total market and are growing at a rate of 50% per year. U.S. firms supply a major part of the West German computer requirements through their subsidiaries or by exports. The leading computer manufacturers in West Germany include IBM, Univac, Bull-GE, NCR, Control Data, Burroughs, Eurocomp, and Honeywell. As of 1966, it was estimated that IBM controlled about 68% of the computer market.

Business machine exports doubled between 1963-1966. This indicates the rapid growth in exports which is expected to continue. The fastest growing product category is statistical machines and electronic computers. The major markets for West German business equipment are France, United States, and the United Kingdom, in that order.

Imports are increasing almost as fast as exports. The miscellaneous category of duplicating, addressing and other business machines contributes most to this rise. Statistical machines (including electronic computers) and typewriters are also imported to a significant degree. The leading suppliers, in order of market shares, are the United States, France, and Italy.

WEST GERMANY (Continued)

VALUE OF IMPORTS
OF BUSINESS MACHINES, 1967

Country or Area Of Origin	Value ($1,000)	Country or Area Of Origin	Value ($1,000)
Total	**286,445**	Italy	45,489
EC CL I	281,975	Netherlands	10,385
EC CL II	3,971	EFTA	47,929
EC CL III	449	U.K.	29,026
Sterling Area	29,164	Denmark	1,120
U.S.	87,871	Norway	188
Canada	1,412	Sweden	12,395
Lat. Am. Rps.	3,855	Austria	484
Argentina	957	Switzerland	4,692
Brazil	2,894	Other W. Europe	308
W. Europe	186,721	Spain	120
Com. Market	138,484	Finland	171
Belg.-Lux.	928	E. Europe	499
France	81,682	Czechoslovakia	460
		Japan	5,937

VALUE OF EXPORTS
OF BUSINESS MACHINES, 1967

Country or Area Of Destination	Value ($1,000)	Country or Area Of Destination	Value ($1,000)	Country or Area Of Destination	Value ($1,000)	Country or Area Of Destination	Value ($1,000)	Country or Area Of Destination	Value ($1,000)
Total	**336,999**	Honduras	135	Austria	11,650	Libya	229	Mozambique	161
EC CL I	302,672	Mexico	1,951	Portugal	2,030	Israel	938	Algeria	105
EC CL II	30,008	Nicaragua	249	Switzerland	13,306	Iran	1,006	Morocco	339
EC CL III	4,319	Panama	253	Oth. W. Europe	23,852	Saudi Arabia	207	Japan	13,773
Sterling Area	54,605	Paraguay	124	Iceland	115	Lebanon	295	Other Asia	7,619
Africa	8,313	Peru	1,687	Ireland	580	Aus.-N.Z.-SAF	12,284	Burma	320
Non-Afr. ME	2,750	Uruguay	328	Greece	1,371	Australia	5,410	Ceylon	122
U.S.	42,928	Venezuela	2,549	Turkey	1,073	New Zealand	1,974	India	238
Canada	4,335	W. Europe	229,352	Spain	11,860	South Africa	4,900	Pakistan	383
Lat. Am. Rps.	15,336	Com. Market	121,006	Finland	5,319	Other Africa	2,985	Malaysia	1,488
Argentina	2,734	Belg.-Lux.	11,297	Yugoslavia	3,534	Kenya	298	Hong Kong	1,389
Bolivia	302	France	67,555	E. Europe	4,304	Uganda	108	China Taiwan	206
Brazil	1,469	Italy	25,786	U.S.S.R.	958	Nigeria	144	Viet Nam Rep.	170
Chile	2,487	Netherlands	16,368	Bulgaria	327	Zambia	504	Indonesia	268
Costa Rica	168	EFTA	84,494	Czechoslovakia	965	S. Rhodesia	129	Philippines	1,365
Dominican Rep.	116	U.K.	35,137	Hungary	403	Malawi	126	Thailand	1,507
Ecuador	320	Denmark	7,385	Poland	134	Ivory Coast	112	Other C NES	890
El Salvador	245	Norway	3,255	Romania	1,517	Congo LEO	150	Jamaica	283
Guatemala	153	Sweden	11,731	Mid-East	3,178	Angola	243	Trinidad T	141

HONG KONG

BUSINESS MACHINES

	Value of Imports ($1,000)	Value of Exports ($1,000)
1962	3,188	None
1963	3,432	None
1964	4,976	None
1965	4,989	None
1966	4,561	None
1967*	15,000	1,000

* Estimate based on Government figures.
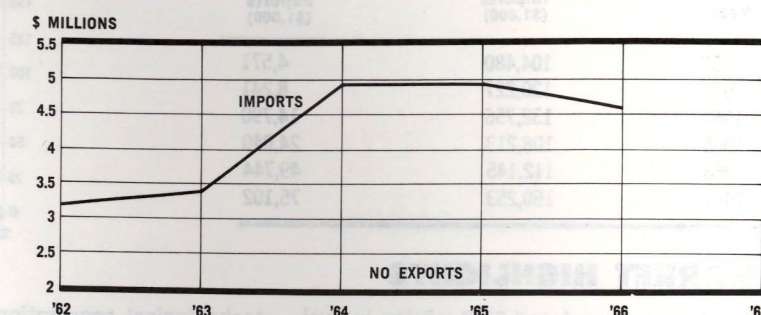
MARKET HIGHLIGHTS

No production figures are available for Hong Kong business machines. Various foreign firms have offices in Hong Kong but little manufacturing is done. The offices serve only as sales headquarters for the Asian market.

Business machines valued at $1 million were exported from Hong Kong in 1967 according to UN statistics. Imports totaled approximately $15 million, $11 million of which were from the United States. The greater part of this amount represented parts.

VALUE OF IMPORTS
OF BUSINESS MACHINES, 1967

Country or Area Of Origin	Value ($1,000)	Country or Area Of Origin	Value ($1,000)

Not Available

VALUE OF EXPORTS
OF BUSINESS MACHINES, 1967

Country or Area of Destination	Value ($1,000)	Country or Area of Destination	Value ($1,000)

Not Available

JAPAN

BUSINESS MACHINES

Year	Value of Imports ($1,000)	Value of Exports ($1,000)
1962	104,480	4,571
1963	120,227	8,241
1964	132,756	14,790
1965	108,213	24,040
1966	112,145	49,744
1967	160,253	75,102

MARKET HIGHLIGHTS

The Japanese produced $220 million in business machines in 1966 and it is estimated that a total of $260 million was produced in 1967. Almost half of this total represents electronic computers.

The principal conventional business machine produced is the duplicating machine. Although production of this type machine is the largest in terms of value, it has grown little since 1964, and the market is not dynamic. Typewriters and cash registers are the next largest product categories, based on value. Cash register production has decreased, however, since 1964. The most promising growth has been shown by electronic calculating machines, which have increased almost 900 percent between 1964 and 1966. Copying machines reflect expert Japanese technology and are now becoming internationally competitive. Typewriter production continues to increase with special emphasis on portables.

It is estimated that Japanese computer deliveries totaled $115 million in 1967. Medium-sized computers accounted for over half of this value. Japan relies heavily on technological cooperation with foreign firms in this industry. IBM, Univac, Burroughs, Control Data, General Electric, Bull-GE, and Westinghouse Electric are all established in the Japanese computer market. The Japanese government scrutinizes carefully all computer imports. It gives financial assistance to local firms and the Japanese Electronic Computer Company (JECC) leases all domestic computers. Although foreign interests have a secure foothold in the Japanese market, the Government discourages additional competition to the domestic computer industry and is said to fear the threat of foreign monopoly of technology. Greater reliance on imports for software and peripherals is evident, however, and is due to foreign superiority in these areas.

Japan's exports of business machines were valued at $75 million in 1967. Exports have risen sharply in recent years as Japanese business machines increasingly penetrate international markets. Exports to the United States almost doubled each year between 1962-1966 and rose about 50% in 1967. Typewriters are the leading export ($13 million in 1967). The other significant exports include statistical machines ($10 million), electric calculating machines ($7 million) and digital computers ($7 million). Approximately 72% of all Japanese typewriter exports go to the United States. Most of these are portables manufactured by Brothers Industries. The United States was the leading recipient of Japanese business machines in 1967 ($31 million). The next highest export recipient was West Germany ($6 million).

Imports of business machines into Japan reached $160 million in 1967. Digital computers and related auxiliary equipment are the major items imported. Electric calculators are also imported to a significant degree, but the total has not increased in recent years. Foreign bookkeeping and accounting machines and parts for electronic calculating machines continued to be major imports during 1967. The United States was the largest supplier of business machines to Japan in 1967 ($89 million). Canada was second ($16 million), followed by West Germany ($16 million), France ($11 million), and the United Kingdom ($10 million).
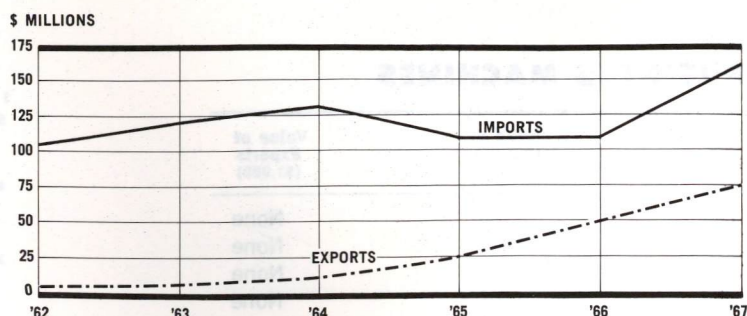
VALUE OF IMPORTS
OF BUSINESS MACHINES, 1967

Country or Area Of Origin	Value ($1,000)	Country or Area Of Origin	Value ($1,000)
Total	**160,253**	Netherlands	699
		Italy	6,893
EC CL I	159,815	EFTA	19,622
EC CL II	316	U.K.	10,296
EC CL III	123	Denmark	2,065
		Norway	234
Sterling Area	10,515	Sweden	3,673
		Switzerland	3,339
U.S.	88,965	E. Europe	123
Canada	16,290	E. Germany	119
W. Europe	54,555	Other Asia	305
Common Market	34,932	Hong Kong	213
France	11,347		
W. Germany	15,988		

VALUE OF EXPORTS
OF BUSINESS MACHINES, 1967

Country or Area of Destination	Value ($1,000)	Country or Area of Destination	Value ($1,000)	Country or Area of Destination	Value ($1,000)
Total	**75,102**	W. Europe	19,174	Australia	3,054
EC CL I	57,543	Common Market	12,273	New Zealand	886
EC CL II	16,877	Belg.-Lux.	241	South Africa	647
EC CL III	683	France	3,176	Other Africa	130
Sterling Area	8,981	W. Germany	6,099	China M X	471
Africa	791	Italy	1,374	China MNLD	468
Non-Afr. ME	310	Netherlands	1,383	Other Asia	5,618
U.S.	30,993	EFTA	6,104	India	846
Canada	2,790	U.K.	2,322	Malaysia	168
Lat. Am. Rps.	10,172	Denmark	908	Singapore	293
Argentina	1,173	Sweden	713	Hong Kong	192
Brazil	2,555	Austria	211	China Taiwan	754
Chile	161	Switzerland	1,865	Viet Nam Rep.	202
Colombia	901	Other W. Europe	797	Korea Rep.	950
Costa Rica	227	Spain	367	Philippines	1,010
Ecuador	120	Finland	331	Thailand	541
Mexico	2,097	E. Europe	212	Ryukyu Isl.	486
Panama	508	U.S.S.R.	155	Other C NES	632
Peru	418	Mid-East	234	Bahamas	129
Venezuela	1,728	Iran	156	Neth. Antilles	249
		Aus.-N.Z.-SAF	4,587		
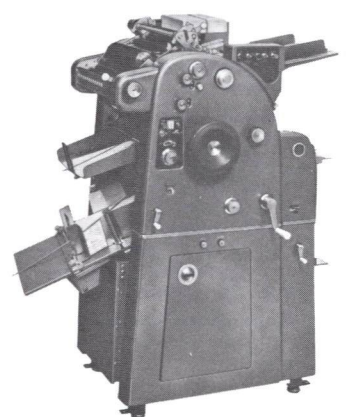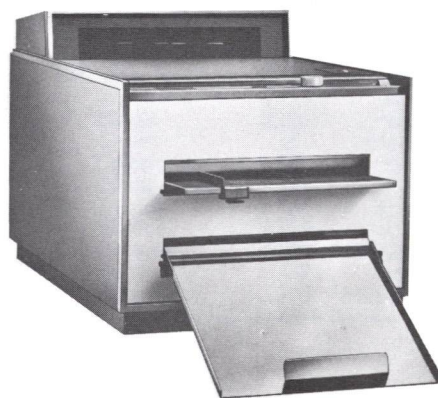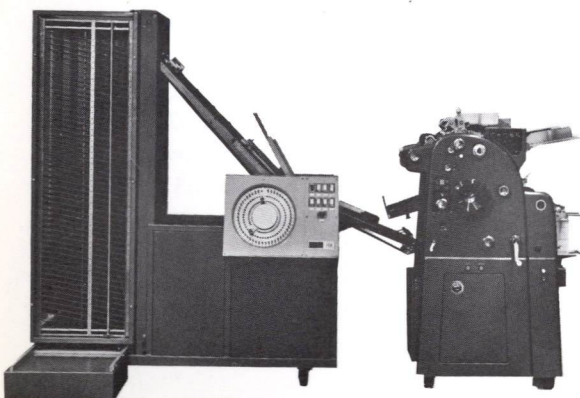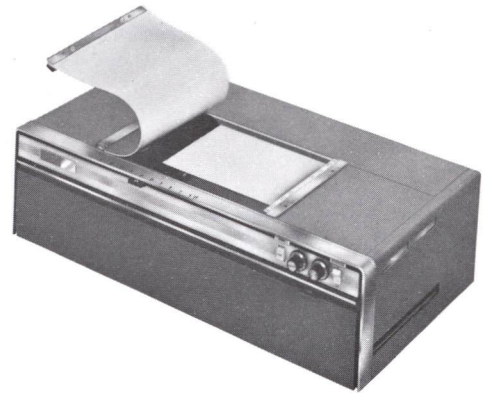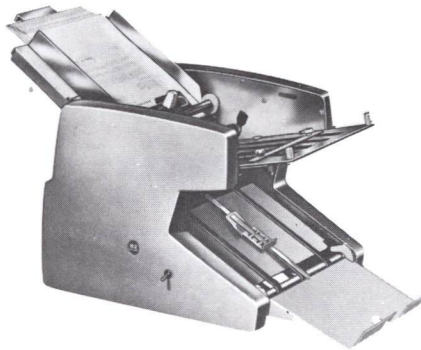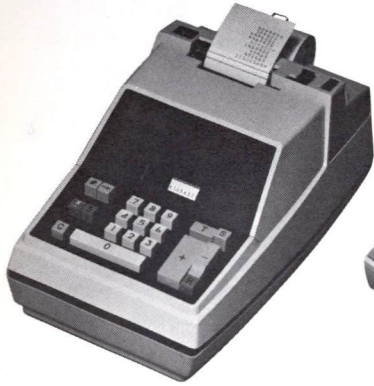
MASTERS' AND DOCTORS' THESES
IN
COMPUTING SCIENCE

MASTERS' AND DOCTORS' THESES IN COMPUTING SCIENCE

THIS COLLECTION OF THESES IN COMPUTER SCIENCE IS ESSENTIALLY BASED ON DR. PETER WEGNER'S COMPILATION. THESE ARE BASICALLY NOT REVIEWS: THE AUTHORS' ABSTRACTS WERE MINIMALLY EDITED, CHIEFLY TO SHORTEN FOR PUBLICATION IN COMPUTING REVIEWS. THE CLASSIFICATION AND CROSS REFERENCES WERE SOLICITED FROM THE AUTHORS, AND ONLY WHEN RESPONSES WERE NOT FORTHCOMING WERE CATEGORIES ASSIGNED BY COMPUTING REVIEWS. THE AUTHORS WERE ALSO ASKED TO NOTE OTHER PUBLICATION BASED ON THE THESIS, AND THIS HAS BEEN NOTED. THE PUBLICATION OF THE THESES RESULTED IN THE RECEIPT OF ADDITIONAL THESES DIRECTLY FROM THEIR AUTHORS.

A RETROSPECTIVE SEARCH IS IN PROGRESS TO IDENTIFY THESES THAT WERE NOT SO LABELLED WHEN THEY WERE REVIEWED. SOME UNIVERSITY CENTERS THAT ISSUE "REPORTS" IN A STANDARD FORMAT OFTEN FAIL TO MAKE CLEAR WHEN A PUBLICATION IN THE SERIES IS, IN ACTUALITY, A GRADUATE THESIS.

CATEGORIES OF THE COMPUTING SCIENCES
Classification System for *Computing Reviews*

1. **GENERAL TOPICS AND EDUCATION**
   1.0 General
   1.1 Texts; Handbooks
   1.2 History; Biographies
   1.3 Introductory and Survey Articles
   1.4 Glossaries
   1.5 Education
     1.50 General
     1.51 High School Courses and Programs
     1.52 University Courses and Programs
     1.53 Certification; Degrees; Diplomas
     1.59 Miscellaneous
   1.9 Miscellaneous

2. **COMPUTING MILIEU**
   2.0 General
   2.1 Philosophical and Social Implications
     2.10 General
     2.11 Economic and Sociological Effects
     2.12 The Public and Computers
     2.19 Miscellaneous
   2.2 Professional Aspects
   2.3 Legislation; Regulations
   2.4 Administration of Computing Centers
     2.40 General
     2.41 Administration Policies
     2.42 Personnel Training
     2.43 Operating Procedures
     2.44 Equipment Evaluation
     2.45 Sureys of Computing Centers
     2.49 Miscellaneous
   2.9 Miscellaneous

3. **APPLICATIONS**
   3.1 NATURAL SCIENCES
     3.10 General
     3.11 Astronomy; Space
     3.12 Biology
     3.13 Chemistry
     3.14 Earth Sciences
     3.15 Mathematics; Number Theory
     3.16 Meteorology
     3.17 Physics; Nuclear Sciences
     3.19 Miscellaneous
   3.2 ENGINEERING
     3.20 General

   3.21 Aeronautical; Space
   3.22 Chemical
   3.23 Civil
   3.24 Electrical; Electronic
   3.25 Engineering Science
   3.26 Mechanical
   3.29 Miscellaneous
   3.3 SOCIAL and BEHAVIORAL SCIENCES
     3.30 General
     3.31 Economics
     3.32 Education; Welfare
     3.33 Law
     3.34 Medicine; Health
     3.35 Political Science
     3.36 Psychology; Anthropology
     3.37 Sociology
     3.39 Miscellaneous
   3.4 HUMANITIES
     3.40 General
     3.41 Art
     3.42 Language Translation and Linguistics
     3.43 Literature
     3.44 Music
     3.49 Miscellaneous
   3.5 MANAGEMENT DATA PROCESSING
     3.50 General
     3.51 Education; Research
     3.52 Financial
     3.53 Government
     3.54 Manufacturing; Distribution
     3.55 Marketing; Merchandising
     3.56 Military
     3.57 Transportation; Communication
     3.59 Miscellaneous
   3.6 ARTIFICIAL INTELLIGENCE
     3.60 General
     3.61 Induction and Hypothesis-formation
     3.62 Learning and Adaptive Systems
     3.63 Pattern Recognition
     3.64 Problem-solving
     3.65 Simulation of Natural Systems
     3.66 Theory of Heuristic Methods
     3.69 Miscellaneous
   3.7 INFORMATION RETRIEVAL
     3.70 General
     3.71 Content Analysis
     3.72 Evaluation of Systems
     3.73 File Maintenance

   3.74 Searching
   3.75 Vocabulary
   3.79 Miscellaneous
   3.8 REAL TIME SYSTEMS
     3.80 General
     3.81 Communications
     3.82 Industrial Process Control
     3.83 Telemetry; Missiles; Space
     3.89 Miscellaneous
   3.9 Miscellaneous

4. **PROGRAMMING**
   4.0 General
   4.1 PROCESSORS
     4.10 General
     4.11 Assemblers
     4.12 Compilers and Generators
     4.13 Interpreters
     4.19 Miscellaneous
   4.2 PROGRAMMING LANGUAGES
     4.20 General
     4.21 Machine Oriented Languages
     4.22 Procedure and Problem Oriented Languages
     4.29 Miscellaneous
   4.3 SUPERVISORY SYSTEMS
     4.30 General
     4.31 Basic Monitors
     4.32 Multiprogramming; Multiprocessing
     4.39 Miscellaneous
   4.4 UTILITY PROGRAMS
     4.40 General
     4.41 Input/Output
     4.42 Debugging
     4.43 Program Maintenance
     4.49 Miscellaneous
   4.9 Miscellaneous

5. **MATHEMATICS OF COMPUTATION**
   5.0 General
   5.1 NUMERICAL ANALYSIS
     5.10 General
     5.11 Error Analysis: Computer Arithmetic
     5.12 Function Evaluation
     5.13 Interpolation; Functional Approximation
     5.14 Linear Algebra
     5.15 Nonlinear and Functional Equations
     5.16 Numerical Integration and Differentiation

   5.17 Ordinary and Partial Differential Equations
   5.18 Integral Equations
   5.19 Miscellaneous
   5.2 METATHEORY
     5.20 General
     5.21 Formal Logic
     5.22 Automota; Turing Machines
     5.23 Mechanical and Algorithmic Languages
     5.24 Theory of Programming
     5.29 Miscellaneous
   5.3 COMBINATORIAL AND DISCRETE MATHEMATICS
     5.30 General
     5.31 Sorting
     5.32 Graph Theory
     5.39 Miscellaneous
   5.4 MATHEMATICAL PROGRAMMING
     5.40 General
     5.41 Linear and Nonlinear Programming
     5.42 Dynamic Programming
     5.49 Miscellaneous
   5.5 Mathematical Statistics; Probability
   5.6 Information Theory
   5.9 Miscellaneous

6. **DESIGN AND CONSTRUCTION**
   6.0 General
   6.1 LOGICAL DESIGN; SWITCHING THEORY
   6.2 COMPUTER SYSTEMS
     6.20 General
     6.21 General Purpose Computers
     6.22 Special Purpose Computers
     6.29 Miscellaneous
   6.3 COMPONENTS and CIRCUITS
     6.30 General
     6.31 Circuit Elements
     6.32 Arithmetic Units
     6.33 Control Units
     6.34 Storage Units
     6.35 Input/Output Equipment
     6.36 Auxiliary Equipment
     6.39 Miscellaneous
   6.9 Miscellaneous

7. **ANALOG COMPUTERS**
   7.0 General
   7.1 Applications
   7.2 Design; Construction
   7.3 Hybrid Systems
   7.4 Programming; Techniques
   7.9 Miscellaneous

⊖Brooks, Frederick Phillips, Jr.   13,560
The analytic design of automatic data processing systems.
   (Thesis) *PhD*
Harvard Univ., Cambridge, Mass., 1956.

   The present investigation explores the problem of designing automatic data processing systems by analytic—rather than intuitive—methods, and considers in detail the characteristics of such a system determined by restricting its application to the problem of calculating payroll data.

   Part I presents several general methods for describing and analyzing data processing systems and general methods for designing the automatic machinery for such systems. Chapter One is an introduction. . . .

   Chapter Two presents a number of methods for analyzing and describing different aspects of an automatic data processing system: fundamental ordering, physical information carriers, input and output requirements, flow of information carriers, and control of errors and fraud. These methods are generally applicable to data processing systems, whether manual, semimanual, semiautomatic, or fully automatic. . . .

   In Chapter Three, methods are presented for designing the central computer of an automatic data processing system to meet the requirements of a specified class of problems.

   . . . In Part II the general methods are illustrated in detail by application to the design of a special purpose automatic system for payroll calculations. This universal business problem is especially appropriate for such an investigation since most companies begin using automatic equipment by mechanizing this particular process. The first chapter of this part, Chapter Four, discusses in detail the payroll calculation problem and the requirements it imposes upon systems. . . .

   In Chapter Five a system is outlined for the treatment of payroll problems, using the general methods developed in Chapter Two. . . .

   In the sixth chapter the design of the special purpose computer at the heart of such a payroll system is outlined, utilizing the general machine design methods developed in Chapter Three. . . .

   In Chapter Seven suggestions are offered for a basic attack upon the payroll problem.   *From the Abstract*

1.1 Texts; Handbooks

⊖Worsley, Beatrice H.   13,561
A mathematical survey of computing devices, with an appendix on an error analysis of differential analyzers.
   (Thesis)
M.I.T., Cambridge, Mass., 1947.

   The survey is intended to serve either as an introduction to the subject of Computing Devices for those who are newly entering the field, or as a brief guide to workers in other fields who would have an overall picture of the subject with a view to its possible bearing on their own work. The approach is mathematical in the sense that the emphasis is on the mathematical forms which can be treated by the methods. However, sufficient description has been included to give an idea of the working principles involved.

                From the Introduction

3. Applications

3.1 Natural Sciences

3.12 Biology

⊖Flanigan, Larry Karl.   13,735
A cellular model of electrical conduction in the mammalian atrioventricular node. (Thesis)
Univ. Michigan, Ann Arbor, Mich., 1965.

   The purpose of the investigation is to formulate and test a cellular model of electrical conduction in the mammalian A–V node. The model is based upon the behavior of an individual cell which is specified by a set of formulas which determine the cell state as a function of time over a firing cycle. The interrelationships of cells in a network are specified by a set of rules which govern electrical conduction from cell to cell, as a function of cell state, and provide both spatial and temporal summation in the network. Random cell-to-cell variations and a global cell variation across the network are supplied by the assignment of a distinct, random K value to each cell which is used in computing the cell's ARP duration. A local geometry is assumed which provided each cell with six neighbor cells over which summation may occur, and a global geometry is enforced which provides a funnel shape to the cell network. The model is based upon present knowledge of cardiac electrophysiology in all these aspects.

   The results of a computer simulation of this model are reported. These results show that the model behaves much like the mammalian A–V node, with certain discrepancies which do not appear to be of major importance, and the model produces no behavior which is not found in the A–V node. Specifically, for rhythmic inputs, for premature best inputs, and for atrial flutter and fibrillation inputs, the output of the model is quite similar to that of the A–V node under similar circumstances, except that directionality is less marked and $n:n-1$ cycles do not occur in the model. . . .   *From the Abstract*

⊖Rosenberg, Richard Stuart.   13,568
Simulation of genetic populations with biochemical properties. (Thesis)
Univ. Michigan, Ann Arbor, Mich., 1967

It is only with the advent of high-speed, large-storage digital computers that simulations of some complexity have become possible. The development of the present simulation, which differs in many important respects from other genetic simulations, and its application to a few specific problems are described. It constitutes a broad, flexible system for the study of evolutionary problems related to a closed, small population. Of particular importance are the many similiarities to natural populations such as a time-varying phenotype, a dynamic interaction between the population and its environment, and mating rules, mortality rules, and selection rules of wide variety. The definition of the phenotype on the basis of chemical concentrations, whose levels are under genetic control via enzyme action, is the central feature of the model.

The relation between the number of crossover positions in the chromosome pair to the rate of evolution of the population is explored. The importance of the dynamic relationship between a population under selection pressure and its environment is underlined. An important result is achieved in the final set of experiments in which the selection of crossover probabilities is demonstrated. In this effort it is necessary to apply strong selection pressure to combat the disruptive stochastic effects in a small population. This pressure is manifested both in more powerful mortality procedures and in an increased number of allowable offspring per mating. . . .

From the Abstract

3.14 Earth Sciences

⊖Gellman, Harvey.   13,330
Computation of the magnetic field produced by a moving liquid. (Thesis)
Univ. Toronto, Toronto, Ont., Canada, 1951.

The present thesis provides a partial test of the dynamo theory of the origin of the earth's magnetic field. The dynamo theory, originally suggested by Larmor, has recently been reexamined by Frenkel, Elsasser, and Bullard. . . .

The version of the dynamo theory considered here is that proposed by Bullard. A system of motions is assumed, together with an initial magnetic field: the resulting electromagnetic interactions are investigated to determine whether the complete system can provide a self-inductive mechanism which will maintain the earth's magnetic field. The mathematical problem involves integration of a system of differential equations derived from Maxwell's equations, and it is a very formidable one. An approximate solution has been obtained through the use of a new polynomial method of successive approximations. It is found that with the assumptions and formalism used here, the dynamo mechanism proposed by Bullard does not provide a self-inductive scheme. Until now Bullard's dynamo mechanism was considered plausible and promising. The present thesis contains the first detailed examination of this mechanism and contributes to the development of a general dynamo theory by showing that the course adopted by Bullard requires modification before it can be expected to produce positive results. The thesis also contains a detailed quantitative analysis of the westward drift of the earth's magnetic field and a general study of certain differential equations by a method of asymptotic expressions.

From the Abstract ✓

3.16 Meteorology

⊖Hockney, Roger Willis.   13,951
The computer simulation of anomalous plasma diffusion and the numerical solution of Poisson's equation. (Thesis)
Stanford Univ., Stanford, Calif., 1966.

The purpose of this research has been to study the diffusion of a collisionless plasma across a constant magnetic field by means of a two-dimensional Lagrangian computer model. This model represents the plasma by means of approximately 1,000 charged rods and calculates their motion, stepwise in time, as they move according to the laws of Newton and Maxwell. The model is quasi-electrostatic and takes 1.7 sec to perform a time-step on the IBM 7090 computer. . . . Results of the investigation of anamolous diffusion were displayed in a 2-minute motion picture, which shows the position of every plasma particle and the shape of the potential surface. The buildup of a "steady-state" potential distribution that is unstable can be observed in a sequence of frames. The diffusion, which can all be attributed to the coherent E-field of an unstable wave, is several orders of magnitude greater than that due to binary collisions in a real plasma with the same constants. Classical collisional diffusion between rods in the model is negligible, and the model simulates essentially collective phenomena such as instabilities and "anomalous" diffusion.

To check the validity of the model, we solve the Vlasov equation numerically for the steady state, taking into account the precise size of the Larmor radii. The results agree reasonably well with the model.

The stability has been analyzed using the simplest-possible fluid equations; two unstable waves are predicted, with slightly different wave velocities, which beat together to give phase and amplitude variations strikingly similar to those observed. The calculated growth rates of these instabilities also agree very well. However, such a linear analysis cannot give the wave amplitudes or the amount of diffusion, both of which come out naturally in the computer model. . . .

From the Abstract

ΘFINLEY, MARION.   13,349
An experimental study of the formation and development
of Hebbian cell-assemblies by means of neural net-
work simulation. (Thesis)
Univ. Michigan, Ann Arbor, Mich., 1967.

The primary objective of this study is to derive a
structural and dynamic characterization of Hebbian
cell-assemblies in terms of a particular class of models
of neural networks. Within these models, Hebb's
postulate of synapse-growth occupies a pivotal posi-
tion. The networks of the given class of models may,
together with any appropriate environments, be simu-
lated by means of a digital computer program.

A number of subsidiary goals immediately became
apparent, however. First of all, it was found necessary
to characterize stable, steady-state behavior of a net-
work. Next, the role of negative connections in such a
network needed clarification. Finally, the problem of
guaranteeing localization of certain neural events
arose.

To meet these goals, a steady-state stability calculus
relating the essential network parameters N (number
of neurons in $\mathfrak{M}$), the threshold curve, and ρ (density
of connections in $\mathfrak{M}$) was worked out. This was done
first for the case that positive equal connections only
are present in $\mathfrak{M}$. This calculus was then modified to
include the case that positive and negative connections
(inhibitory connections) are present in $\mathfrak{M}$. The
inhibitory connections are shown quantitatively to
be essential to ensure the negative feedback necessary
to sustain steady state. Again, relationships for the
"mix" of positive vs. negative connections and the
relationship of these quantities to the threshold curve
are given.

A series of experiments was performed . . . with
networks of progressively greater complexity. . . . In
the concluding experiment, an embryonic cross-in-
hibiting pair of such closed cycles was formed by
applying alternating periodic stimuli to two disjoint
input areas of $\mathfrak{M}$.

. . . Hebb's basic theory (especially the synapse-
growth law) is thus vindicated in terms of the given
models.   *From the Abstract*

ΘHART, RICHARD DRAKE.   13,351
An information processing model of the detection and use
of form properties. (Thesis)
Univ. Texas, Austin, Texas, 1964.

An information processing model was developed in
an attempt to relate mechanisms of stimulus input and
sensory processes to the detection of form properties
and other perceptual behaviors. The model contains
an explicit statement of assumed structures and
processes which are derived from an investigation of
anatomical and physiological characteristics of the
visual system. The essential characteristics of the
model, a computer program, are a set of cells and
processes of cell interaction. In addition, the model

provides unambiguous predictions of behavior in the
form of program output.

From cellular input of figures and processes defined
in terms of cell interaction, the model is capable of
detecting a set of form properties upon which to base
descriptions, comparisons, reproductions, set descrip-
tions, and judgments of complexity of input figures.
Processes of cell interaction also provide a basis for the
model to predict brightness contrast, grouping by
proximity and similarity, figural aftereffects, and
contour enhancement phenomena. Experimental re-
sults were presented which indicated the similarity
between form perception responses of the model and
human subjects.

The motivation behind constructing the model was
the belief that it is a proper concern of psychologists
to determine the relation between observed behaviors
and the structures and processes or organisms which
are responsible for these behaviors. Although the
model's processes and responses are simplified, it
represents an initial step toward unifying physiological
and psychological data into a single theory of form
perception.   *Abstract*

⊖KALAN, JAMES E.   13,569
Some results on amplitude damped vibrations. (Thesis)
Purdue Univ., Lafayette, Ind., 1967.

The real system

$$\ddot{x} + 2d(t, x^2 + y^2)\dot{x} - 2\omega\dot{y} + (\omega_n^2 - \omega^2)x = 0$$

$$\ddot{y} + 2d(t, x^2 + y^2)\dot{y} + 2\omega\dot{x} + (\omega_n^2 - \omega^2)y = 0$$

of ordinary differential equations describes the vibrations or deflections of an idealized whirling shaft maintained at a constant angular velocity. . . . For a generalization of the equations to the system

$$\ddot{Z} + 2D(t, \|Z\|^2)\dot{Z} + \mu Z = 0 ,$$

where Z is an n-vector valued function, D a continuous matrix, and μ a scalar, it is shown that in the context of an initial value problem the existence and uniqueness of twice continuously differentiable solutions is assured. . . . Some asymptotic properties are determined for the case in which the symmetric part of D is a scalar matrix independent of t. In the underdriven case, $\mu > 0$, it is proven that all solutions are bounded and the zero solution is uniformly asymptotically stable. In the critical case, $\mu = 0$, all solutions are bounded but the zero solution is only uniformly stable. In the overdriven case, $\mu < 0$, it is shown that for a certain restriction on the initial data the resulting solutions are unbounded. . . . The results are finally extended to include time-dependent amplitude damping. An application to a problem involving nonlinear material damping where the symmetric part of the damping matrix is a scalar given by

$$\phi(t, \|Z\|^2) = a + b \sup_{t' \in T(t)} \|Z(t')\|^2 ,$$

where $T(t) = [0,t) \cap T_i$, T_i being an interval of a partition of $[0,\infty)$ bounded in norm, confirms some experimentally determined conclusions such that a system in the overdriven case is unstable and that unbounded solutions exist. . . .   *From the Abstract*

⊖CAMPBELL, J. A.   13,331
Mechanisation of algebraic procedures in quantum field theory. (Thesis)
Univ. Oxford, Oxford, England, 1966.

A system of computer programs which performs symbolic operations characteristic of algebra and analysis has been developed from the basis of the programming language LISP 1.5. This system has been applied to the deduction of matrix elements in quantum electrodynamics from Faynman diagrams (especially those containing continuous connected internal paths, which imply integrations over at least one internal four-momentum variable), and in particular, to the calculation of radiative corrections to cross sections for electron/proton scattering. Numerical values of these corrections compare quite well with previously-calculated figures, but the improvements in detail achieved in the present work arise from the consideration of several algebraically complicated terms whose derivation would have been very difficult without the help of a digital computer.   *Abstract*

3.2 ENGINEERING

3.22 CHEMICAL

⊖SUSSENGUTH, EDWARD HENRY, JR.   13,741
Structure matching in information processing. (Thesis)
Harvard Univ., Cambridge, Mass., 1964.

[*Editorial note:* A paper partly based on this was reviewed as SALTON, GERALD G; and SUSSENGUTH, EDWARD H., JR. "Some flexible information retrieval systems using structure matching procedures" in *Proc. AFIPS 1964 Spring Joint Comput. Conf.*, Washington, D.C. (April, 1964), 587–597. Spartan Books, Baltimore, Md. $16; *CR* 6, 1 (Jan.-Feb. 1965), Rev. 6916; also as SUSSENGUTH, EDWARD H. "A graph-theoretic algorithm for matching chemical structure." *J. Chem. Doc.* 5, 1 (Feb. 1965), 36–43; *CR* 6, 4 (July-August 1965), Rev. 7812.]

A new technique for comparing structured data is presented in this thesis. In particular, an algorithm is developed which makes possible the efficient comparison of any two structures which can be represented by a graph, that is, by a collection of nodes with interconnections between certain pairs of nodes. The graphs can be tested to determine whether or not they are isomorphic (equal), or whether or not one is contained within the other as a specific substructure. . . .

Briefly, the procedure consists of determining certain simple properties of the nodes of the structures being tested. These subsets of nodes of the two structures which exhibit equivalent properties are equated. A standard procedure is then employed to reduce the subsets to other subsets with fewer members, and other procedures are used to generate new subsets from those which have been previously formed.

The structure-matching algorithm is described in detail and several examples illustrate its operation. It is proved that the algorithm converges and that a match is detected whenever one exists.

To determine the practical applicability of the algorithm, it has been programmed for the IBM 7090 computer. Experiments with this program indicate that the algorithm is useful as a practical structure-matching technique. Graphs with 50 nodes can be matched for isomorphism in six or seven seconds, and, if there is no match between the graphs, this fact can be detected in a few milliseconds in most cases. Moreover, it is shown that the computation time is proportional to the square of the number of nodes of the graphs; this is in marked contrast to the cut-and-try methods in which the time is an exponential function of the number of nodes. . . .

From the Abstract

ΘSCHWIEG, ZEEV.   14,653
An application of the dynamic programming method to the
    planning of the Taleghan conduit in Ghazvin area, Iran.
[in *Proc. 3rd National [Israeli] Conference on Data Process-
ing*, 17–19. See main entry *CR* Rev. 14,618.]

[*This paper summarizes the author's thesis for the degree
of Master of Science, submitted to the senate of the Technion
—Israel Institute of Technology, Haifa, 1966.*]

The Ghazvin Area is a semi-arid plain in the Iranian
Plateau, about 140 km. northwest of Tehran.

Water is rather scarce. . . . Apart from engineering plan-
ning of water works, the consultants are dealing with all
the other aspects of development: agricultural, industrial,
economic and organizational. . . .

The description of this proposal forms the essence of
the present thesis.

The first part of this work deals with methods of plan-
ning development projects in semi-arid regions, as ex-
perienced throughout Iran and in Ghazvin Area Develop-
ment Project in particular.

It is based mainly upon the publications of TAHAL,
Water Planning Ltd. (The Reconnaissance Report and the
latest Progress Report), and a book by J. P. Gittinger on
agricultural planning in Iran.

The author stresses the special advantage of the program
in that it enables comparison of many planning alterna-
tives in a short time, and also determination of sensitivity
of the results to changes in the basic data used. Due, how-
ever, to financial limitations, it was not possible to also
test the sensitivity of results of the three alternatives to
changes in discharges, prices, design-criteria etc.

. . . The author further suggests some improvements to
be included before it is put to practical use by TAHAL.

It is generally possible to apply this program to other
cases, although limited to more or less flat topographies.
Only slight changes in details of computations will have
to be introduced if technological conditions are much dif-
ferent from those of Ghazvin. Anyhow, the principle of
aqueduct-route optimization by the sequential optimiza-
tion process, using cross-sections of the area seems ap-
plicable to many similar problems.   *From the Summary*

3.3 SOCIAL & BEHAVIORAL SCIENCE

3.31 ECONOMICS

ΘVENTURA, JOSE M.   14,42:
The use of quantitative systems for macro-economic
    analysis. (Ph.D. thesis)
Columbia Univ., New York, N. Y., 1967.

This study is an application of quantitative sys-
tems for the purpose of reproducing economic
variables, and the utilization of the digital computer
for calculation of the relevant relationships within a
productive sector of a developing economy. The ob-
jective of the study is to generate endogenously . . .
the main economic variables of an industrial sector.
The material thus generated is compared with
statistical data of the period under consideration in
order to evaluate the outcome of the quantitative
system with respect to goodness of fit with historical
data. . . .

Chapter I explains the theoretical and methodolog-
ical aspects, specifically the problems encountered in
developing the structure of a system of the type
presented in terms of measurement and logical formu-
lation. The computational aspects are discussed and
the basic underlying assumptions are stated. . . . In
Chapter II the history of the economy under study is
discussed. . . . The evolution of the particular sector
of greatest interest for this work is also explained fully.
In this analysis interest is focused on the relationship
between the overall economy and the particular in-
dustry under study. The quantitative system, com-
prising a series of economically meaningful logical-
mathematical relationships, is presented in Chapter
III. . . .

Chapter IV discusses the results of the study. . . .
This analysis shows that, when compared to the his-
torical data, the simulated variables have a small
margin of error. Therefore, it may be concluded that
the system is sufficiently refined to produce accurately
the history of the period under study. It is also noted
that the system was able to develop full data series
that previously were not available.

The computer program used for this work demon-
strates how this study can be applied to problems of a
different nature; thus for example financial decision
making. . . . One possibly interesting suggestion for
financial analysis is found in the area of inter-industry
comparisons.

There are several appendices with information on
technical details, history, the program, and output
samples. There is an extensive bibliography of pub-
lications relevant to the study.   *From the Abstract*

⊙DENTON, WILLIAM BARRETT.   13,348
**An information processing model of human concept learn-
ing.** (Thesis)
Univ. Texas, Austin, Texas, 1965.

A critical analysis was made of certain already-existing accounts of concept learning. After an enumeration and discussion of various shortcomings in these accounts, an alternative theoretical treatment of concept learning was proposed—an information processing model. . . . The behavior of the model was then carefully observed over a range of concept learning tasks, and its behavior compared with that of humans in solving identical problems. . . .

After . . . isolating an initial set of strategies or elementary information processes which yielded a very accurate prediction of human performance curves, three other concept problems were devised.

These concepts differed among themselves in various ways, but the program generated a uniformly good prediction on each of them. . . . More interesting, however, was the effect of the instructions and problem variables on the classification of individual stimulus words. In many cases, it was possible to infer that, as a function of certain instructions and certain previous concept learning experiences, subjects were using one rule rather than another in their classifications of different stimulus words.

. . . In addition to the set of elementary information processes which produced fairly accurate simulations of the human data, several other concept learning strategies and processes were tried out in the program at various stages in the investigation.

. . . A concluding chapter was devoted to a comparison of the present information processing model with other similar models of concept formation—specifically, the systems of Hunt and Kochen.

In conclusion, it is suggested that the significance of this investigation lies in 1) the high degree of accuracy attained in the simulation of a very specific aspect of concept learning behavior, the classification of individual stimulus words; and 2) the demonstration that some elementary information processes or strategies were much more useful than others in producing a good simulation.   *From the Abstract*

⊙FELDMAN, JULIAN.   13,352
**An analysis of predictive behavior in a two-choice situa-
tion.** (Thesis) *Ph.D.*
Carnegie Inst. Tech., Pittsburgh, Pa., 1959.

A large number of articles in the recent psychological literature and several articles in the economic literature have been concerned with the behavior of people in a very simple experiment.

The subject in this experiment is asked to predict which of two alternative events will occur on each of a series of trials. After the subject makes his prediction, he is told which event actually occurred. Which event occurs is determined by the experimenter, usually in a random fashion, independently of the predictions of the subject. The subject is instructed to maximize the number of correct predictions that he makes.

This experiment will be referred to as the binary choice experiment. Despite all the literature devoted to this small area of human behavior, no adequate explanation of behavior in this situation has been made. The experiment was originally of interest because of its possible relevance to more realistic decision-under-uncertainty situations. However, the inability of the investigators to explain binary choice behavior has been sufficient to cause interest in the explanation of binary choice behavior *per se*.

This dissertation presents an explanation of binary choice behavior in the form of an information-processing model of human behavior. This model differs substantially from most of the models that have previously been offered to explain behavior in the binary choice experiment. Some of the models that have been presented in the literature are described in Chapter I. Chapters II, III, and IV each contain the analysis of the behavior of a subject in a binary choice experiment and a model of this behavior. Chapter V contains an outline of a general model of binary choice behavior and a discussion of the assessment of the model. In Chapter VI an effort is made to dispel some of the confusion that has been associated with binary choice behavior, and the relation of the proposed explanation of binary choice behavior to behavior in other situations is discussed.   *Abstract*

ΘKLATT, DENNIS H.   13,756
Theories of aural physiology. (Thesis)
Univ. Michigan, Ann Arbor, Mich., 1964.

The purpose of the investigation is to formulate and test theories of the physiology of the hearing process. Each theory pertains to a particular subdivision of the mammalian peripheral auditory system. A set of formal hypotheses are based on available information about the anatomy and physiological variables and related to auditory information encoding and processing in the peripheral ear and central nervous system.

The implications of the theoretical assumptions are deduced experimentally by employing homomorphic electronic analogs. When the behavior predicted by the theory agrees with relevant experimental data, then the formal system provides a useful model of certain aspects of aural physiology.

The study has resulted in the construction of electronic circuitry which models: 1) cochlear mechanics; 2) the encoding transformation which generates firing patterns on the primary auditory neurons; and 3) the processing of encoded information by second-order neurons of the cochlear nucleus. In each of these areas, the behavior of the model reveals the extent to which the theory is an adequate representation of the underlying physiological processes. In some cases, the model indicates certain of the directions which further experimental and theoretical work should take.

In the last section of the report, a formal representation of the information contained in neural firing patterns is proposed. A method of grouping neurons into response types is suggested, and certain average measures are defined over the fiber populations. These measures are shown to be a convenient representation of encoded information in the eighth nerve and the cochlear nucleus.   *From the Abstract*

ΘMINSKY, MARVIN L.   13,350
Theory of neural-analog reinforcement systems and its application to the brain-model problem. (Thesis) *Ph. Δ.*
Princeton Univ., Princeton, N. J., 1954.

This paper attempts a new approach to the problem of how the brain works. A series of "brain models" are developed as follows. The theory of neural nets is examined and the notion of "random net" is introduced. The nets are based, to a large extent, on established neurological data, both in the properties of the individual cells and in the manner in which they are interconnected. Each "brain-model" is composed of a small number of very large random nets with a small number of interconnecting channels between them. The behavior of these assemblies is examined, and it is shown that when they are embedded in appropriate environments, they evolve from their initial low level of organization into systems capable of manipulating their environments in a manner comparable to that of the higher animals.

. . . In applying the theory to higher animals, we consider models in which the evolution of a flexible "secondary" reinforcement system is directed by a much simpler and more rigid "primitive" reinforcement system. This "primitive" system is, in turn, under the direct influence of the "physiological internal state" of the "animal." The result is that the evolution of higher forms of behavior is biased in such a direction as to select activities which are most successful in maintaining the internal state within some "normal" domain.

It is felt that there is a close resemblance between the systems of this theory, and of higher animals, both in regard to their behaviors and in the nature of the structures responsible for their behaviors.

From the Abstract

⊖Weinberg, Gerald M. 13,750
Experiments in problem solving. (Thesis)
Univ. Michigan, Ann Arbor, Mich., 1965.

This thesis has a dual aim. First, it seeks to develop a method for precise recording and analysis of human behavior on a wide class of complex problems. Second, it seeks to apply the method to exploring the behavior of subjects on a specific set of concept formation problems.

The first two chapters of the dissertation explain the philosophy behind the experimental technique and show precisely how both general and specific experiments are set up. The third chapter develops the special analytical methods that must be used with the data generated.

Chapter IV gives a detailed analysis of each of the individual experiments of this study, reconstructing the decision structure the subject used to solve the problem, the strategy by which he arrived at that structure, and the relationship of his verbal report to that decision structure and strategy.

Chapter V presents findings which are common among the experiments. These findings include the demonstration of the underlying continuous nature of concept learning . . . and the formulation of a method for automatically predicting a subject's success or failure early in his work on a problem. In Chapter VI, these and other findings are related to diverse models of concept learning; models drawn from the point of view of basic learning, perception, and information processing, as well as the more recent algorithmic models.

Although the experimental findings lend support to many of the assumptions in these theories, no theory is found to be entirely satisfactory. Chapter VII concludes the thesis by showing how new experiments can be formulated which will resolve many of the outstanding difficulties with models of problem solving, concept formation, and verbal learning.

From the Abstract

3.4 HUMANITIES

3.42 Language Translation & Linguistics

⊖Allen, George Douglas. 13,581
Two behavioral experiments on the location of the syllable beat in conversation American English. (Thesis)
Univ. Michigan, Ann Arbor, Mich., 1966.

Rhythm is one of the elements of the prosodic level of speech. The basic units of rhythm, upon which are carried many other prosodic units, are points or intervals of time. . . . Native speakers of English feel the rhythm of their speech intuitively and can react consistently to the beat of a stressed or rhythmic syllable. The present work determined the validity of this rhythmic intuition and used it to locate the syllable beat.

Previous investigators of speech rhythm have located the syllable beat by tapping to the beat with a finger and by placing an audible click on the beat. The present work studied the reliability and validity of these two behavioral tasks as measures of syllable beat location. The investigation of reliability calibrated the variability among and within subjects in reacting to syllable beats, and identified different sources of variability. The validity studies were of two kinds: the first matched experimentally obtained differences in behavior with intuitively perceived differences in speech rhythm; the second abstracted from the experimental data rules for locating the syllable beat. . . . Because agreement was found between perceived stress rhythm and tapping behavior, it was concluded that conversational English has rhythm and might therefore be stress-timed. Since bias in the location of tapping can be calibrated, the time between successive beats in the rhythm of an utterance can be measured; therefore the hypothesis that English is a stress-timed language may be tested. *From the Abstract* ✓

⊖Chai, David T. 13,582
Communication of pronominal referents in ambiguous English sentences for children and adults. (Thesis)

Univ. Michigan, Ann Arbor, Mich., 1967.

An experiment was designed to investigate the linguistic performance of children and adults in using their unspecified grammar for resolving ambiguities. The ambiguities were contained in sentences constructed with more than one possible antecedent or referent. . . . The purpose of this investigation was to discover some parameters that the human subjects used in their process of resolving the ambiguity.

Three mathematical models are proposed to explain the observed results. The Bernoulli trials model partitions the entire set of sentences into two subsets, one containing the unambiguous sentences, the other containing sentences with ambiguous pronouns. The k-limited transducer model characterizes the human as a sentence processor with very limited memory. This model explains the degenerative behavior (tendency toward random responding) when sentences become more complex syntactically or when Ss are younger, other variables remaining constant. The information transmission model characterizes the Ss' task of reading each sentence and giving a response for the pronominal referent as a communication system. This model computes from group response data the *transmitted information* terms as measures of the degree of predictability of the pronominal referent.

The results of this experiment demonstrated that resolution of the ambiguous referent is possible from the structure of the sentence rather than from the immediate neighboring words. . . . *From the Abstract*

ⒽGIULIANO, VINCENT EDWARD. 13,357
An experimental study of automatic language translation.
(Thesis) *Ph D*
Harvard Univ., Cambridge, Mass., 1959.

This thesis is concerned with three major instruments for research in automatic language translation. The first instrument is a tested system of manual procedures and computer programs for compiling a Russian/English automatic dictionary on magnetic tape. The second instrument is a computer program that uses the automatic dictionary for the processing of Russian technical texts; it produces rough English translations and a number of byproducts valuable for research purposes. The third instrument, called *trial translator*, is a proposed system of computer programs that will enable linguists to test experimental syntactic algorithms necessary for the production of smooth and grammatical automatic translations.

The first two instruments have been tested and proven in actual operation; the first large-scale automatic dictionary has been compiled at the Harvard Computation Laboratory and is now being used for the processing of Russian texts.

Chapter 1 contains an introductory discussion of computers and automatic programming, and of the problems of automatic language translation.

Chapter 2 is concerned with the novel semi-automatic process used to compile the Harvard Automatic Dictionary. . . . The description in Chapter 2 covers the complete compilation process in its developed form. To the writer's knowledge, this is the first major system of semi-automatic lexicography to be described in the literature, and the only such system now operating.

. . . The second major research instrument, the operating program of the Harvard Automatic Dictionary, is described in Chapter 3. The program accepts, as inputs, a Russian text and the Russian/English dictionary file. It produces, in a single automatic computer run, a word-by-word translation of the text and a number of byproducts valuable for research purposes. . . .

. . . Word-by-word translations of Russian texts can be post-edited, to convert them into smooth and readable English translations. The post-editing of a Russian text is described in Chapter 4.

The third major instrument, the trial translator, is a proposed set of machine programs designed to place the computer more directly at the disposal of linguists and Slavic scholars. . . . The system, described in Chapter 5, represents independent research on the part of the writer; it has not yet been programmed or tested. *From the Abstract*

ⒽMcKINNEY, NORRIS PAUL. 13,760
Laryngeal frequency analysis for linguistic research.
(Thesis)
Univ. Michigan, Ann Arbor, Mich., 1965.

This study is concerned with the measurement of the rate of vocal fold vibration during speech production. The measurement is accomplished with a laryngeal frequency analyzer, which determines the laryngeal frequency from the speech wave. . . . The dissertation begins with the definition of basic and supplementary terms which are employed throughout the remainder of the study. . . . The literature relevant to laryngeal frequency analysis is then reviewed in detail. Reference standards for automatic laryngeal frequency analysis is considered, and it is concluded that the visual location of laryngeal period boundaries would provide the most suitable reference for the present investigation. Laryngeal frequency analyzers may be classified as either primarily time-domain or primarily frequency-domain systems according to the principles they employ. However, most analyzers utilize both filtering and nonlinear transformation.

Throat microphones are considered as possible signal detectors for laryngeal frequency analysis, but they are rejected in favor of microphones which respond directly to the speech wave. . . . One part of the investigation is a study of the effects of linear filtering and nonlinear transformation of the performance of preprocessors. Speech waves are linearly filtered; then they are nonlinearly transformed and harmonically analyzed by a digital computer. The harmonic analysis shows squaring and full-wave rectification to be more appropriate for increasing the relative level of the fundamental signal component than half-wave rectification or a logarithmic transformation.

A set of speech waves is processed through several experimental analyzers and the indicated laryngeal frequency was recorded oscillographically. A comparison of the records indicates that full-wave rectification is more practical than squaring, and that both peak detectors and zero crossing detectors are useful as basic extractors. . . . *From the Abstract*

ΘOETTINGER, ANTHONY G.   13,358
A study for the design of an automatic dictionary. (Thesis)
Harvard Univ., Cambridge, Mass., 1954. *PhD*

This thesis is a report on the first steps in the design of an automatic Russian/English technical dictionary and is believed to be the first published extensive experimental study in the machine translation of Russian.

The automatic dictionary is expected to accept Russian texts transcribed from printed pages, and to deliver printed English at the output. Hence the linguistic analysis required by this study is based exclusively on the orthography of printed Russian and English. A new theoretical framework is constructed on a strictly operational foundation especially adapted to the capabilities and limitations peculiar to machines.

The methods of logical design evolved in the study of mathematical machines are here applied in an original fashion to a natural language. The technique of "inverse alphabetization" exhibits the structural characteristics of printed Russian in a strikingly clear form. Logical expressions of the conditions under which certain significant affixes are to be separated from Russian words can be derived with little effort from inversely alphabetized lists. The techniques and the results developed in this connection should be of interest to structural linguists. The separation of these affixes leads to substantial savings in the storage required for the glossary of an automatic dictionary, and to a basis for automatic grammatical analysis.

A model of the texts to be produced by an automatic dictionary is constructed, and used to evaluate the effectiveness with which such texts can be used by monolingual English readers. The results indicate that the construction of an automatic dictionary would be of considerable practical value.

The application of a general-purpose digital computer to the study of the structure of Russian is described, and its use as a model of an automatic dictionary considered. Statistical data of value in the design of a prototype dictionary have been compiled as a byproduct. These should be of interest also to linguists and to students of information theory.

Abstract

ΘPLATH, WARREN JOSEPH.   13,759
Multiple-path syntactic analysis of Russian. (Thesis)
Harvard Univ., Cambridge, Mass., June 1963.

[*Editorial note:* A paper based on this was reviewed when published as "Automatic sentence diagramming" in Report No. NSF 6, Computation Laboratory, Harvard Univ., Cambridge, Mass., 1961, 126 pp.; *CR* 2, 6 (Nov.-Dec. 1961), Rev. 1183.]

A new system for the automatic syntactic analysis of Russian sentences is described in this thesis. The approach employed in the system, an extension of the method of predictive syntactic analysis, makes possible the production of multiple analyses of syntactically ambiguous sentences, as well as a more reliable treatment of sentences which are not syntactically ambiguous. Analyses are obtained through the systematic application of a set of rules, called a grammar table, which constitutes a description of syntactic structures that can occur in Russian.

The system incorporates a special-purpose language of grammatical indices; this language not only serves to express agreement and government relationships in the grammar table, but also makes the treatment of such relationships by the analysis program much easier. The operation of the system is described from both the technical and the linguistic points of view. In connection with the technical aspects of the system, several methods are presented for increasing the operating efficiency of the program; while surveys both of the content of the grammar rules and of the quality of the output produced are made as part of the description of the linguistic aspects of the system. A somewhat more detailed outline of this thesis appears in Chapter 1.

Both the Russian grammar table (including the compression techniques, the word classification scheme, and the system of grammatical indices), and the path-testing techniques of Sections 3 and 4 of Chapter 3, are the work of the writer. The writer also prepared a substantial proportion of the input texts processed, and designed and flowcharted the multiple-path analyzer program for Russian.

Abstract

ΘSHERRY, MURRAY ELLIOT.   13,583
Syntactic analysis in automatic translation. (Thesis)
Harvard Univ., Cambridge, Mass., 1960. *PhD*

This thesis is concerned with a method for the syntactic analysis of Russian sentences. Applied to automatic translation, this method is divided into a morphological word-by-word phase and a syntactical sentence-by-sentence phase.

An idealized canonical stem dictionary is presented, and its significant lexicographic properties are pointed out. This idealized dictionary then serves as a basis for evaluating the actual Harvard Automatic Dictionary. Aspects of morphological analysis of Russian, the construction of the new model of natural language and substantial aspects of the realization of an operating experimental syntactic analysis program represent efforts of the writer.   *From the Abstract*

3.54 MANUFACTURING; DISTRIBUTION

ΘCARROLL, DONALD CARY.   13,999
Heuristic sequencing of single and multiple component jobs. (Thesis)

M.I.T., Cambridge, Mass., June 1965.

The purposes of this research are to extend understanding of more realistic versions of the job shop sequencing problem, to propose and test heuristics designed to cope with some of the new complications, and to evaluate assess to a "global" data base in real-time, this being a requirement to support the more elaborate heuristics. The additional features of the job shop studied here are multiple channel work stations and multiple component orders, i.e., orders

involving assembly operations. The former introduces channel availability time as relevant data for sequencing, the latter, measurements of relative progress of components (something similar to "critical path" information).

The basic model is similar to those used previously. It assumes, among other things, known processing times, nearly "pure" job shop routings, continuous manning of work stations, and sequence-independent setup costs. Exponential arrivals and service times are assumed for the most part; order release times and due dates are exogenously supplied. A departure is made from previous practice by assuming that early (i.e., prior to due date) shipments are not permitted and that all orders incur tardiness penalties at the same (linear) rate. Since all sequencing systems are submitted to the same inputs, a single measure of effectiveness, namely, mean order tardiness, is thereby established.

The sequencing system proposed here, called COVERT (for "c over t"), is based on a theorem by Wayne Smith (and others) to the effect that to sequence n jobs through a single machine, given that delay cost rates c_i and processing times t_i are known, the minimum delay cost is obtained by sequencing by decreasing c_i/t_i ratio.

... The experimental medium is a digital simulation program developed by the author. Considerable effort is taken to rationalize the solutions to "tactical problems" noted by Conway as inherent in simulation experimentation. ...   *From the Abstract*

3.51 EDUCATION; RESEARCH

ΘKELLER, MARY KENNETH (Sister).   13,779
Inductive inference on computer-generated patterns. (Thesis)

Univ. Wisconsin, Madison, Wisc., 1965.

This thesis constructs a set of subroutines in CDC FORTRAN 63 which can be used efficiently for the syntactic analysis of input strings representing algebraic expressions. A program for performing analytic differentiation in accordance with this mode of analysis is developed. These preliminary operations are used to generate a pattern for examination with the expectation of predicting a subsequent configuration. A method of examining and evaluating this pattern of change is implemented which leads, by induction, to the construction of an algorithm for an nth derivative of the input expressions.   *Abstract*

ΘSAURE, WALDEMAR.   13,588
A single-machine scheduling problem in the box container industry. (Thesis) *Master's Thesis*

Lehigh Univ., Bethlehem, Pa., 1967.

The single-machine scheduling problem for a box container plant is defined. The problem is to assign orders to a printing press, which can be formulated in a linear programming framework. The resulting matrix, however, is too large for any realistic set of data to be computed in a reasonable time on a computer.

Hence the approach taken is to use suboptimizing algorithms. Two algorithms are devised and tested with simulated data. An efficiency quotient is defined to evaluate the resulting production schedules against an ideal, normally not attainable schedule. Some of the generated schedules are uneconomical in the sense that high production cost would be incurred if implemented. This is due in part to a constraint placed upon them, which requires all orders to be filled exactly. In actual practice, production scheduling is more flexible, i.e., orders can be over or under shipped.

The efficiency quotient of the production schedules developed by the two algorithms averages around 0.97. This result gives cause for optimism, since the underlying view of this study is that future production scheduling systems in the industry will be computerized systems.   *Abstract*

ΘSTEVENSON, HSIOH-FAN.   14,456
Scientific inventory control: theory and application. (M.S. Thesis)

Univ. Tennessee, Knoxville, Tenn., 1967.

The basic inventory control system is designed to answer the twin questions of managerial policy of "how much" to order by setting proper order quantities, and "when" to order by establishing reorder points. In establishing order quantities and reorder points, the system has as its "objective function" the minimization of the total of holding, ordering, and shortage costs—conflicting objectives in that reducing any one cost increases the size of at least one of the others.

This study reviews the literature relating to the modern concepts of scientific inventory control and sets up a simple but typical inventory management system by means of analytical formulas and a FORTRAN IV program for an IBM 7040 computer. The purpose of the exercise is

less to extend the scope of present techniques than to review the groundwork that has already been laid and to design an inventory control system which, though simple enough for the average businessman to understand, represents a significant advance toward greater operating efficiency when compared with traditional procedures. ...

This thesis is concerned only with the operating control questions of when and how much to order. ...

The thesis first develops the basic economic order quantity model under conditions of known demand and zero lead time. It then considers the determination of reorder points as these and other simplifying assumptions are systematically relaxed. ...

The conclusion recommends the use of inventory control models for integrated system control as opposed to mere record-keeping, attempts to synthesize the economic order quantity and optimum reorder point models by the construction of a total cost minimizing model of inventory control, and presents suggestions for extending the analysis in ways which would get around some of the limitations imposed by the nature of the study.

From the Abstract

ⴲSALTON, GERARD A.   13,391
An automatic data processing system for public utility revenue accounting. (Thesis) *Ph.D.*
Harvard Univ., Cambridge, Mass., 1958.

The data processing equipment presently available is well suited only to the first type of process where substantially the same sequence of operations is applicable to all accounts and no file rearrangement is needed. . . . The investigation of customer accounting operations undertaken in this thesis leads to an automatic system based on a single customer file. Access is obtainable to any part of the file in a reasonably short amount of time so as to permit the satisfaction of random requests as well as the processing of the routine billing operations. Exceptions are not allowed to interfere with the processing of the vast majority of standard cases, and machine programming is simplified.

Present customer accounting procedures are examined in Chapter One. The regulations covering the operations of public utility companies are described, and the main characteristics of the accounting processes are given. . . . The inputs and outputs of the revenue accounting process are analyzed in Chapter Two. . . . In Chapter Three various kinds of automatic equipment are examined and an evaluation is made of equipment characteristics for potential use in a customer accounting system. . . . The proposed customer accounting system is described in Chapter Four. Two alternative systems are suggested, one based on the use of tape bins for data storage, and the other on the use of magnetic cards as a storage medium. . . . Under the proposed system, flexibility is obtained by storing inactive programs in data storage and by separating the exceptional cases from the bulk of the accounts. However . . . it is suggested that the accounting problem be broken down into subroutines to be handled by different programmers; these routines can be assembled automatically. Special programming devices for replacing decision operations by straight-line arithmetic calculations are also briefly discussed.

From the Abstract

ⴲERNST, HEINRICH ARNOLD.   13,392
MH-1, a computer-operated mechanical hand. (Thesis)
Harvard Univ., Cambridge, Mass., 1961. *Ph.D.*

. . . In this study, instead of using the digital computer as a tool during the execution of human thought processes that are ultimately concerned with the real world, we wish to let the computer deal directly with the real world by itself, beginning with the perception of the real world and the appreciation of it, and ending with the performance of a purposeful, active task in the real world.

As a vehicle for this experimental study a mechanical servomanipulator has been adapted for operation by the TX-O computer. The sense organs of this mechanical hand feed information into the computer; the program processes this information, and the computer controls the motors that move the hand. The difference between this system and a conventional control system (for instance, a numerically controlled machine tool) is that the MH-1 system performs more than just the classical control functions, such as position control or speed control, in accordance with a prerecorded program that has been written by a human programmer after a careful analysis of the task and the environment. MH-1 itself performs automatically some of this analysis of the real world with respect to the broad description of the task to be performed. Thus it can select appropriate routines by itself and find out what to do in unexpected situations for which the programmer has not provided an explicit instruction.

The most important aspects of this coupling of the machine and the real world which have emerged during the work concern, first, the interrelation between the sense organs and the programming language, and second, the concepts of awareness and understanding. . . . Awareness is defined as the possession of an internal representation of the actual state of the outside world plus the ability to compare this representation with an internal representation of the desired state of the outside world. . . . Understanding is defined as the capability of relating a model to the real world.

From the Abstract

3.6 ARTIFICIAL INTELLIGENCE
3.60 GENERAL

ⵔBLACK, FISCHER.   13,596
A deductive question answering system. (Thesis)
Harvard Univ., Cambridge, Mass., 1964.   *Ph D*

... I decided to try to develop a deductive system
with the following properties:
1) it can be programmed effectively for a digital
   computer;
2) it is relatively easy to translate from mathe-
   matical or everyday language to the language
   used by the deductive system;
3) it is oriented toward answering questions rather
   than proving theorems; and
4) it is not restricted to a specific subject matter.

After several versions of the system had been written
and were working correctly, I discovered that the sys-
tem was close to being the "advice taker" proposed by
McCarthy. At this time I adopted the formal language
suggested by McCarthy for the advice taker. The sys-
tem was able to handle the "airport problem" and two
other problems—the "monkey problem" and the "Mi-
kado problem"—developed by McCarthy and his
group at Stanford, as typical problems for the advice
taker.

Comparing the system with the "Logic Theorist,"
which finds proofs for theorems in the propositional
calculus, I found a basic similarity of structure. By
putting it in a single statement plus the necessary
theorems, I enabled the system to "prove" theorems
by a method very much like the method the logic
theorist uses. In particular, the system can prove at
least one of the theorems the logic theorist could not
prove. Since the system does not prove theorems ex-
plicitly, the "proof" is implicit in the deductive process
that results when the theorem is taken as a question
and answered.

Finally, I have begun to study some ways of improv-
ing the efficiency of the system by rewriting statements
and by setting up a hierarchical classification of state-
ments. Improving efficiency seems to be the most
promising area for future research. ...

From the Abstract

ⵔBOBROW, DANIEL G.   13,594
**Natural language input for a computer problem solving
system.** (Thesis)   *Ph D*
M.I.T., Cambridge, Mass., 1964.

The STUDENT problem-solving system, pro-
grammed in LISP, accepts as input a comfortable but
restricted subset of English which can express a wide
variety of algebra story problems. STUDENT finds the
solution to a large class of these problems. STUDENT
can utilize a store of global information not specific to
any one problem, and may make assumptions about
the interpretation of ambiguities in the wording of
the problem being solved. If it uses such information,
or makes any assumptions, STUDENT communicates
this fact to the user.

The thesis included a summary of other English
language question-answering systems. All these sys-
tems, and STUDENT, are evaluated according to four
standard criteria.

The linguistic analysis in STUDENT is a first approxi-
mation to the analytic portion of a semantic theory of
discourse outlined in the thesis. STUDENT finds the set
of kernel sentences which are the base of the input dis-
course, and transforms this sequence of kernel sen-
tences into a set of simultaneous equations which form
the semantic base of the STUDENT system. STUDENT
then tries to solve this set of equations for the values
of requested unknowns. If it is successful it gives the
answers in English. If not, STUDENT asks the user for
more information, and indicates the nature of the de-
sired information. The STUDENT system is a first step
toward natural language communication with comput-

ers. Further work in the semantic theory proposed
should result in much more sophisticated systems.

Abstract

ӨEvans, Selby H.   13,795
A model for perceptual category formation. (Thesis)
Texas Christian Univ., Fort Worth, Texas, 1964.

The purpose of this investigation was the development and preliminary testing of a model for perceptual category formation in the absence of information as to the correctness of category assignment. The development was based on the assumption that potentially useful categories are indicated in the visible environment by association with a large number of covarying perceptual characteristics. A theoretical machine was proposed to describe a process by which category formation consistent with this assumption could occur. The theoretical machine was developed under restrictions intended (1) to make the machine compatible with a statistical model for learning, and (2) to facilitate the exploration of relationships between the requirements of the model and neurophysiological theory.

Investigation of the basic assumption entailed for [sic] preparation of a computer program which could generate patterns having the characteristics specified by the assumption. The theoretical machine was then simulated in the form of a computer program and presented with the patterns; the machine demonstrated that it could indeed form categories consistent with the basic assumption. The patterns were also presented to human subjects with the request that they assign the patterns to one of two categories. Some, but not all, of the human subjects showed a significant tendency to categorize in a fashion consistent with the assumption. An effort was made to find parameters for the model which would cause it to produce categorizing performance similar in detail to that of the human subjects. Some gross correspondences between the two performances were achieved, but the model exhibited an irremediable tendency to achieve consistent categorization more rapidly than humans did. Consideration of the requirements imposed on the human and the model suggested that the model had a less difficult task than did the humans and might more nearly approximate the human performance if the model were modified to allow it to undertake a task more nearly comparable to that of the human subjects.   *Abstract*

ӨEvans, Thomas George.   13,794
A heuristic program to solve geometric-analogy problems. (Thesis)
M.I.T., Cambridge, Mass., 1963.

A program has been constructed for solving a wide variety of intelligence-test problems of the "geometric-analogy" type: "figure A is to figure B as figure C is to which of the following figures?" The program, which is written in the Lisp language, uses heuristic methods to calculate, from relatively primitive representations of the input figures, descriptions of these figures in terms of subfigures and relations among them. It then utilizes these descriptions to find an appropriate rule and to apply it, modified as necessary, to arrive at an answer. The program has solved a large number of such problems, including many taken directly from college-level intelligence tests.

The novel organization of the program in terms of figure descriptions, which are analyzed to find transformation rules, and rule descriptions, which are analyzed to find "common generalizations" of pairs of transformation rules, has implications for the design of problem-solving programs and for machine learning. These implications are discussed at length and a specific proposal is made for work on pattern-recognition and learning techniques based on ideas developed in the course of the present investigation.   *Abstract*

ӨFeigenbaum, Edward A.   13,793
An information processing theory of verbal learning. (Thesis)
Carnegie Inst. Tech., Pittsburgh, Pa., Dec. 1959.

This paper presents a theory of some elementary forms of human symbolic learning—memorization, discrimination, association, and attention direction. This theory is concerned with mental activity at the level of the processing of information symbols, which are the basic units manipulated.

The precise statement of the theory is given in the language of a digital computer, specifically as a set of programs in IPL-V, called EPAM.

The paper deals generally with information structures and processes for discrimination and association learning, and specifically with behavior in the standard rote learning task. A number of implications of the theory in rote learning situations are explored; comparisons are drawn between the behavior of human subjects in these situations and the behavior of the Epam model.   *Abstract*

⊖WYNN, WILLIAM HAROLD. 13,595

An information-processing model of certain aspects of paired-associate learning. (Thesis)

Univ. Texas, Austin, Texas, 1966.

A theoretical model was designed to account for certain aspects of pattern-recognition, information retrieval, and associative memory as revealed by human subjects engaged in the paired-associate learning of nonsense syllables. The model is concerned with mental activity at the level of the processing of information symbols. Called WEPAM (for Wynn's Elementary Perceiver and Memorizer), the model is a modification of Feigenbaum and Simon's EPAM model. . . .

The WEPAM model was designed to overcome the above shortcomings of the EPAM models, as well as their failure to account for such well-established phenomena as proactive inhibition, effects of overlearning, and reduction of reaction-time with practice. . . . While an item in EPAM's memory may be retrieved only by means of a single, predetermined sequence of tests applied to an input stimulus, WEPAM provides for multiple retrieval pathways that may converge upon the same item in memory, thus permitting different fractional parts of an item to elicit its retrieval from memory. WEPAM also incorporates incidental learning by which its retrieval structure is augmented while classifying an object to permit more efficient retrieval later. . . .

Run on the same lists given the subjects, WEPAM's performance closely approximated that of the subjects in number of trials to criterion, total errors to criterion, errors of stimulus and response generalization, and success in stimulus redintegration. . . . *From the Abstract*

⊖COLLINS, JOHN S. 13,393

The processing of lists and the recognition of patterns with application to some electrical engineering systems. (Thesis)

Queen Mary College, Univ. London, London, England, 1964.

The possibility of using a general-purpose digital computer for essentially nonnumerical tasks has long been recognized. It was not, however, until the development of list-processing languages for specifying such procedures that computers were used to any extent for the solution of symbolic rather than numerical problems. A program which solves a class of symbolic problems is written in one such list-processing language. It uses Kirchhoff's laws to transform the symbolic description of a network and a statement of the desired results into an algorithm for producing the numerical values of the desired results from the numerical values of the network parameters.

Much of the rather disconnected work which has been carried out in recent years under the general heading of artificial intelligence is brought together to develop a method by which a process may be specified to a computer by a set of representative examples. The method is demonstrated by two specially written computer programs. One program is concerned with hypothesizing on the nature of relationships existing in a multivariable system from representative measurements on the system. The second program is designed to construct logical networks to have specified properties. It demonstrates the use of a "human subroutine" by which a computer can generate its own program from observations on the behavior of a human operator. *Abstract*

⊖WINDEKNECHT, THOMAS G. 13,597

A theory of simple concepts with applications. (Thesis)

Case Inst. Tech., Cleveland, Ohio, 1965.

A theoretical study leading toward the solution of a class of inventory problems by digital computation is reported. Using a formal model of concepts in the activity of object recognition due to Banerji, a theory of simple concepts is constructed. The algebraic structure of the class of simple concepts is developed. A relationship between the formal notions of relevance and simplicity on the set of concepts is proved. The simple concepts are shown to be precisely that class that can be learned by certain focusing strategy. Consideration of the characteristics of the set of simple concepts leads to a new technique for concept description, which is presented as a formalism. Progress on a concept learning machine based upon the proposed formalism for concept description is discussed. The machine will have a formidable capacity for self-organization, and appears to be applicable for solution of some of the inventory problems discussed. *Abstract*

ΘBLACK, RICHARD H. 13,798

A method of pattern recognition by machine. (Thesis)
Univ. Wisconsin, Madison, Wisc., 1963.

In this paper, any procedure for recognizing patterns is treated as an evaluation of a function of a set of properties of the pattern—a set of properties considered sufficient to represent the pattern. This *recognition* function is invariant over sets of properties belonging to patterns of the same class. The function values differ for patterns from different pattern classes. The property sets and the function values are both assumed to be expressible as vectors of real numbers.

Attention is directed toward patterns that are positive area subsets of a square. Some recognition functions used by others are discussed and reinterpreted as transformations of any pattern of a class to a unique canonical pattern for the class. Two assumptions, basic to the methods of this paper, are: 1) a sufficient property set for all such patterns is the set of $2m$ x and y coordinates of a fixed number m of points of the square; and 2) in a metric pattern space derived from the first assumption, the transformation of a pattern to the canonical pattern of its class can always be done continuously along a connecting arc.

Also considered are procedures by which a machine can *learn* a recognition function which when applied agrees with the preclassification of a sample set of patterns each presented to the machine along with a class designation. It is shown that certain assumptions, about the regions in pattern space occupied by all patterns of the same class, are sufficient for such a recognition function to extend to nonsample patterns. ✓ *Abstract*

ΘDAMMANN, JAMES EDWARD. 13,598

Studies in the application of adaptive threshold devices to the recognition of acoustic-phonetic states. (Thesis)
Univ. Michigan, Ann Arbor, Mich., 1964. *Ph D*

The relation of acoustic/phonetic states to the problem of speech recognition is discussed. It is suggested that a first step toward understanding the dynamics of the speech signal could be made by recognizing a small number of acoustic/phonetic classes.

Adaptive threshold elements are proposed as a means of recognizing these classes, and a method of utilizing the adaptive threshold elements in a decision procedure is presented.

The means employed to gather the data representing the classes consists essentially of taking amplitude samples from a bank of 15 filters at $10ms$ intervals. Samples obtained in this manner are used as input for the adaptive decision procedure which is simulated in a general purpose computer.

Samples representative of each class are used to train the adaptive decision procedure, and the capability to generalize to new samples is observed.

For one speaker, generalization results of 92% correct sample classification were achieved, and generalization from one speaker to another was demonstrated. It was further shown that the selection of an output code can significantly affect the generalization and that sequences of recognized samples can represent dynamic changes through words. ✓ *Abstract*

ΘHANNE, JOHN R. 13,801

Formant analysis. (Thesis)
Univ. Michigan, Ann Arbor, Mich., 1964.

This dissertation is concerned with the basic properties and with the analysis of formants in speech. The dissertation is organized according to three main areas: overall perspective, theoretical considerations, and a scheme for measuring voiced speech formants.

. . . As a basis for the discussion . . . the analysis of the output of a simple resonator is considered in detail. The analysis presented here differs from most speech analyses in that it is synchronous with the laryngeal pulses. Attention is then centered upon the parameter values associated with speech. Next, two forms of speech analysis are discussed in terms of the model presented. A theoretical comparison of the errors introduced by each of the systems is included.

Finally, a feasibility study was made of a fixed filter, pitch synchronous form of formant estimation. In the feasibility study the possibility of automatically detecting the fundamental period, and of tracking the first formant that a formant estimate derived from a portion of a period, would provide sufficient formant information for most uses. Thus, the sampling frequency for the formant measurements is the fundamental frequency. The approach employs a combination of analog and digital techniques. Speech is first processed by wide-band, overlapping filters, which are spaced so that all frequencies about 300 cycles occur in the pass-band of two different filters. The analog part of the process is a form of frequency domain analysis. The formant estimation technique is a pitch synchronous technique in which successive samples of the speech wave are analyzed in the digital computer at the spacing of the fundamental voice frequency. The results of analyzing various speech inputs are presented.

From the Abstract

ⵙKASHYAP, RANGASAMY L.   13,397
Pattern classification and switching theory. (Thesis)
Harvard Univ., Cambridge, Mass., 1965.

... A pattern classification problem consists of three fundamental aspects; namely, characterization ... abstraction ... generalization. ... The abstraction aspect of the problem, which is the main topic of the discussion here, can be stated briefly as follows: Given the vector x of primary attributes a set of samples $x_C^{(i)}$, $i = 1, ..., n_C$ belong to class C and another set of samples $x_D^{(i)}$, $i = (n_C + 1), ..., N$, belonging to class D, we wish to determine a function $f(x)$ such that

(i)
$$f(x_C^{(i)}) > 0 \quad \text{for} \quad i = 1, \cdots, n_C$$
$$f(x_D^{(i)}) < 0 \quad \text{for} \quad i = (n_C + 1), \cdots, N.$$

... In order to make the abstraction problem mathematically tractable, we will parameterize the function $f(x)$ in terms of certain functions $\varphi_i(x)$:

(ii)
$$f(x) = \sum_{i=0}^{n-1} \alpha_i \varphi_i(x).$$

The two basic questions which naturally arise at this juncture, and which are the primary concern of this thesis, are posed below:

(A) Given the functions $\varphi_i(x)$, how does one determine the coefficients α_i so that the function $f(x)$ satisfies (i)?

(B) If the functions $\varphi_i(x)$ are now known, how does one select them for any problem, and hence determine the decision function $f(x)$?

Chapter 1 ... outlines the main facets of the theory of pattern classification. ... An answer is presented to question (A) ... in Chapter II. ... Both questions (A) and (B) are answered in Chapters III and IV. Chapter V provides a partial answer to question (B). ... In Chapter VI, the methods of solution of switching problems developed in earlier chapters are applied to the design of a real-time function generator. Some suggestions for further research are contained in Chapter VII.

From the Abstract

ⵙLEE, FRANCIS FAN.   13,799
A study of grapheme to phoneme translation of English. (Thesis)
M.I.T., Cambridge, Mass., Nov. 1965.

The result of this thesis research is the identification and development of an efficient scheme for automatic translation of English text from letters to phonemes. The motivation arises from the specific desire for artificial-speech outputs from reading machines and also from the general desire to provide background for modelling the cognitive processes involved in human reading and speech.

In order to determine whether phonic rules can be generalized to the extent that an algorithmic approach of grapheme (primarily letter spellings) to phoneme translation can be implemented for a reading machine, a body of 17,777 most commonly used English words together with their pronunciation in General American was processed and placed in various forms so that graphemic context was plainly observable. It was found that while the consonant letter mapping relationship is more regular, vowel letter mapping is heavily dependent on the root word and suffixes. A detailed study of the cases of the paradigmatic suffixes [-ed, -er, -ing] revealed that the algorithmic approach, even when supplemented by large exception lists, not only leads to extreme complications, but leaves many serious problems unsolved.

The study led to the belief that phonic rules do not play a significant part in the mature reader's reading habit. His reading capability is based principally on the existence of the learned morpheme lexicon and the application of morphophonemic rules. Furthermore, it is believed that in reading unfamiliar words or nonsense words, morphophonemic rules are applied to the parts which agree with bound morphemes, if any, and phonic rules are then applied to the remaining unfamiliar or pseudo-morpheme. These phonic rules depend on personal experience and differ among individuals thus accounting for the variation of responses to nonsense words.   *Abstract*

⊖Reddy, Dabbala Rajagopal.   13,800
An approach to computer speech recognition by direct analysis of the speech wave. (Thesis)
Stanford Univ., Stanford, Calif., 1966.

... After an introduction in Chapter 1, in Chapter 2 we discuss the requirements of a usable computer system for speech research, its input/output configuration, and the design of a suitable man/machine communicative system. ... An interconnected IBM 7090-PDP-1 disk system was used in this investigation. In Chapter 3 we tell how the program divides a two-second speech utterance into segments approximately corresponding to phonemes, determines the pitch of those segments when this is appropriate, and computes a list of parameters for each segment that is later used to assign phonemic values. In Chapter 4 we tell how phonemes are associated with segments of speech.

... Chapter 5 contains the results of classification of 32 sounds of 1 to 2 second duration and the error analyses. These sounds consist of nonsense sounds such as "raareeroorehro," where each consonant is combined with various vowels, and meaningful sounds such as "John has a book" or "one two three." The intended phonemes, viz., "J AA N H AE X EH B U K," and the computer phonemes, vix., "J AA M AE Z EH B U K," are given for each sound. Confusion matrices are given for phoneme subgrouping and final classification. About 81% of a total of 287 phonemes were classified correctly. The time taken for phoneme generation by the IBM 7090 starting from the raw speech wave of each sound varied from about 40 to 75 seconds for 1 to 2 second samples.

The flexibility offered by the computer system and the ease of experimenting with various new ideas was mainly responsible for the success of this investigation. No claim is made that the problem of phoneme recognition is completely solved. However, the approach used here appears to be very fruitful and points to a new direction which is likely to be more successful than the previous ones. ...

From the Abstract

⊖Scott, Robert James.   14,019
Temporal effects in speech analysis and synthesis. (Thesis)
Univ. Michigan, Ann Arbor, Mich., 1965.

This investigation is concerned with adjustment of the time domain in speech. Various of adjustments of the time dimension in speech are possible, but their implementation requires an effective instrumental technique. ... Two major methods of adjusting the time domain of speech were investigated. One was linear time normalization in which the time scale is expanded or compressed by a constant factor. The second method employs a nonlinear measure of "arclength."

In the experiments conducted the distribution of special energy was derived by scanning the outputs of a bank of 16 vocoder analyzer filters. A hybrid computing facility was the primary tool employed in the research. The system consisted of a digital computer and several special analog devices including an analog channel vocoder. The computer was used to simulate the various methods of speech time compression, including the Fairbank's method.

The perceptual effects of time-adjusted synthesized utterances were investigated in an intelligibility test. It is not only possible to perform a linear or nonlinear time normalization of utterances processed through the vocoder analyzer, but it is also possible to regenerate the normalized utterances with the vocoder synthesizer. A dichotic method of time-compression of speech was investigated which makes information available to the ear which is lost when the Fairbank's method of time compression is employed.

It was found that the hybrid computing system provided a highly flexible technique for time adjusting speech. A comparison of the linear and non-linear methods of time normalization suggests that the arclength method may be superior for use in automatic speech recognition. A number of potential applications of time adjusted speech and possibilities for future research are suggested in the dissertation.

From the Abstract

⊖Stanat, Donald Ford. 14,017
Nonsupervised pattern recognition through the decomposition of probability functions. (Thesis)

Univ. Michigan, Ann Arbor, Mich., 1966.

Two problems of parametric statistics are investigated with a view to their application to nonsupervised pattern cognition. . . . The first problem investigated is that in which all summand functions are distinct multivariate normal functions with arbitrary means and covariance matrices. A method of decomposing $f(X)$ uniquely is given for the case where $f(X)$ is known exactly. The method involves the reduction of the multivariate problem to a set of univariate problems. . . . The second problem investigated is concerned with finite mixtures of probability functions over the set of binary n-tuples. In particular, each of the summand functions is assumed to be the joint probability function of n dichotomous independent random variables; such a function is called a multivariate Bernoulli function. The sum function $F(X)$ can then be described by

$$f(X) = \sum_{\alpha=1}^{r} w_\alpha \prod_{i=1}^{n} p_\alpha, \qquad i^{(1-x_i)} q_\alpha, \qquad i^{x_i},$$

where $q_\alpha, i = 1 - p_\alpha, i$ and x_i denotes the ith entry of the binary vector X, where $x_i = 0$ or 1. It is assumed that $p_\alpha, i \neq \frac{1}{2}$ for all α, i. The function $f(X)$ is called spherical if $\frac{1}{2} - p_\alpha, i \mid = \mid \frac{1}{2} - p_\alpha, j$ for all i and j. The functions $f_\alpha(X)$ and $f_\beta(X)$ are said to be identical except for translation if $\mid \frac{1}{2} - p_\alpha, i = \mid \frac{1}{2} - p_\beta, i$ for all i. Four cases are investigated. . . . The discrete Fourier transform is used in obtaining the solutions. The problem of estimating $f(X)$ and its discrete Fourier transform is investigated; unbiased and consistent estimates are found for the function values. *From the Abstract*

3.64 Problem-Solving

⊖Raphael, Bertram. 13,803
SIR: a computer program for semantic information retrieval. (Thesis)

M.I.T., Cambridge, Mass., June 1964.

[*Editorial note:* A paper based on this was reviewed when published as "A computer program which understands" in *Proc. AFIPS, 1964 Fall Joint Comput. Conf.*, 577–589. *CR* 6, 2 (March-April 1965), Rev. 7207.]

SIR is a computer system, programmed in the Lisp language, which accepts information and answers questions expressed in a restricted form of English. This system demonstrates what can reasonably be called an ability to "understand" semantic information. Sir's semantic and deductive ability is based on the construction of an internal model, which uses word associations and property lists for the relational information normally conveyed in conversational statements.

A format-matching procedure extracts semantic content from English sentences. If an input sentence is declarative, the system adds appropriate information to the model. If an input sentence is a question, the system searches the model until it either finds the answer or determines why it cannot find the answer. In all cases Sir reports its conclusions. The system has some capacity to recognize exceptions to general rules, resolve certain semantic ambiguities, and modify its model structure in order to save computer memory space.

Judging from its conversational ability, Sir is more "intelligent" than any other existing question-answering system. The author describes how this ability was developed and how the basic features of Sir compare with those of other systems.

Sir is a first step toward intelligent man/machine communication. The author proposes a next step by describing how to construct a more general system which is less complex and yet more powerful than Sir. This proposed system contains a generalized version of the Sir model, a formal logical system called Sir 1, and a computer program for testing the truth of Sir 1 statements with respect to the generalized model by using partial proof procedures in the predicate calculus. The thesis also describes the formal properties of Sir 1 and how they relate to the logical structure of Sir. *Abstract*

Θ Slagle, James Robert. 13,804
A heuristic program that solves symbolic integration problems in freshman calculus, symbolic automatic integrator (SAINT). (Thesis)
M.I.T., Cambridge, Mass., 1961.

[*Editorial note:* A paper based on this was reviewed when published as *A heuristic program that solves symbolic integration problems in freshman calculus, symbolic automatic integrator* (*SAINT*). Lincoln Lab., M.I.T., Lexington, Mass., 5G-0001 (May 1961), 110 pp.; *CR* **3,** 6 (Nov.-Dec. 1962), Rev. 3068.]

Some ideas about problem solving by a machine were tried out on the nontrivial problem domain of elementary symbolic integration. To this end, the author programmed a large, high speed, general-purpose digital computer (IBM 7090) to use these ideas to solve some symbolic integration problems. The computer so programmed is called SAINT, an acronym for "symbolic automatic integrator." SAINT performs symbolic integration which includes indefinite integration. It also performs definite and multiple integration when these are trivial extensions of indefinite integration. SAINT solves symbolic integration problems approximately at the level of a good college freshman and, in fact, uses many of the same methods (including heuristics) used by a freshman. Taking an average of two minutes per problem, SAINT solved 52 (96%) of the attempted 54 MIT freshman calculus final examination problems. The author draws many conclusions from this and other experiments with SAINT and makes suggestions for future work in the field of artificial intelligence. *Abstract*

Θ Williams, Thomas G. 13,599
Some studies in game playing with a digital computer. (Thesis) *PhD*
Carnegie Inst. Tech., Pittsburgh, Pa., 1965.

The general trend in artificial intelligence is to try to write programs that have general problem-solving ability, rather than ones that are particularly good at one specific task. The program described in this dissertation is designed to play a large number of common board and card games.

To play a game in this system, it is necessary to describe the objects used in playing the game and the rules of the game to the system. Each object used in the game is represented by a symbol. The properties of that object are kept on a property list associated with that symbol. The rules of the game are represented by a sequence of "if-then" statements. The "if" portion of the statement describes a situation that can occur in the game; the "then" portion describes the action to be taken if that situation actually exists. Each situation and each action is described in terms of a primitive function of the system.

An important part of any game playing program is the routine for searching for the various conditions that can arise in a game. This system contains a fairly efficient general searching routine which will perform most of the searching necessary for any of the common board games. This routine contains some useful automatic methods for using the results of past searches to reduce the amount of searching actually done.

An analysis of the concepts needed to play various classes of games shows that only a few fundamental abilities are needed to play most of the common games. These abilities are included in the system. *Abstract*

3.65 Simulation of Natural Systems

Θ Bossert, William Hines. 13,600
Simulation of character displacement in animals. (Thesis)
Harvard Univ., Cambridge, Mass., 1963. *PhD*

A formal model of the displacement of reproductive behavior in animals is developed in Chapter 2, with particular interest in the analogy between such displacement and the evolution of an abstract code. A number of computer simulations with the model are reported in Chapter 3 leading to some general results on the nature of the displacement process. In Chapter 4 the model is used to predict the extent of gene flow between displacing populations. From these predictions criteria are drawn for judging the degree of speciation in allopatric populations. The model is applied to the study of two natural systems in Chapter 5, and its relevance to other systems of character displacement is considered briefly in the concluding chapter.
Abstract

Θ Lindsay, Robert K. 13,807
Toward the development of a machine which comprehends. (Thesis)
Carnegie Inst. Tech., Pittsburgh, Pa., May 1961.

[*Editorial note:* This thesis was reviewed when published in *Computers and thought.* Feigenbaum, E. A., and Feldman, J. (Eds.). McGraw-Hill, New York, 1963; *CR* **6,** 4 (July-August 1965), Rev. 7473.]

. . . In this paper, the fundamental aspects of the reading machine problem are discussed. An attempt is made to define meaning and understanding in useful terms. Means of organizing the storage of information are examined in terms of efficiency and power. Finally, a digital computer program is described in detail. This program implements the major features of the reading machine requirements by making some deductions from English text which, though trivial to adult humans, display the kernel of the problem.

To accomplish this task, guideposts from many fields of study are employed: Chapter One reviews the findings of experimental psychology in the area of higher mental processes. These results are particularly helpful as guides for efficient means of organizing complex systems. Chapter Two discusses recent results in the study of complex information processes and communication theory. These results are analyzed in terms of the problem under discussion, and some definitions and strategies are offered for carrying out the development of a reading machine.

Chapters Three and Four are detailed examinations of a computer program which analyzes English syntax and discovers implicit meanings along the lines of the earlier descriptions. It is felt that the exactness of specification required for the construction of this system is necessary for uncovering pertinent questions which do not arise from a more superficial discussion.

Chapter Five analyzes some of the questions raised by the computer system. The final topic is the application of these discussions to the psychological questions which were their source. *From the Abstract*

⊖ROTHENBERG, MARTIN.　　　　　　13,601

The breath-stream dynamics of simple-released-plosive production. (Thesis)

Univ. Michigan, Ann Arbor, Mich., 1966.

This study explores a linear, lumped parameter model of the speech mechanism within which are represented the average (nonacoustic) variations of pressure and air flow, called here the breath-stream dynamics. A set of pertinent, physiologically based parameters are represented in the model, using electrical circuit terminology and symbols. Evidence is presented to support the claim that the model is complete enough to represent the breath-stream dynamics of the class of speech sounds referred to as the simple-released-plosives. A simple-released-plosive is defined as a released stop with an egressive, pulmonic pressure and a single articulatory closure, in addition to a possible velopharyngeal closure. The simple-released-plosives present an intermediate level of difficulty in the study of the breath-stream dynamics of speech. . . . The control of respiratory movements is considered in some detail. . . . It is shown that the inertive constraints due to the masses of the respiratory structures are relatively small compared to the physiological constraints in the active change of respiratory muscle tension. . . . Also treated in some detail is the relationship of the "movements or actions" of the glottis in plosive production to the underlying "adjustments" of the glottis. It is shown that any appreciable voicing during the period of articulatory closure requires either an incomplete velopharyngeal closure or a passive or active expansion of the supraglottal cavity. These various possibilities are analyzed in terms of the model for the speech mechanism used in this study.

From the Abstract

⊖SAMBLES, ARTHUR WILLIAM CHARLES.　　　13,602

On the mechanization of algebraic manipulation by digital computer. (Thesis)

Institute of Computer Science, London, England, 1965.

This thesis describes a system for performing tedious algebraic calculations on a digital computer. The system enables differentiation, restricted integration, evaluation, and a number of other simple algebraic manipulations to be carried out automatically by machine. The system is written as one large FORTRAN 11 program, the Algebra MAnipulation Program and is referred to as ALMAP. It has been implemented on an IBM 7090 machine. . . .

The syntactic analysis language SHADOW V is used to check the syntax of the expressions to be manipulated. The features of this language which are used here are explained in detail. The ALMAP system uses a method of prime representation for the internal form of an expression. The method used to place an expression into this form and the way in which these forms are manipulated for the various operations of differentiation, integration, etc., are fully explained.

The system has been successfully applied to the calculation of some functions and integrals in molecular quantum chemistry. . . . An attempt has been made to compare and contrast the type of approach described in this thesis with the various other methods that could have been used. The merits and faults of each method are discussed at length.

From the Abstract

⊖ELLIOTT, ROGER WILLIAM.　　　　　13,402

A model for a fact retrieval system. (Thesis)

Univ. Texas, Austin, Texas, 1965.

A model for a fact retrieval system is developed. The model accepts facts and queries couched in a relational language, and it automatically constructs data structures which are efficient for storing the input data and which permit efficient inference-making.

A computer implementation of the model called GRAIS (*GRaphical Information System*) is discussed. GRAIS is a fact retrieval scheme with genuine inference-making ability that can operate in any context without programming modifications to the system. In addition, storage and retrieval times are essentially independent of the size of the data base.

Several possible extensions of the model and its implications for the general area of information retrieval are discussed.

Abstract

⊖LEFKOVITZ, DAVID.　　　　　　13,816

Automatic stratification of descriptors. (Thesis)

Univ. Pennsylvania, Philadelphia, Pa., 1964.

Library classification systems in general use today arrange the descriptors or terms, used to catalog the books, into a hierarchy of relations. At the bottom of the hierarchy more terms can be added and new subdivisions created, but the structure above the lowest level remains fixed unless the entire tree of relations is to be reconstructed. . . . A system is suggested that would make use of a digital computer in order to constantly revise the classification of the descriptors in terms of their actual usage within the document descriptions themselves. A two-stage process is intended to produce a two-level tree or reference catalog which in the first level presents aggregates of highly associated descriptors, while the second level presents respective aggregates of completely dissociated descriptors. The former is called an inclusive partitioning, and the latter, an exclusive partitioning. The dissertation is principally concerned with the exclusive partitioning, but the last chapter is devoted to a discussion of the complete two-stage process, where a small selection of descriptors taken from the file of the Armed Services Technical Information Agency (ASTIA) is used to illustrate the construction of a sample index or thesaurus.

An exclusive partitioning of descriptors implies that any pair of descriptors selected from a given exclusive partition will not co-occur within any document description of the file. . . . In the concluding chapter, the process of exclusive partitioning along with a preliminary program for inclusive partitioning is applied to a selection of descriptors from the ASTIA catalog in order to illustrate the general method of two-level classification.

From the Abstract

⊖Rocchio, Joseph J., Jr.   13,605
Document retrieval systems—optimization and evaluation. (Thesis)
Harvard Univ., Cambridge, Mass., 1966.

A model for document retrieval systems consisting of the functional elements: indexing, search request formulation, and request-document matching is examined in this thesis.

... Chapter 1 is introductory in nature and attempts to define the area of discourse and its relation to the general field of information retrieval. A general model for document retrieval systems is introduced, and the basic functional elements of this model are briefly outlined. ...

The indexing component of the model is discussed in Chapter 2, which is primarily descriptive in nature. The work of a number of researchers in this area is cited in describing the development and current trends of automatic content analysis. Particular emphasis is placed on concept vector indexing techniques which incorporate thesaurus-type semantic associations. ...

A search request optimization algorithm analytically derived from an assumed optimality criterion is presented in Chapter 3. The optimization algorithm and the notion of request optimization by an iterative sequence of retrieval operations are original with the author. In addition, the notion of testing index language devices by the use of optimal search requests is original. ...

Chapter 4 presents an original automatic document classification algorithm, heuristically motivated by considerations of search efficiency, and by the functional nature of query-document matching operations. ... Some experimental results illustrating the use of the classifications for improving search efficiency are presented.

... The statistical basis for the evaluation of document retrieval systems is discussed in Chapter 5. Several of the topics considered are based on previous work which is cited by bibliographic reference. ...

From the Abstract

⊖Sable, Jerome David.   13,815
Language and information structure in information systems. (Thesis)
Univ. Pennsylvania, Philadelphia, Pa., 1963.

The solution of a particular information-retrieval problem is viewed as a sequential decision process involving the inquirer and the system with the retrieval of information concerning the directory and the language, and several stages of reference-providing occurring as steps in this process. A conceptual model of the information storage and retrieval system is formulated that can meet the basic design requirements. ... The clinical procedures and analytic tools that can be developed to discover an aspect of "meaning" that can serve the use of the system are investigated. The approach taken to this problem has been to formalize the notion of semantic structure in a way that makes it possible to use a linguistic experiment with the users of the information system to determine the appropriate terms and structure of the system vocabulary.

It is shown that the terms appearing in a query can be identified with units of meaning upon which an inclusion relation can be defined. The units of meaning, called semantemes, form a partially ordered set under the inclusion relation. The interpretation of the relation is dual if A includes B, then a query for A should retrieve a text indexed with B. ... A mechanical command language is illustrated that can be used by the indexer, operator, and inquirer for storing, maintaining, and requesting information.

The results of this work indicate that it should be possible for a homogeneous group of users to communicate with an information system in a formalized language that preserves an aspect of the semantic structure of their natural language. Furthermore, it is possible to incorporate facilities in the system that enable its users to compare in a multistage dialog with the system, leading from a partially formulated need for information to the fully developed query to which the system can respond with the appropriate information.

From the Abstract

3.8 REAL TIME SYSTEMS

3.81 COMMUNICATIONS

⊖Berger, Toby. 13,610
Nyquist's problem in data transmission. (Thesis)
Harvard Univ., Cambridge, Mass., 1965.

. . . Formulas are derived which permit one to explore the dependence of system performance on the signaling rate, the correlation properties of the data, the signal power, the noise spectrum, the impulse response of the transmission medium, and the probability distribution of the timing jitter.

Mean square error vs. signal-to-noise ratio performance characteristics of the optimal systems are determined for several examples. These characteristics are compared both with those of certain suboptimal systems and with optimal performance theoretically attainable (OPTA). The Opta is derived by combining two of the basic concepts of Shannon's information theory, namely the information capacity of a communication channel and the rate distortion function of an information source, with respect to a fidelity criterion.

The optimal PAM systems, which may be interpreted as ideal combinations of infinite memory convolution encoders and decoders, are seen to perform very close to the Opta for low signal-to-noise ratios. For high signal-to-noise ratios, however, the optimal Pam mean-square error decreases as the reciprocal of the signal-to-noise ratio, whereas the Opta often decreases exponentially. Accordingly, in many cases there exists a potential for realizing significant improvement over optimal Pam performance at high signal-to-noise ratios by resorting to complex, nonlinear coding techniques. An exception is provided by the ideal band-limited channel corrupted by white Gaussian noise. In this special case, the optimal Pam performance characteristic can coincide with the Opta. . . . √From the Abstract

⊖Beusch, John U. 13,609
Dynamic behavior and control of communications networks. (Thesis) *Ph.D*
M.I.T., Cambridge, Mass., June 1965.

An arbitrary store-and-forward network where messages without priorities can enter the network of any node and be destined for any other node is considered. The problem of routing messages is considered to be a feedback control problem in which information about the number of bits waiting at various places in the network is fed back to points where decisions are made.

Mathematical models which represent system behavior are developed. The model of a single channel is a new Markov process queueing model with random arrivals and deterministic service times. Simple models which predict future queue lengths are developed. A way of reducing a set of series-parallel channels to a single equivalent channel is presented.

A method of determining message routing decision rules which are based on what is known at a decision point is developed. A method of determining whether and how often to obtain information about another part of the network is developed.

Many of the methods apply only to series-parallel networks.

Several examples to illustrate the methods and a computer program for analyzing networks are presented. Results of simulations to compare various routing techniques with the feedback technique are presented. In all cases feedback improves performance and when average arrival rates of messages change it improves performance drastically. / Abstract

4.0 PROGRAMMING: GENERAL

⊖London, Ralph L. 13,840
A computer program for discovering and proving sequential recognition rules for well-formed formulas defined by a Backus normal form grammar. (Thesis)
Carnegie Inst. Tech., Pittsburgh, Pa., 1964.

[*Editorial note:* A paper based on this was reviewed when published as "A computer program for discovering and proving recognition rules for Backus Normal form grammars" in *Proc. ACM 19th Natl. Conf.*, Philadelphia, Pa., (August 1964), *CR* Rev. 7267.]

This report is based upon a computer program which will discover rules for the recognition of grammatical strings when given a simple Backus Normal Form grammar. The program attempts to prove that these rules are both necessary and sufficient to characterize grammatical strings. The main mathematical techniques that are mechanized are induction and case analysis. In addition, the program is capable of producing counterexamples. Since the program is writing proofs, several (meta-) proofs are included asserting the correctness of the produced proofs.

The program exists for two reasons. First, it will construct a recognizer for some Backus Normal Form grammars and provide a proof of the validity of the recognizer. Second, its domain is a convenient one for proving theorems by machines, especially those whose proofs may use fairly involved case analysis.

The overall strategy used to discover the rules and to prove them valid is described, followed by a discussion of the program organization and internal representations. Limitations and possible improvements to the present program are mentioned. An assessment is made of the mathematical accomplishments of the program and the value of the program as a mathematical aid. An appendix presents the output of four examples of program runs. *Abstract*

⊖Worsley, Beatrice H.   13,628
Serial programming for real and idealized digital calculating machines. (Thesis)
Univ. Cambridge, Cambridge, England, 1953.

. . . This dissertation defines this broad class of machines, and details idealized representations. Descriptions are given of three existing machines, with which the author has been privileged to work in the course of this study. Brief examples serve to compare the use of their order codes. Descriptions are given of three large-scale computations carried out on the EDSAC.

The first computation represents a determination of the second-order correction to be applied to the value of gravity from pendulum measurements made at sea. The problem was well suited to the Edsac because of its magnitude and requirement of many solutions of similar basic forms. The second problem is an automatic rendition of the Hartree self-consistent field method for the solution of atomic wave equations with exchange. These extensive calculations were programmed in a form which could be used to solve any atom within a wide range. Since an extensive application of this program would require several months, it is shown to be better suited to a machine equipped with permanent auxiliary internal store. The third problem illustrates the way in which an automatic calculator may be used to explore the merits of a method together with its variations. The Liebmann one-dimensional process compares unfavorably with step-by-step and adjustment methods.

Finally, from experience gained in using existing machines, an empirical theory of axiomatic programming is evolved. It is hoped that this will be a guide to

the design of order codes and libraries. It is based on the proposal of an optimum basic automatic universal digital machine.   ⁄ *From the Abstract*

⊖McKeeman, William Marshall.   13,436
An approach to computer language design. (Thesis)
Stanford Univ., Stanford, Calif., 1966. *Ph D*

A formal mathematical description of a class of analysis algorithms . . . is given and two new syntax preprocessor algorithms are presented. Some theorems concerning the behavior of the algorithms and the nature of the acceptable grammars are given.

In language design, we attempt to carry the EULER development by Wirth and Weber to a more concise and powerful form. We advocate languages that are *minimal* and *involuted*. A minimal language combines into a single construct any two conceptually similar, but notationally different constructs. An involuted language avoids constructs that are applicable only in local context. In the resulting language we find such previously diverse constructs as lists, parameter lists, blocks, compound statements, for lists and arrays to be identical. After combining the features of the reduced EULER with some ideas from Iverson and PL/I we find that our control over the flow of execution within a program is so complete that we discard the traditional label and go-to statement as irrelevant.

As a final example of the kernel language, we present an extendable compiler written in the kernel language itself.

Our conclusions are that the precedence grammar techniques are quite efficient and useful. Further improvement could make them substantially superior to other methods of compiler generation. The computing community would be better served with a minimal common language . . . than by any large general purpose language. The growing agreement on the constructs common to all programming tasks should have a much more significant effect upon machine design than is presently the case.   *Abstract*

Θ PRATT, TERRENCE WENDALL. 13,629
Syntax-directed translation for experimental program-
ming languages. (Thesis)
Univ. Texas, Austin, Texas, 1965.

In the development of new and more powerful pro-
gramming languages, two basic problems are 1) the
development of more general and flexible data organi-
zations; and 2) the extension of the types of formalisms
used in representing language statements. The devel-
opment of new languages, however, is hindered by the
difficulty of implementing translators for program-
ming languages. . . . To encourage experimentation
with new programming languages, a computer system,
AMOS-II, has been designed which simplifies the con-
struction of translators for programming languages.

The system is based upon an executive organization
which allows considerable flexibility in translator con-
struction. Under this executive the translation process
is segmented into a number of translation blocks.
Within each block an arbitrary translation method
may be used. . . .

Other significant features of the system include a
partial self-compiling ability and a pre-editing phase
which all input to the system must undergo. This pre-
editing allows the system to be independent of the type
of input medium (e.g., cards, paper tape, teletype). It
also allows normally "meta-syntactic" program ele-
ments such as records and fixed fields to be used as
syntactic units.

The resulting total system simplifies the construc-
tion of translators for new programming languages
without restricting the types of languages which may
be translated. The program is coded in assembly lan-
guage and is currently running on the Control Data
1604 computer at the University of Texas.

√ From the Abstract

Θ FELDMAN, JEROME A. 13,841
A formal semantics for computer-oriented languages.
(Thesis)
Carnegie Inst. Tech., Pittsburgh, Pa., 1964.

[*Editorial note:* A paper based on this was reviewed when
published as "A formal semantics for computer languages
and its application in a compiler-compiler." *Comm. ACM*
9, 2 (Feb. 1966), 72–76, 79; *CR* **7**, 4 (July-August 1966);
Rev. 10,080.]

This dissertation presents a number of results at-
tained in a study of the formalization of certain
properties of computer-oriented languages. The most
important result is a computer program which is
capable of translating into machine language any of a
large class of source languages. Included in this class
are all the usual high-level, problem-oriented lan-
guages.

The presentation of the results in the thesis is based
on the structure of this program, called the compiler/
compiler. Although there are several sections devoted
to theoretical questions, these are set off from the
main development. This organization was chosen so
that the thesis could also serve as a user's guide to the
compiler/compiler as a computer system.

A more detailed introduction to the paper is given
in Chapter I, where we also consider some of the
philosophical questions raised by formalizing se-
mantics. Chapter II contains a discussion of a formal
syntax language used in the compiler/compiler. In
this chapter we establish relationships between this
formalization of syntax and others appearing in the
literature.

Chapter III is a complete discussion of the Formal
Semantic Language which is the main contribution of
this thesis. In Chapter IV we show how the two
formal systems were combined to form the basis for a
useful computer technique. The final chapter contains
a discussion of the strengths and weaknesses of out
systems, as well as several suggestions for future re-
search.

The appendices form an integral part of the thesis.
The examples contained there include a record of the
development of a translator for one small language
from a formal definition of the language to examples
of resultant machine code.
√ Abstract

Θ PIERSON, HAROLD L. 13,441
A finite transducer model of compiler scanners. (Thesis)
Case Western Reserve Univ., Cleveland, Ohio, 1966.

A finite transducer is presented as a model for com-
piler scanners. Functions, which generate the maxi-
mum parse from only two input symbols, are defined
and shown to be computable. Using binary relations to
calculate these functions, an algorithm is developed
which generates the transducer for any type-2 gram-
mar. In addition, this algorithm eliminates from the
grammar all symbols and productions absorbed in the
scanner.
Abstract

Θ WALTER, KENNETH G.   13,630
Compiler optimization of object programs. (Thesis)
Case Western Reserve Univ., Cleveland, Ohio, 1966.

The design of a compiler which is not only fast but which also produces an efficient object program is the goal of most software managers. Detailed inspection of two existing compilers (one for FORTRAN IV and the other for ALGOL 60) reveals the reasons why one is quite fast but fails to produce correct object code; while the other produces correct object code, but is relatively slow in compiling speed. The problem is one

of partitioning the program efficiently and quickly into "large" pieces where it is possible to determine the effect of changes within the pieces on the operation of the program. Presented herein are some heuristics for the partitioning process as well as the details of their implementation. In particular, the techniques presented concern themselves with 1) elimination of common sub-expressions; 2) removal of invariant expressions from explicit loops; and 3) recursive ALGOL procedures. When the techniques presented here are all embodied in compiler, the result will be a fast compiler which produces efficient object code.   ✓ *Abstract*

4.2 PROGRAMMING LANGUAGES

4.20 GENERAL

Θ GERARD, JOHN MICHAEL.   13,632
Synthesizing non-linear forms from linear descriptions by syntactic analysis. (Thesis)
Institute of Computer Science, London Univ., London, England, 1965.

The thesis is concerned with the application of syntactic analysis to a general class of problems arising in the non-numeric use of high-speed digital computers. The first part . . . is a brief introduction to the use of syntaxes and syntactic analysis. Examples of various syntactic analysis languages are examined and commented upon. One particularly powerful language, called SHADOW V, is described in detail. Certain computer programs written to facilitate the use of this language are also described.

The second part . . . is a description of a programming system to deal with syntactic analysis. This programming system, called SYNTHS, is an extended form of the programming language FORTRAN II and includes the syntactic analysis language SHADOW V. . . .

The last part . . . gives an account of four programs written using the SYNTHS language, and closes with a discussion of the SYNTHS system and its applications.

. . . A knowledge of the programming language FORTRAN II is assumed throughout the thesis and is fairly essential for full understanding of the contents.   ✓ *From the Abstract*

Θ GOLDEN, DONALD G.   13,631
The use of transition diagrams for syntax representation. (Thesis)
Case Western Reserve Univ., Cleveland, Ohio, 1966.

In this paper we define the concept of a set of transition diagrams, with particular emphasis on its use in syntax representation; we also discuss the No-Loop and No-Backup conditions and give algorithms for detecting these conditions. A series of transformations which may be used to derive and manipulate a set of transition diagrams while preserving certain characteristics of the language is discussed, and the derivation by means of these transformations of a set of transition diagrams for Extended ALGOL 60 is described in detail. We also present a linear notation for representing transition diagrams, show how this representation may be stored within a computer in the form of syntax tables, and suggest an algorithm which may be used to manipulate these tables as the basis of a language recognizer.   ✓ *Abstract*

Θ KARP, RICHARD MANNING.   13,445
Some applications of logical syntax to digital computer programming. (Thesis) *Ph D*
Harvard Univ., Cambridge, Mass., 1959.

In this thesis the methods of logical syntax are applied to the analysis of programming languages. The programming languages considered include not only computer languages, but also flowcharting languages and the source languages of automatic programming

systems. Syntactic models are defined and used for the development of analytic check-out procedures and techniques for improving the efficiency of programs.

In Chapter 1, various types of programming languages are described, and the linguistic and operational merits of each type are discussed. The relevance of the syntactic concepts of equivalence and well-formation to the analysis of programs and flowcharts is shown, and examples of the application of these concepts are given. A particular class of syntactic models emphasizing the pattern of control is selected for further consideration.

Chapter 2 is concerned with the following criterion of well-formation: 1) every one of its sentences is part of at least one sequence which can potentially be executed; 2) the execution of the algorithm described by the flowchart always terminates after a finite number of steps. In determining whether a given flowchart satisfies this criterion, the flowchart is considered as a net of operational elements and decision elements, connected by directed lines.

. . . In Chapter 3, a program is considered as a net of program sections and decisions. . . .

. . . The underlying theme of this thesis is the treatment of a program or flowchart as a net, and the application of the theory of nets to the problems of check-out and efficiency. . . . Several problems of practical interest not treated in this thesis seem amenable to this approach. Some of these problems are mentioned in the concluding section of Chapter 3.   ✓ *From the Abstract*

ΘANDERSON, ROBERT H.   14,287
Syntax-directed recognition of hand-printed two-dimensional mathematics. (Ph.D. Thesis)
Harvard Univ., Cambridge, Mass., 1968.

This dissertation presents a generalization of the standard linguistic techniques used to process languages whose sentences consist of strings of characters. The techniques are generalized to handle groups of characters spatially distributed in two (or more) dimensions. The use of these linguistic processes for graphical man/machine communication is emphasized; however, the processes are also given a formal linguistic definition to aid the study of their properties.

Chapter 1 gives an introduction to the subject, and indicates the motivation for this research.

Chapter 2 defines the linguistic concepts which are assumed in the remainder of the dissertation. The presentation closely follows that of existing sources.

Chapter 3 contains a survey of related research, and describes the relationships between my work and that of others.

Chapters 4 through 8 present a system for the syntactic analysis of spatially distributed character configurations, and four applications of this system: recognition of two-dimensional mathematical notation, symbolic matrix descriptions, directed graphs, and a two-dimensional programming language. . . .

Chapter 9 contains a discussion of two implementations of the syntax-directed recognition system, giving experimental results obtained in these implementations.

Chapter 10 presents an original formalism by which graphical languages may be described and analyzed. . . .

Chapter 11 contains some concluding remarks about the integration of the recognition system into an interactive man-machine environment, and mentions areas for further research suggested by the results contained in this dissertation.

Appendix I shows how a very efficient recognizer may be constructed for the particular language of algebraic mathematical notation. An existing implementation of the efficient recognition scheme on a PDP-1 computer is illustrated and discussed. . . .

Appendices II and III contain the syntax rules which are described in Chapters 5 (math notation) and 6 (matrix notation). . . .   ✓ *From the Abstract*

ΘLADNER, ROBERT L.   13,454
List processing in ALGOL 60. (Thesis)
Case Western Reserve Univ., Cleveland, Ohio, 1966.

With the increasing importance of non-numeric processing, a need has developed for a standard list processing language. It has also become apparent that a combination of a list processing language and an algorithmic language would be extremely profitable. A description of the addition of list processing to an already extended ALGOL 60 system is given as an example of such a combination.   *Abstract* ∕

ΘLYNCH, WILLIAM CHARLES.   13,844
Ambiguities in Backus normal form languages. (Thesis)
Univ. Wisconsin, Madison, Wis., 1963.

This thesis develops sufficient computable conditions, for languages (such as ALGOL 60) defined in Backus Normal Form to be unambiguous. A practical computational procedure to test the ambiguity of a syntax is developed, formalized, and proven correct.

The analysis is effected by constructing a mathematical model of the diagrams of sentences and of the syntax that controls their formation. Transformations of the syntax are developed. Certain conditions occurring only in ambiguous sentences are investigated and traced back into the syntax.   ∕ *Abstract*

ΘMORRISON, GORDON E.   13,456
Investigation of micro-programming as a technique in the control of digital computing systems. (Thesis) PhD
Univ. California, Berkeley, Calif., 1958.

The micro-program technique produces desired external operations in a digital computing system by sequences of internal operations controlled by a stored program of internal orders called "micro-orders." The various "micro-program" sequences are selected by a second level of command, called "sequence command." This evaluation of the technique consists of an investigation of the effect of use on hardware complexity, computing speed, and ease of use.

Investigation of design considerations indicated the choice of a system consisting of an arithmetic section designed to be controllable by micro-orders, a memory which stores the micro-order sequences, a second memory which stores the sequence commands, a third memory which stores the problem data, a unique modified index register system for memory address control, and appropriate buffer and control registers.

It is shown that the arithmetic section could be achieved with no more functional elements than the minimum required in any system for the selected arithmetic operations and computing times. No unusual requirements were found for the problem data and sequence memories other than the need for independent control. Investigation of the micro-program memory indicated that a capacity of 10^6 bits with a speed comparable to the data memory would be desirable.

By investigation of a "standard" operation and matrix multiplication program, it is found that the micro-program system was significantly faster than a "typical" conventional system. However, it was about as fast as a conventional system modified to provide more effective subroutine operation with a resulting complexity which was comparable to that of the micro-program system. . . .   ✓ *From the Abstract*

⊖Olynyk, Frank J.   13,455
The intertranslation of ALGOL and FORTRAN. (Thesis)
Case Western Reserve Univ., Cleveland, Ohio, 1966.

The problem of the intertranslation of Algol and
Fortran is discussed. Internal documentation of the
two translators written to translate from Algol to
Fortran (Alftran) and from Fortran to Algol
(Faltran) is provided. In addition, the reasons for
translating in the manner described are given, as well
as any alternatives which might have been available.
The various areas of Algol and Fortran which can-
not be translated are discussed, as well as methods
which could be used (by the translator and/or the
user) to circumvent these. Finally, a description of
how to use the translators at Case is included.

Abstract

⊖Reiter, Raymond.   13,639
A study of a model for parallel computations. (Thesis)
Univ. Michigan, Ann Arbor, Mich., 1967.

This paper deals with a model for parallel computa-
tions as formulated by Karp and Miller. A computa-
tion is viewed as a directed graph (computation graph)
in which a node represents an operation to be per-
formed upon data on the node input branches with the
results of this operation being placed upon the output
branches. . . . An integer linear program is given for
the determination of the maximum storage required by
a computation graph G. In the case that G satisfies
$W_p = T_p = I$, $U_p = 0$ or 1, for each branch d_p, this re-
duces to an ordinary linear programming problem.

The concept is introduced of an admissible schedule
defining valid node initiation times. . . . The minimum
period, π, which yields the maximum computation
rate, is definable in terms of graph parameters. A
maximal computation rate "quasi periodic" schedule
is given for the case that G is required to compute syn-
chronously, i.e., at integer times. Finally, for more
general computation graphs, an analysis of the so-
called free admissible schedule is given.

The assignment of node function to processors is
considered and the notion of sequence introduced. A
sequence defines the order in which a given processor
executes the nodes assigned to it. A cyclic sequence is
determined when each processor executes its nodes
cyclically. Necessary and sufficient conditions for the
existence of a cyclic sequence are given. . . . The Karp/
Miller model is generalized to include a restricted class
of data-dependent node decisions. It is shown that such
a computation graph defines a unique computation
independent of the timing of node initiations. . . .

From the Abstract

⊖Storm, Edward F.   13,636
An algorithmic notation for symbol manipulation. (Thesis)
Harvard Univ., Cambridge, Mass., 1966.

This thesis is concerned with the realization of sym-
bol manipulation processes on a large scale digital com-
puter. The principal contribution consists of a new
programming language for these processes called ISM
(*Interpretive Symbol Manipulator*).

In Chapter I this programming language is described
in summary and is related to other languages for
similar processes.

In Chapter 2 a primitive form of the language is in-
troduced and it is proved that the notation for this
language is equivalent to the notation for the descrip-
tion of Turing Machines in the sense that any al-
gorithm realizable in one notation is realizable in the
other. This is done first by showing how to write any
Turing Machine as an ISM program, and second by
showing that every ISM program corresponds to a re-
cursive function.

In Chapter 3 a more comprehensive algorithmic no-
tation for symbol manipulation is introduced by the
contextual definition of new constructs in terms of the
primitive notation.

In Chapter 4 the IBM 7090 realization of the com-
prehensive notation is described and is used to realize
the Wang algorithm for the propositional calculus.
Finally, a new decision procedure for the propositional
calculus is described.

Chapter 5 reports the results of some ISM programs
to verify the proofs in Quine's *Mathematical Logic*.
There is a discussion of ways to improve the efficiency
of the realization of ISM and a description of the trial
runs that are made.

Abstract

4.3 SUPERVISORY SYSTEMS
4.30 General

⊖Olson, Alan K.   13,640
Exec III. (Thesis)
Case Western Reserve Univ., Cleveland, Ohio, 1966.

An operating system, called EXEC III, for the
Univac 1107 computer is described. Exec III
processes users' programs sequentially according to a
dynamic priority system. However, Exec III multi-
programs the input and output operations associated
with the users' programs. One of the major problems
involving executive systems today is that of protection
of the systems. Exec III has the ability to protect it-
self from users' programs. The 1107 computer lacks the
features with which the system can protect itself.
These deficiencies are examined. The hardware modifi-
cations which have been made to the 1107 computer
are also described. An explanation of how these modi-
fications eliminate the protection deficiencies of the
basic 1107 is given. The use and operation of the Exec
III system is discussed. A description of the construc-
tion and design of the Exec III system is also given.

Abstract

Θ SCHERR, ALLAN LEE.   14,069
An analysis of time-shared computer systems. (Thesis)
M.I.T., Cambridge, Mass., June 1965.

Some of the aspects of the operation of time-shared, interactive computer systems are analyzed. The emphasis is on the reaction of hardware systems to the demands that its users make upon it. Simply stated, the problem is to characterize both time-shared systems and their users in order to be able to predict the performance of the two operating together. Portions of this problem include the specification and measurement of user characteristics, the development and verification of both simulation and mathematical

models for time-shared systems, and the specification and measurement of performance metrics for such systems. The user and some of the performance measurements were made on Project MAC's "Compatible Time-Sharing System" (CTSS).

First simulation models are used to study the effects of changing small details in the operation of CTSS-like systems. Then, a continuous-time Markov process model is derived to predict the performance of a broad class of systems. Throughout, the CTSS data are used as a basis for comparison with model predictions. In order to be able to take measurements and to build models, many definitions of commonly used time-shared system terminology are made precise.   ✓ *Abstract*

4.39 MISCELLANEOUS

Θ SHOMER, JON A.   13,643
An ALGOL 60-compatible sort-merge package. (Thesis)
General Electric Co., Phoenix, Ariz., 1966.

A generalized ALGOL 60-oriented sort-merge package is discussed with a presentation of the Case ALGOL 60-compatible sort-merge package. User-defined files, keys, pools, and character rank are used in conjunction with the Case ALGOL 60 strings to provide a flexible system capable of sort, merge, and item transfer operations. Calls on the sort, merge, or transfer processes may be nested within a given call, with temporary storage allocation and file processing handled by the sort-merge system. General compiler requirements are discussed, and a broad view of the basic system philosophy is presented.   ✓ *Abstract*

4.4 UTILITY PROGRAMS

4.40 GENERAL

Θ LANDAUER, WALTER I.   13,851
The tree as a stratagem for automatic information handling. (Thesis)
Univ. Pennsylvania, Philadelphia, Pa., 1962.

In the model of memory organization presented in this paper the tree constitutes the basic building block of the associatively organized memory. It may be regarded as a translator whose inputs are the information carriers and whose outputs are the addresses at which the information is stored. It proceeds upon the assumption that the information is available in terms of complete and/or incomplete code words, called keys. . . .

Two methods of implementing the tree organization in the memory are given. At the inception of an automated file the need often arises to incorporate an existing numerically organized file in which the keys are completely sorted according to their order of magnitude. The scheme that takes advantage of this order by pre-planning the storage allocation is delineated. After the existing file has been incorporated additions are expected to enter the file in random order. The insertion of these random entries in the tree is discussed and illustrated. The discussion leads to the formulation of the search and shift algorithms that provide the programs for the computer to maintain the numerical order of the keys in the construction of the tree.

The number of search and transfer steps required is proportional to the distance x (in memory units) between the location where a new key is to be inserted and the closest vacant space in the tree. Probability expressions for the occurrence of a vacant space at distance x are derived and numerically evaluated on a computer. The results are plotted as functions of the occupance u (i.e., the number of keys filed in a tree level). . . .

The Automatic Memory Assignment is a basic requisite for the implementation of the tree structure in the memory. The unit that accomplishes this task is the Memory Synchronizer. Algorithms for two basic synchronizer operations, "Store Item" and "Delete Item," are given in flowchart form.
                                          ✓ *From the Abstract*

4.9 MISCELLANEOUS

Θ PARNAS, DAVID LOGE.   13,853
System function description ALGOL. (Thesis)
Carnegie Inst. Tech., Pittsburgh, Pa., Feb. 1965.
[*Editorial note:* A paper based on this was reviewed when published as "A language for describing the functions

of synchronous systems." *Comm. ACM* **9**, 2 (Feb. 1966), 72–76, 79; *CR* **7**, 4 (July-August 1966), Rev. 10,082; also as "State table analysis of programs in an ALGOL-like language" in *Proc. ACM 21st Natl. Conf.* 391–400, *CR* **8**, 4 (July-August 1967), Rev. 12,529.]

A language for the description of the functions of finite state systems, the simulation of finite state systems, and the automatic production of the state tables of such systems is developed.   ✓ *Abstract*

5. MATHEMATICS OF COMPUTATION

5.1 NUMERICAL ANALYSIS

5.11 ERROR ANALYSIS; COMPUTER ARITHMETIC

⊖MOORE, RAMON EDGAR. 13,856
Interval arithmetic and automatic error analysis in digital computing. (Thesis)
Stanford Univ., Stanford, Calif., 1963.

A digital computation and an analysis of its error as an approximation are necessarily viewed as separate processes when one is dealing with real numbers. On the other hand, in the present study, an interval arithmetic is studied which forms the basis for a concomitant analysis of error in a digital computation. In this system computations with intervals are performed and intervals are so produced to contain, by construction, the exact numerical solutions sought. Hence, an approximation and an error bound are obtained at the same time; choosing, say, the midpoint of the interval as the approximation, the radius of the interval becomes the error bound.

Convergence theorems are obtained for interval computations of 1) the range of values of a rational function; 2) the definite integral of a rational function; and 3) the solution on a finite interval to the initial value problem for an arbitrary finite system of first-order ordinary differential equations in rational functions. . . .

For actual machine computations, rounded interval arithmetic is introduced so that round-off errors are also taken into account. Machine programs using rounded interval arithmetic and the computational schemes based on 1); 2); and 3) above are shown to produce by finite machine computations intervals containing the exact solutions. The widths of the bounding intervals can be made arbitrarily small at the cost of the amount of computation required.

Discussion is given of efficient choices of the order of method and step size for some examples of differential equations and definite integrals.

Matrix computations are considered and practical limitations on the method of refinements are revealed.

The machine generation of programs to evaluate needed interval extensions of higher derivatives in connection with the kth order differential equation methods is discussed. ✓ *From the Abstract*

5.13 INTERPOLATION; FUNCTIONAL APPROXIMATION

⊖MARTIN, LeROY BROWN, JR. 13,652
Approximation by ratios of integers chosen from a limited range. (Thesis) *Ph D*
Harvard Univ., Cambridge, Mass., 1955.

Selection of the gear train whose ratio is closest to an arbitrary fraction is considered from two general points of view. The first of these involves selection of a ratio from certain trial approximations which form a sequence of conjugate fractions, while the second required a partial tabulation and an associated procedure for choosing the best solution. Trains of up to four gears are considered and the number of teeth per gear is limited to a specified range.

In Chapter 2 a complete solution of the two-gear case is presented. Simple continued fractions are treated extensively and proofs are provided for those properties of interest in gear train analysis. The properties of conjugate fractions and the Farey series are investigated and applied to the selection of gear trains. The best possible result is shown to be furnished by a complete tabulation of two-gear ratios provided that the highest tooth number in the available set of gears is not unreasonably large. Such a table appears in Appendix B where the decimal equivalents of the Farey terms of order 120 are tabulated to eight places. Two other methods of calculation are shown which can be used in the absence of such tables.

The theoretical development in Chapter 2 provided a basis for three methods of finding the best four-gear train. These are presented in Chapter 3. Each method provided the best solution and although not excessively complex, they are rather tedious. Two important characteristics of these procedures not previously noted in the literature are a simple checking procedure and the considerable saving of work resulting from the observation that only a few numerators of the trial approximations need to be calculated.

. . . The second general approach is embodied in two new tabular procedures presented in Chapter 4. The first of these requires a very simple calculation but an extremely large table. The second requires more calculation but may be based on fairly limited tables. ✓

From the Abstract

Ⓞ RUDIN, BERNARD DAVID.
Convex polynomial approximation. (Thesis)   13,860
Stanford Univ., Stanford, Calif., 1965.

[*Editorial note:* A paper based on this thesis was reviewed when published as "Convex polynomial approximation," Stanford Univ., Stanford, Calif., Tech. Report CS23, June 1965, 44 pp.; *CR* **7**, 5 (Sept.-Oct. 1966), Rev. 10,503.]

Let $f(t)$ be a continuous function on $[0, 1]$, or let it be discretely defined on a finite point set in $[0, 1]$. The problem is the following: among all polynomials $p(t)$ of degree n or less which are convex on $[0, 1]$, find one which minimizes the functional $\|p(t) - f(t)\|$, where $\| \ \|$ is a suitable defined norm (in particular, the L^p, l^p, and Chebyshev norms).

The problem is treated by showing it to be a particular case of a more general problem: let f be an element of a real normed linear space V; let $x_1(z), \cdots, x_k(z)$ be continuous functions on a subset S of the Euclidean space E^n into V such that for each z_0 in S the set $\{x_1(z_0), \cdots, x_k(z_0)\}$ is linearly independent in V; let $(y_1, \cdots, y_k)$ denote an element of the Euclidean space E^k and let H be a subset of E^k; then among all (y, z) in $H \times S$, find one which minimizes the functional $\|y_1 x_1(z) - f\|$. It is shown that solutions to this problem exist when H is closed and S is compact. Conditions for uniqueness and location of solutions on the boundary of $H \times S$ are also given.

Each polynomial of degree $n + 2$ or less which is convex on $[0, 1]$ is shown to be uniquely representable in the form $y_0 + y_1 t + t y_2 + \int\int p(z, t) \, dt^2$, where $p(z, t)$ is a certain representation of the polynomials positive on $[0, 1]$, $y_2 \geq 0$, and z is constrained to lie in a certain convex hyperpolyhedron. With this representation, the convex polynomial approximation problem can be treated by the theory mentioned above. It is reduced to a problem of minimizing a functional subject to linear constraints.

Computation of best least squares convex polynomial approximation is illustrated in the continuous and discrete cases.

Abstract

Ⓞ USOW, KARL H.
Computational aspects of approximation in the L_1 metric   13,65
(Thesis)
Purdue Univ., Lafayette, Ind., 1966.

Let $f(x)$ be continuous on $[0,1]$, or defined on the finite set $\{x_1, \ldots, x_m\}$. Let $F(A,x)$ be a continuous function of $x \in [0,1]$ and of n parameters $A \in P \subset E_n$, where E_n denotes Euclidean n-space. The primary results of this thesis concern the following problems. Given $f(x)$ find an $A^* \in P$ which minimizes

(1) $$R_C(A) = \int_0^1 |f(x) - F(A, x)| \, dx \,,$$

or

(2) $$R_D(A) = \sum_{i=1}^m |f(x_i) - F(A, x_i)| \,.$$

For the case that

$$F(A, x) = \sum_{i=1}^n a_i \phi_i(x)$$

and $\{\phi_i(x) | i = 1, 2, \ldots, n\}$ is a Chebyshev set, algorithms are given for minimizing (1) and (2), along with proofs of their convergence. For the case that $F(A,x)$ does not depend linearly on A, an algorithm is described for minimizing (1), but proof of convergence is not established.

A summary of tests from the computer implementation of each algorithm is given and numerical procedures are discussed.

We also present results on the continuity of the dependence of the solution of (1) on $f(x)$ and the rate of convergence of best approximations on finite sets to the best approximation on $[0,1]$. In particular, let $F(A^*,x)$ be a best approximation to $f(x)$. It is shown that if $R_C(A)$ is close to $R_C(A^*)$, it does not follow that

$$\int_0^1 |F(A, x) - F(A^*, x)| \, dx$$

is small unless certain Lipschitz conditions are assumed; even if $F(A,x)$ is linear.

Abstract

⊖WILLIAMS, LELAND.   13,653
Extended algebra of polynomials in several variables for a
digital computer. (Thesis)
Duke Univ., Durham, N. C., 1961.

In this thesis an interpretive system for automatic
polynomial manipulation by a digital computer is pre-
sented. Its purpose is to make possible the error free
solution of certain types of problems which require for-
mal manipulation of polynomials. The polynomial
manipulation system (PMS), therefore, capitalizes on
the logical capability rather than the arithmetic
capability of a digital computer. The PMS is an exer-
cise in machine symbol manipulation. . . .

It is capable of handling polynomials in m variables,
where m is determined by the number, α, of digits re-
quired to represent the degree in each variable and by
the work length of the machine. The product, $m\alpha$,
cannot be greater than the work length. The formal
manipulations of the PMS are those producing the
sum, difference, product, remainder after division with
respect to one variable, and eliminent of two poly-
nomials.

. . . The basic problem in developing the PMS was
the choice of a polynomial representation. The require-
ments controlling the choice were that the representa-
tion must have a machine realization which is con-
sistent with computer logic. The logical ability of most
modern computers is such that the desired procedures
could probably be carried out for any reasonable repre-
sentation. However, much efficiency is to be gained by
a judicious choice. A sum of monomials representation
was the one chosen. The basic machine realization
consists of a table whose arguments are subscripts (or
ordered exponents) and whose values are the numerical
coefficients.

The machine methods for the formal manipulations
are presented by flowcharts. These are logical descrip-
tions of the elementary processes and logical decisions
involved in the various formal manipulations. The
methods can be programmed for any digital computer
of sufficient size. They have been programmed for the
IBM 650. Some examples of this program's use are
given in the Appendix. . . .   *From the Abstract*

⊖BROWN, KENNETH M.   13,663
A quadratically convergent method for solving simul-
taneous non-linear equations. (Thesis)
Purdue Univ., Lafayette, Ind., 1966.

An iterative method for the numerical solution of a

system of N simultaneous nonlinear algebraic equa-
tions is presented. A proof of local convergence for the
method is given in which it is shown that the conver-
gence is quadratic in nature. Computable bounds on
the region of convergence are obtained in connection
with a nonlocal convergence theorem. Computer re-
sults for specific applications of the method are given,
and comparisons are made with other currently used
methods. In particular, it is shown that the method
requires only $(N^2/2 + 3N/2)$ function evaluations per
iterative step as compared with $(N^2 + N)$ evaluations
for Newton's Method. An ALGOL procedure for the
method is also given.   *Abstract*

⊖BUSINGER, PETER ARTHUR.   13,660
Matrix scaling with respect to the maximum-norm, the
sum-norm, and the Euclidean norm. (Thesis)
Univ. Texas, Austin, Texas, 1967.

The condition number of a nonsingular matrix A
with respect to the inversion problem and with respect
to a vector norm $||\cdot||$ is defined by cond$(A) =$ lub(A)
lub(A^{-1}), where lub$(\cdot)$ denotes the matrix bound sub-
ordinate to the norm $||\cdot||$. The spectral condition num-
ber can be regarded as a "measure by which A fails to
be a scalar multiple of a unitary matrix." Other such
measures are considered and related to cond(A).

F. L. Bauer considered the minimization problems

(i) $\inf_{D_1}$ cond $(D_1 A)$;

(ii) $\inf_{D_2}$ cond $(A D_2)$; and

(iii) $\inf_{D_1,D_2}$ cond $(D_1 A D_2)$;

where D_1 and D_2 are diagonal matrices. It can be
shown that for all absolute norms there actually exist
diagonal matrices D_1 and D_2 such that the infima (i)
and (ii) are achieved. For fully indecomposable A and
with respect to the maximum-norm and the sum-norm,
D_1 and D_2 can be explicitly constructed such that the
infimum (iii) is achieved. It can also be shown that,
with respect to the maximum-norm and the sum-norm,
alternating between (i) and (ii) leads to the solution of
(iii).

J. Stoer and C. Witzgall considered the minimization
problem

(iv) $\inf_D$ lub $(D^{-1}AD)$

for strictly positive matrices A. It can be shown that,
with respect to the maximum-norm and the sum norm,
inf lub$(D^{-1}AD)$ is equal to the spectral radius of the
matrix $|A|$. Furthermore, if A is indecomposable, then
a D can be constructed for which the infimum (iv) is
achieved. With respect to the Euclidean norm, prob-
lem (iv) is solved for checkerboard matrices. *Abstract*

ΘCAUSEY, ROBERT LEWIS.   13,867
On closest normal matrices. (Thesis)
Stanford Univ., Stanford, Calif., 1964.

Let $\mathfrak{M}_n$, $\mathfrak{N}_n$, $\mathfrak{U}_n$, $\mathfrak{K}_n$, and $\mathfrak{D}_n$ denote, respectively, the sets of all arbitrary, normal, unitary, hermitian, and diagonal n by n complex matrices. A norm v on $\mathfrak{M}_n$ is said to be *unitarily invariant* if $v(A) = v(UAV)$ for all U, $V \in \mathfrak{U}_n$ and for all $A \in \mathfrak{M}_n$. The *distance* $d_v(A)$ between a fixed A in $\mathfrak{M}_n$ and the set $\mathfrak{N}_n$ with respect to the norm v is defined by $d_v(A) = \inf v(A - X)$ (infimum over $X \in \mathfrak{N}_n$). A normal matrix N_0 satisfying $v(A - N_0) = d_v(A)$ is called v-*minimal*. For $A = (a_{ij}) \in \mathfrak{M}_n$ with eigenvalues $\lambda_1, \cdots, \lambda_n$, let $\Omega(A) = \text{diag}(\lambda_1, \cdots, \lambda_n)$ and let ϵ denote the *Euclidean norm*:

$$\epsilon^2(A) = \sum_{i,j}|a_{ij}|^2 .$$

Mirsky (*Quart. J. Math. Oxford* 11(1960), 50–59) proved (*)

$$d_\epsilon^2(A) \leq (\tfrac{1}{2}) (\epsilon^2(A) - |\text{tr}(A^2)|)$$

and conjectured that $d_v^2(A) = (\tfrac{1}{2}) (v^2(A) - v^2(\Omega(A)))$ for all unitarily invariant norms v.

The central problems considered in this paper are those of finding v-minimal matrices and determining $d_v(A)$, especially in the case $v = \epsilon$. Let $\alpha_1, \cdots, \alpha_n$ denote the singular values of $A \in \mathfrak{M}_n$ (i.e., the nonnegative square roots of the eigenvalues of A^*A where A^* denotes the hermitian conjugate of A). Mirsky's conjecture is shown to be true for $v = \epsilon$ and $n = 2$, false for $v = \epsilon$ and $n \geq 3$, and false for $n \geq 2$ and $v = v_p(2 < p \leq \infty)$ where v_p denotes the unitarily invariant norm $v_p(A) = (\sum_k \tfrac{n}{=} 1\alpha_k{}^p)^{1/p}$. After a proof that v-minimal matrices exist for any $A \in \mathfrak{M}_n$ and for any norm v, it is shown that v-minimality is generally invariant under the transformations $T_U(A) = U^*AU$, $T_z(A) = A + zI$, and $T_\alpha(A) = \alpha A$ where $U \in \mathfrak{U}_n$ and z, α are complex numbers ($\alpha \neq 0$). Also, unequality (*) above is sharpened as follows: $(d_\epsilon^2(A) \leq (\tfrac{1}{2}) (\epsilon^2(A) - |\text{tr}(A)|^2/n - |\text{tr}(A^2))^2/n|)$. Another quite different upper bound for $d_\epsilon(A)$ is also obtained.   *From the Abstract*

ΘFARRELL, F. J.   14,534
A matrix symmetrization method for the algebraic eigenproblem. (M.Sc. Thesis)
University of Ottawa, Ottawa, Ont., Canada, 1963.

An arbitrary matrix M is said to be symmetrized by the symmetric matrix B whenever the product $A = BM$ is symmetric. When such a symmetrizing matrix is known for a given matrix M, the eigenvalue problem $(M - \lambda I)x = 0$ for M becomes $(A - \lambda B)x = 0$ where $(A - \lambda B)$ is symmetric.

The method of minimized iterations may be applied to construct symmetrizing matrices. For, when this method is applied to a real matrix M it produces a tridiagonal matrix V which is similar to M and is a direct sum of nonderogatory matrices. Also produced is a nonsingular diagonal matrix D which symmetrizes V and makes possible the formulation of the eigenvalue problem for M in the symmetric tridiagonal form $(DV - \lambda D)x = 0$.

An extension of the Rayleigh Quotient iteration may be applied to determine the real and complex eigenvalues of the problem $(DV - \lambda D)x = 0$ generated from a given, real, matrix M. In case M is nonderogatory, this method is modified slightly to determine the multiplicity of multiple eigenvalues and to inhibit convergence to known eigenvalues.

Abstract

ΘHANSEN, ELDON ROBERT.   14,0[
On Jacobi methods and block-Jacobi methods for computing matrix eigenvalues.**
Stanford Univ., Stanford, Calif., 1960.

This thesis considers several aspects of applying Jacobi methods for computing the eigenvalues of a Hermitian matrix or the principal values (singular values) of an arbitrary square matrix of complex elements. . . . Portions of the thesis consider ordinary Jacobi methods, for which $v = 1$. Cyclic Jacobi methods are considered in which the index pairs $\pi_k = (i_k, j_k)(i_k < j_k)$ are chosen cyclically so that each index pair occurs once in each cycle. It is argued that the ordering in the sequence $\{n_k\}$ affects the rate of (assumed) convergence of cyclic methods. An a priori criterion is given for determining which of two given orderings can be expected to produce faster convergence. Experimental evidence is presented which apparently confirms this analysis, even though it indicates that the rates of convergence for different orderings differ only slightly.

It is proved that certain orderings are equivalent in that the matrix A_k after any fixed number of complete cycles is the same for each ordering. In particular, it is shown that the so-called ordering-by-rows and ordering-by-columns are equivalent. . . . Quasicyclic Jacobi methods are also considered and are shown to converge under certain conditions.

Biased Jacobi methods are introduced in which each rotation is such that the larger of the two affected diagonal elements after each transformation occurs higher on the diagonal. The matrix A is partitioned in the form

$$A = \begin{bmatrix} A_1 & A_2 \\ A_3 & A_4 \end{bmatrix}$$

and rotations are performed only on the elements of A_2. It is shown that these elements converge to zero. However, an example is presented showing that, despite biasing, the eigenvalues of A_1 are not necessarily larger than those of A_2. Experimental evidence is presented which indicates that this method is quite inefficient.

The general problem of block-diagonalization of a Hermitian matrix by a unitary similarity transformation is considered. Certain similarities to Jacobi methods are described, as is the inherent difficulty of any noniterative method.

Finally, most of the results in a paper by G. E. Forsythe and P. Henrici ["The cyclic Jacobi method for computing the principal values of a complex matrix." *Trans. Amer. Math. Soc.* 94 (1960)] are extended to block-Jacobi methods.   *From the Abstract*

ΘKahan, W.   14,312
  Gauss-Seidel methods of solving large systems of linear
    equations. (Ph.D. Thesis)
  Univ. Toronto, Toronto, Ont., Canada, 1958.
    [*Editorial Note: This corrects a substantive error in
  quoting from the thesis [CR **9**, 1 (January 1968), Rev.
  13,470]. The author's own editing of his abstract follows.*]
    We consider the application of these iterative methods
  to the solution of the system

(1) $Ax = b$;   i.e., $\Sigma_j a_{ij} x_j = b_i$, $1 \le i, j \le N$.

Assume all the diagonal coefficients $a_{ii} = 1$; then the

matrix $A = -L + I - U$ where L and U are, respec-
tively, lower and upper triangular matrices with null
diagonals.
    The Extrapolated Gauss-Seidel iteration G_δ is defined
by

(2) $x^{(n+1)} = x^{(n)} + (1 + \delta)c^{(n)}$ where

$$c^{(n)} = b + Lx^{(n+1)} - x^{(n)} + Ux^{(n)}$$

and δ is the extrapolation parameter. When $\delta = 0$, (2)
defines the well-known ordinary Gauss-Seidel iteration
G_0; and positive and negative values of δ correspond, re-
spectively, to overrelaxation and underrelaxation. This
algorithm requires one of the simplest possible pro-
grammes and the least possible storage space in the com-
puter. In some cases (cf. chapter 4 in the thesis) this
algorithm provides an approximate solution to (1) which
is almost as accurate as it is possible to obtain. But if
the iteration G_δ converges at all it may do so only very
slowly. The thesis contains a large body of new results
about the rate of convergence of G_δ, with emphasis upon
the influence of the extrapolation parameter δ upon the
rate of convergence of G_δ.
    Systems (1) associated with elastic structures and least-
squares often have real symmetric positive definite ma-
trices A, and in such cases G_δ is known to converge if
$-1 < \delta < +1$. The thesis contains improved bounds for
the rate of convergence of G_δ and an analysis of Aitken's
modification of the Gauss-Seidel iteration. Semi-definite
matrices A are considered too.

    Systems (1) associated with diffusion and potential
problems often have matrices A which satisfy

(3) $a_{ij} \le 0$ if $i \ne j$ but $a_{ii} = 1$,

and when such matrices appear in certain economics prob-
lems they are called Leontieff matrices. The following
theorem is presented in the thesis:
    G_δ diverges when $|\delta| > 1$. If (3) is satisfied and G_0
    diverges, then G_δ diverges for all real δ. But if G_0
    converges, then G_δ converges when $-1 < \delta \le 0$ and
    also for some positive values of $\delta < 1$; and under-
    relaxation retards convergence.
Also presented are bounds for the rate of convergence of
G_δ; these bounds are of interest because none of them can
be improved unless more than (3) is assumed about the
matrix A of (1).

The matrix A often satisfies (3) and is symmetric too
when (1) is associated with the solution by finite differ-
ences of linear elliptic self-adjoint partial differential
equations, or with passive resistive electrical networks.
Then sharp bounds for the rate of convergence of G_δ may
be obtained with sufficient accuracy that the choice of
the best value for δ is facilitated. If R_{max} denotes the rate
of convergence of G_δ when the best value of δ is used,
and R_0 the rate of convergence of the ordinary Gauss-
Seidel iteration G_0, then when R_0 is small, (R_0 is usually
<.05)

$$1 \le R_{max}/\sqrt{R_0} \le 2 \text{ approximately.}$$

R_{max} is comparable with the rate of convergence of two
other well-known but more cumbersome iterations—the
Method of Orthogonal Polynomials described in Chapter

1, and Successive Block Overrelaxation, discussed in
Chapter 6 of the thesis.
                                    ↙ Abstract

ΘLewis, Jesse C.
13,655
A computer study of permanents of n-square $(0,1)$—matrices in the class $U(k,k)$. (Thesis)
Syracuse Univ., Syracuse, N. Y., 1966.

If $A = [a_{ij}]$ is a square matrix of order n then the *permanent* of A is defined by

$$\operatorname{per}(a) = \sum a_{1i_1} a_{2i_2} \cdots a_{ni_n},$$

where $i_k, i_2, \ldots, i_n$ range over all permutations of the integers $1, 2, \ldots, n$.

In Chapter II (the first chapter is the Introduction) we give a brief exposition on the permanent function in combinatorial mathematics. We also construct a computer program for calculating the permanents of $(0,1)$-matrices by counting systems of distinct representatives.

Let A be a $(0,1)$-matrix of order n with exactly k 1's in each row and column. Then A is said to be in the class $U(k,k)$. One of the unsolved problems of interest in permanent theory is concerned with maximum and minimum values of the permanents of matrices in $U(k,k)$. For matrices of small order, a few cases can be solved by hand calculations and, like many problems in combinatories, only a few additional cases can be solved by a computer. In Chapter III we use a computer (IBM 7074) to solve these few additional cases and partition the matrices into permanent subclasses. We also verify a conjecture due to Henryk Minc for matrices of order less than or equal to 7.

Chapter IV describes the main computer program in detail. This program has been completely debugged and is very efficient. Hence with a faster computer, such as the IBM 7094, it could be used to extend the investigations of this dissertation. We also wrote a double precision program to extend a table for the permanents of the $(0,1)$-circulants

$$\sum_{j=0}^{k-1} C_n^j,$$

where C_n is the n-square permutation matrix with 1 in the $(1,2),(2,3),\ldots,(n-1,n)$ and $(n,1)$ positions, and k is the number of 1's in each row and column of the circulants. The table was done for matrices of order less than or equal to 7 at the University of Florida Computing Center using a program written by Paul J. Nikolai. We extended the table to matrices of order 15.

The Appendix contains these two programs and others used for computing the results of this dissertation.
✓ *Abstract*

ΘOrtega, James M.
13,866
An error analysis of Householder's method for the symmetric eigenvalue problem. (Thesis)
Stanford Univ., Stanford, Calif., 1962.

[*Editorial note:* A paper based on this was reviewed when published as "An error analysis of Householder's method for the symmetric eigenvalue problem." Applied Math. and Statistics Labs; Stanford Univ., Stanford, Calif., No. 18 (Feb. 1962), 103 pp.; *CR* **3**, 6 (Nov.-Dec. 1962), Rev. 3339.]

The Householder reduction of a real symmetric $N \times N$ matrix A to tridiagonal form is the principal step of a numerical method for calculating the eigenvalues of A. If this reduction is carried out on a digital computer in floating point arithmetic, an upper bound for the possible eigenvalue error due to rounding is shown to be

$$f(N, m_b, m_s)[1 - f(N, m_b, m_s)]^{-1}||A||,$$

where m_b and m_s are bounds for relative errors in the arithmetic operations and square root, respectively. If the spectral norm of A is used then

$$f(N, m_b, m_s) = 55(N-2)m_s + (3.2 N^{5/2} + 9.75 N^2 + 6.0 N^{3/2} + 157.0 N - 397)m_b,$$

while if the Euclidean norm is used then

$$f(N, m_b, m_s) = 55.5(N-2)m_s + (13.9 N^2 + 160.9 N - 378)m_b.$$

Furthermore, if the computation can be made with an exact accumulated innerproduct then for the spectral norm f can be reduced to

$$55(N-2)m_s + (6.0 N^{3/2} + 161.1 N - 348.7)m_b,$$

and for the Euclidean norm it can be reduced to

$$55.5(N-2)m_s + 174.8(N-2)m_b.$$

The results of several numerical experiments with Householder's reduction are also presented. These results indicate that the error bounds are pessimistically large and that the reduction is, in fact, incredibly accurate.
✓ *Abstract*

ΘPARLETT, BERESFORD NEILL.   13,864
I. Bundles of matrices and the linear independence of
  their minors; II. Applications of the matrix eigenvalue
  problem. (Thesis)
Stanford Univ., Stanford, Calif., 1962.

[*Editorial note:* A paper based on this was reviewed
when published as "Laguerre's method applied to the
matrix eigenvalue problem." *Math. Comput.* **18**, 87 (July
1964), 464–485; *CR* 6, 1 (Jan.-Feb. 1965), Rev. 6979.]

PART I. Let K be a commutative field and let

$K[\lambda]$ and $K[\lambda, \mu]$ be the rings of polynomials in, re-
spectively, one and two indeterminates. Consider
equivalence over an integral domain of square matri-
ces with elements in that domain.

Criterion 1: Matrices are equivalent if, and only
if, they generate the same set of determinantal ideals
in the domain.

Criterion 2: Matrices are equivalent if, and only
if, they generate the same set of greatest common
divisors (or invariant factors or elementary divisors).

Definition: Matrices over $K[\lambda, \mu]$ whose elements
are linear and homogeneous in λ and μ are called
bundles. Thus any bundle may be written in the form
$\mu A + \lambda B$, where A and B are square matrices over
K of the same order. . . .

PART II. Let z be an approximation to a zero of
a polynomial $P(z)$. Laguerre's method uses $P(z)$,
$P'(z)$, and $P''(z)$ to obtain a better approximation.
For polynomials with real zeros Laguerre iterations
have interesting properties including good initial
convergence. Some of the properties extend to La-
guerre iterations in the complex plane. In particular,
a proof of the local cubic convergence of the method
is given. These iterations require substantial calcula-
tion but despite this seem to provide a satisfactory
and powerful start to an iterative search for zeros.

Some known results indicating the practical diffi-
culty of computing matrix eigenvalues are given and
then two methods are described. . . . Algorithms for
these methods are described in ALGOL 60 and supple-
mentary notes on some of the decisions taken and
techniques used. . . .   *From the Abstract*

ΘPATTON, P. C.   13,659
The simultaneous computation of eigenvectors and eigen-
  value spectra of arbitrary dynamical matrices. (Thesis)
Technical Univ. Stuttgart, Stuttgart, Germany, 1966.

This dissertation describes a new numerical method
for simultaneously calculating all (or any dominant
subset) of the eigenvalues and eigenvectors of a normal
real or complex matrix. It has also been successfully
applied to a number of non-normal but normalizable
complex matrices arising from various technical fields,
and, particularly, the reduced dynamical matrix of
Frazer, Duncan, and Collar, as it occurs in aircraft
structure dynamics problems.

The method of this thesis is known in the literature
as the A/P (Aronszajn/Patton) Algorithm, and it is
developed for the real symmetric case and extended
for Hermitian, normal, and normalizable complex ma-
trices. An application of the method for a flutter analy-
sis of the Super VC-10 transport aircraft involving 27
degrees of freedom is given as a final example.

The A/P Algorithm is based on the Rayleigh
Quotient, and enjoys the quadratic convergence char-
acteristic of such methods. Given an $n \times n$ normaliza-
ble complex matrix A and estimates of its right- and
left-hand eigenvectors X and Y, respectively, the
eigenvalues $\underline{\Lambda}$ may be estimated from the Rayleigh
Quotient as

$$\Lambda = \lceil Y A X \rfloor,$$

where X is a column matrix and Y is a row matrix of

eigenvectors. The partial bracket notation indicates
taking the diagonal of the product. . . .

To obtain good starting vectors for the algorithm, it
is usually necessary to choose a sequence of auxiliary
matrices

$$A_0, A_1, A_2, \ldots, A_k$$

such that the eigenvectors of A_0 are obvious, A_k is
identical to the original problem A, and the eigenvec-
tors of each A_i are sufficiently good starting approxi-
mations to those of A_{i+1}. Several automatic computer
methods for choosing such sequences of auxiliary
problems are given.

A complete FORTRAN IV program for the applica-
tion of the A/P Algorithm to complex matrices is
given in an appendix.   *From the Abstract*

I. Best possible ratios of certain matrix norms; II. Lower bounds for the eigenvalues of a fixed membrane. (Thesis)

Stanford Univ., Stanford, Calif., 1962.

[Editorial note: Part I of this thesis was reviewed as *Best possible ratios of certain matrix norms*, Applied Math. and Stat. Labs., Stanford Univ., Stanford, Calif., Tech. Report No. 12 (Sept. 1961), 15 pp., CR **3,** 3 (May-June 1962), Rev. 2010; also in Applied Math. and Stat. Labs., Stanford, Calif., ONR contract Nonr-225 (37), Tech. Report No. 19 (May 1962), 1–67; CR **4,** 2 (March-April 1963), Rev. 4015. Part II was reviewed as *Lower bounds for the eigenvalues of a fixed membrane*, Applied Math. Stat. Lab., Stanford Univ., Stanford, Calif., Tech. Report No. 20 (May 1962), 68–110; CR **4,** 2 (March-April 1963), Rev. 4046.]

In the first part of this dissertation are calculated a set of constants

$$p_{\mu,v} = \max_{\substack{A \in M_n(C) \\ A \neq 0}} \left[\frac{\mu(A)}{v(A)} \right],$$

where μ, v are selected from a certain family H of matrix norms, and where $M_n(C)$ is the algebra of square n-rowed matrices over the complex numbers. The class H of matrix norms is constructed from a set H' of six familiar matrix norms as follows. Let p be a norm in H' and let S be any unitary or non-singular diagonal matrix in $M_n(C)$. H is the class of elements pS, where pS is defined on $M_n(C)$ by

$$pS(A) = p(SAS^{-1}).$$

The second part gives asymptotic lower bounds for the eigenvalues λ^k of a plane membrance R, which need not be convex, fixed along a boundary C which is the union of a finite number of piecewise analytic closed curves each of whose corners is convex. These lower bounds are found by calculating the eigenvalues $\lambda_{hT}{}^k$ of a related discrete problem on a regular triangular grid whose mesh constant is h. Under these conditions we are able to prove that

$$\lambda_{hT}^k \le \lambda^k - \frac{\mu^2}{16} (\lambda^k)^2 + 0(h^2), \quad \text{as } h \to 0,$$

$$k = 1, 2, \cdots.$$

✓ Abstract

The computation of bounds for the invariant subspaces of a general matrix operator. (Thesis)

Stanford Univ., Stanford, Calif., 1967.

Let A be a general $n \times n$ complex matrix. We consider the problem of finding the invariant subspaces of A, i.e., solving $AX = XM$ for X nonsingular and M block-diagonal. We first consider finding the eigensystem of A (i.e., M diagonal), assuming approximations to the eigenvalues are given. We show how to find approximate eigenvectors and rigorous machine bounds for the errors in the approximate eigensystem. Then we show how to find approximations and rigorous error bounds for higher dimensional invariant subspaces of matrices which are close—in a sense we describe—to defective matrices, and for which poor results would be obtained for the eigensystem. Burroughs B5500 Extended Algol programs using these methods are also given.

✓ Abstract

On the tridiagonalization of a non-Hermitian matrix using similarity transformations. (Thesis)

Univ. Texas, Houston, Texas, 1964.

This paper contains a detailed discussion of a new method [La Budde, *Math. Comp.* **17** (1963), 433–437] for tridiagonalizing an arbitrary matrix using similarity transformations. La Budde's method is essentially a generalization of Householder's method [Wilkinson, *Comp. J.* **3** (1960), 23–27] for the tridiagonalization of a real symmetric matrix.

The algorithm is composed of $(n - 2)$ steps. Starting with A_1, a sequence of $(n - 2)$ matrices $A_2, \cdots, A_{n-1}$ is generated, each being similar to A_1 and such that A_i has zeros in the off-tridiagonal positions of its first $i - 1$ rows and columns. Thus, A_{n-1} is tridiagonal.

Let the generic ith step (transformation from A_i to A_{i+1}) be denoted by (we shall omit the index i for simplicity of notation)

$$(1) \qquad A' = RAR^{-1}.$$

At the beginning of the ith step, A has the form

$$(2) \qquad A = \begin{bmatrix} T & \begin{matrix} O \\ \hline b^T \end{matrix} \\ \hline O \mid c & B \end{bmatrix},$$

where T is an $i \times i$ tridiagonal matrix, where B is an $(n - i) \times (n - i)$ submatrix, and where $b^T = (b_{i+1}, b_{i+2}, \cdots, b_n)$ and $c^T = (c_{i+1}, c_{i+2}, \cdots, c_n)$ are both $(n - i)$-dimensional vectors.

The transformation matrix R has the form

$$R = \begin{bmatrix} I & O \\ \hline O & H \end{bmatrix}.$$

Hence

$$R^{-1} = \begin{bmatrix} I & O \\ \hline O & H^{-1} \end{bmatrix}.$$

The submatrix H has the form $H = I - \alpha xy^T$ and its inverse has the form $H^{-1} = I - \beta xy^T$, where α and β are nonzero scalars, where $x^T = (x_{i+1}, x_{i+2}, \cdots, x_n)$ and $y^T = (y_{i+1}, y_{i+2}, \cdots, y_n)$ are $(n - i)$-dimensional vectors, and where α, β, x, and y are related by

$$(3) \qquad y^T x = 1/\alpha + 1/\beta.$$

Hence the matrix A' of (1) has the form

$$(4) \qquad A' = \begin{bmatrix} T & \begin{matrix} O \\ \hline (b')^T \end{matrix} \\ \hline O \mid c' & B' \end{bmatrix}$$

The problem is to determine the matrix H so that in A', $(b')^T = [b'_{i+1}, 0, \cdots, 0]$ and $(c')^T = [c'_{i+1}, 0, \cdots, 0]$. The last $(n - i - 1)$ components of b' and c' can be written

$$(5) \qquad \begin{matrix} b_k - \beta(x^T b)y_k = 0 \\ c_k - \alpha(y^T c)x_k = 0 \end{matrix} \qquad (k = i + 2, \cdots, n).$$

... If the original matrix is Hermitian, then following Ortega [*Numerische Mathematik* 6 (1963), 211–225], an a priori error bound has been found for the maximum error that can be introduced in any eigenvalue by the accumulation of rounding errors that occur during the tridiagonalization.

Limited numerical results seem to show that La Budde's algorithm is quite fast and accurate for the matrices tested.

✓ From the Abstract

5.15 NONLINEAR & FUNCTIONAL EQUATIONS

ΘDANIEL, JAMES WILSON.   14,083
The conjugate gradient method for linear and nonlinear operator equations. (Thesis)
Stanford Univ., Stanford, Calif., 1965.

M. R. Hestenes developed the completely general conjugate gradient (CG) method for solving finite

systems of linear algebraic equations; R. M. Hayes extended a special case of the method, as originally presented by Hestenes and E. Stiefel, to linear operator equations in Hilbert space and proved convergence under the assumption that the directions generated during the iteration span the entire space.

This paper develops the general CG method in Hilbert space and proves convergence independently of any assumption on the space spanned by the generated directions; the convergence is shown to be at least as fast as a certain geometric series. The CG method is shown to be optimal in a class of iterative techniques, including that of steepest descent, in the sense that the CG method reduces a certain error measure further in n steps than any other method in the class, for all n; this yields an improved rate of convergence estimate. Special cases are given which exhibit still more rapid (even superlinear) convergence. Some simple extensions of the theory are developed, and applications are presented with suggestions for the numerical treatment of matrix, integral, and differential equations.

A form of the CG method is developed for nonlinear operator equations. Convergence of the iteration is proved in a special case for arbitrary initial approximation and for the general method provided the initial approximation is near enough to a solution; the convergence is faster than any geometric series with ratio greater than that first given in the chapter on linear equations. It is shown that the convergence is not disturbed by making certain changes in the iteration to make it computationally simpler. A general descent technique is discussed, including the steepest descent and CG methods, and the earlier convergence proofs are extended to this technique. Applications are given with suggestions for the numerical treatment of integral, differential, and systems of algebraic equations.

Abstract

ΘSOOFI, A. R.   14,537
A method to determine the Cauchy Index of a real rational function. (M.Sc. Thesis)
University of Ottawa, Ottawa, Ont., Canada, 1967.

The Cauchy Index of a real rational function $R(x)$ arises in connection with the problem of determining the number of zeros of a polynomial within a closed

rational curve by means of the Argument Principle. The number of such zeros is related to the invariants —rank and signature—of Hankel forms whose coefficients are generated by the Taylor series expansions of $R(x)$ and $1/R(x)$. According to a theorem of Jacobi and the law of inertia of quadratic forms, the rank and signature of a Hankel form may be expressed in terms of the variations and permanences of sign in a sequence of Hankel determinants. These determinants may be evaluated in turn in terms of the Taylor coefficients of $R(x)$, or, alternatively of $1/R(x)$, with the aid of a recursive algorithm suggested by Aitken in connection with his generalization of Bernoulli's method for solving algebraic equations.   Abstract

5.16 NUMERICAL INTEGRATION & DIFFERENTIATI

ΘBAXTER, STUART D.   13,665
Numerical methods for the solution of hyperbolic differential equations with the aid of an electronic computer. (Thesis)
Univ. Toronto, Toronto, Ont., Canada, 1958.

The object of the present research was an examination of the method of characteristics as a numerical method for the solution of partial differential equations of the hyperbolic type. In particular, this examination was undertaken with a view to the development of programs for an electronic computer by which partial differential equations of the hyperbolic type may be solved provided such equations belong to one of a few general classes. For the most part, systems of first-order equations in both two and three independent variables were considered. The programs which have been developed are based on the use of a fixed grid rather than on the more customary network of characteristics.

In the first section of the thesis a general quasi-linear system of two first-order hyperbolic equations in two independent variables was considered. It is possible to replace such a system by a system of ordinary differential equations which hold along the characteristics. These equations may be integrated numerically. Such a numerical procedure was programmed for FERUT, the electronic computer at the University of Toronto. . . .

The second section of the thesis dealt with the solution of a system of first-order equations in three independent variables. The numerical approach which was outlined for the solution of a general quasi-linear system of this type was that based on the use of characteristic surfaces. This method was applied to a specific fluid flow problem (the same one considered in the two-dimensional treatment, only now the symmetry was neglected) and results were obtained on FERUT. . . .

From the Abstract

ΘFrank, Thurman Gustav.   14,084
Error bounds on numerical solutions of Dirichlet problems
    for quasilinear elliptic equations. (Thesis)
Univ. Texas, Houston, Texas, 1966.

In this paper, finite difference approximations to
Dirichlet problems for quasilinear, uniformly elliptic
partial differential equations are studied. Conver-
gence, with decreasing mesh width h, of solutions of
finite difference analogs to the solution of the given
continuous problem is established by means of bounds
on the error in the solutions of the finite difference
problems.

A finite difference analog of problem P is formulated
by the use of central divided differences except at
points near the boundary. Two alternative approxi-
mations for use at points near the boundary are
studied. The finite difference formulation includes an
elaboration of a method due to J. H. Bramble and
B. E. Hubbard [see *Contributions to differential equa-
tions* 2 (1963), 319–340.] for approximating the term
$2B\, \partial^2 u / \partial x\, \partial y$.

The error E in the solution of a finite difference
approximation to problem P is defined by

$$E = U - u ,$$

where u is the solution of problem P and U is the
solution of a finite difference approximation to prob-
lem P. Finite difference equations, which are non-
linear, are derived for the error. The error equations
are linearized, and bounds are obtained on solutions
of Dirichlet problems for the linearized error equa-
tions. These bounds, which are $O(h^p)$, $p \geq 1$, are
shown to apply to Dirichlet problems for the original
nonlinear error equations by the use of a fixed-point
argument. . . .

A further analysis of the approximations which are
used at points near the boundary shows that error
bounds which were determined to be $O(h)$ for some
cases are actually $O(h^2)$ in all cases considered.

                                        ✓ *From the Abstract*

ΘOkashimo, Katsumi.   13,66
The numerical integration of integro-differential equations
    of convolution type. (Thesis)
Univ. Toronto, Toronto, Ont., Canada, 1955.

In this thesis, we are concerned with the problem of
obtaining the solution of the integrodifferential equa-
tion,

$$\frac{dn(x, t)}{dt} = \frac{1}{2} \int_0^x n(x - u, t) n(u, x)\, f(x - u, u)$$

$$(1.01) \qquad \times\, du - n(x, t) \int_0^\infty n(y, t) f(x, y)\, dy ,$$

subject to the initial condition,

$$(1.02) \qquad n(x, 0) = g(x) ,$$

where $g(x)$ is a given function of x. . . . It is our purpose
to describe a numerical method by which the function
$n(x,t)$ may be tabulated as a function of the inde-
pendent variables x and t.

. . . Recently, Melzak and Hitschfeld obtained the
general solution for $f(x,y) = a$ and $f(x,y) = axy$. They
also considered $f(x,y) = axy + b(x + y) + c$, where
a, b, and c are constants. Their results are reviewed in
Chapter 3.

In Chapter 2 the derivation of the equation (1.01) is
given as a mathematical description of a particular
birth and death process. We consider a system of
randomly moving cloud droplets which collide and co-
alesce to form larger droplets. The function $n(x,t)$ de-
scribes the frequency distribution of the droplets of size
x at time t.

. . . For such case where the variable x is restricted to
take only discrete values, we have a discrete process
which may be described by a system of ordinary dif-
ferential equations of the first order. Let us speak of
elements with property x for a more general discrete
birth and death process. Since discrete values of x can
always be numbered consecutively, all the elements
may be considered to belong to one of the types 1, 2,
3. . . . If we let $m_i(t)$ be the number of elements belong-
ing to type i, at time t, the discrete process may be de-
scribed by the equations of the type

$$(1.03) \qquad \begin{aligned} \frac{dm_i(t)}{dt} &= B_i(m_1, m_2, m_3, \cdots ; t) \\ &\quad - D_i(m_1, m_2, m_3, \cdots ; t) , \end{aligned}$$

where $i = 1, 2, 3. \ldots$

. . . In Chapter 4, the fundamental equation (1.01) is
approximated by a system of differential equations of
the type (1.03).

. . . A few numerical examples are discussed in Chap-
ter 5. Since the best way to determine the accuracy of
a numerical solution is to compare it with the exact
solution, the first example is the one in which Schu-
mann had solved exactly. . . . The second example con-
cerns the size distribution of raindrops due to coales-
cence. . . .

Finally, in Chapter 6, a numerical procedure based
on Picard's method is considered as a method for ap-
proximating the solution of the system of differential
equations of type (1.03). The convergence of this nu-
merical procedure is studied. . . .   *From the Abstract*

⊖EVANS, BERNARD B.   13,486

Explicit asymmetric difference algorithms for the approximate solution of parabolic partial differential equations. (Thesis) *PhD*

Purdue Univ., Lafayette, Ind., 1967.

The usefulness of asymmetric algorithms for the solution of quasi-linear parabolic problems is investigated. The derived operators are analyzed in a precise mathematical setting with stability and convergence proofs given where possible. Numerical results are presented and a comparison of the computing efficiency of the asymmetric and certain well-known techniques is given.

The results indicate that the derived algorithms are effective tools for computing numerical approximations to the quasi-linear diffusion problem, particularly in two dimensions. A natural extension of one of these methods to the fourth order beam equation is shown to be unstable.   *Abstract*

⊖KERR, DOUGLAS S.   13,875

On some iterative methods for solving a class of nonlinear boundary value problems. (Thesis)

Purdue Univ., Lafayette, Ind., 1967.

Consider the nonlinear two-point boundary value problem

(1) $y'' = f(x, y, y')$, $y(a) = A$, $y(b) = B$,

where $y = (y^1, y^2, \cdots, y^m)$ is an m vector. Introduce the mesh points $x_n = a + hn$, $n = 0, 1, \cdots, N + 1$ where $(N + 1)h = b - a$. This leads to the mN finite difference equations

(2) $y_{n+1}^k - 2y_n^k + y_{n-1}^k + h^2 f^k(x_n, y_n, \dot{y}_n) = 0$,

for $k = 1, 2, \cdots, m$ and $n = 1, 2, \cdots, N$, where y_n^k

is an approximation to $y^k(x_n)$, $y_n = (y_n^1, y_n^2, \cdots, y_n^m)$, $\dot{y}_n = (\dot{y}_n^1, \dot{y}_n^2, \cdots, \dot{y}_n^m)$, and $\dot{y}_n^k = (y_{n+1}^k - y_{n-1}^k)/(2h)$. Assuming $A = B = 0$ for simplicity, (2) may be written as $\mathcal{J}Y + h^2\mathcal{F}(Y) = 0$. Assume that the function f satisfies the Lipschitz condition

(3) $\|f(x, y, z) - f(x, \bar{y}, \bar{z})\| \leq L_0\|y - \bar{y}\| + L_1\|z - \bar{z}\|$

for all $(x, y, z, \bar{y}, \bar{z}) \in R \times R^m \times R^m \times R^m$, where $\|g\| = \max\{|g^k|: 1 \leq k \leq m\}$. Further assume that the constants L_0 and L_1 are such that $K = L_0(b - a)^2/8 + L_1(b - a)/2 < 1$. *Theorem* 1. Picard iteration, $\mathcal{J}Y^{(q+1)} = -h^2\mathcal{F}(Y^{(q)})$, converges linearly to the unique solution of (2). Now assume that (3) is replaced by the somewhat stronger conditions $\|f_y(x, y, z)\| \leq L_0$ and $\|f_z(x, y, z)\| \leq L_1$, and that f_{yy}, $f_{yy'}$, and $f_{y'y'}$ exist and are bounded. *Theorem* 2. If the initial approximation is sufficiently close, then Newton's method applied to (2) converges. . . . *Theorem* 3. Under some additional hypotheses the sequence generated by (4) converges to a solution of (2). . . . *Theorem* 4. The discretization error is $0(h^2)$. *Theorem* 5. The asymptotic error $e_n^K = y_n^K - y^K(x_n) = h^2 e^K(x_n) + 0(h^4)$ and $y_n^k - y^{k'}(x_n) = h^2[e^{k'}(x_n) + y^{k'''}(x_n)/6] + 0(h^4)$, where e satisfies the linear two-point boundary value problem $e'' = R(x)e + S(x)[e' + y'''(x)/y] - y^{IV}(x)/12$, $e(a) = 0 = e(b)$. Finally, the three numerical methods are applied to several sample problems.   *From the Abstract*

⊖MEISSNER, LOREN P.   13,488

Nonlinear resonance for Duffing's differential equation. (Thesis) *PhD*

Univ. California, Berkeley, Calif., 1965.

Some sufficient conditions are given for the existence and uniqueness of solutions to the problem $Py = Qy - \lambda \cdot y = 0$ when a solution y_0 has been found for $\lambda = 0$, i.e., $Qy_0 = 0$. These conditions are applied to the Duffing problem,

$$\gamma^2 \cdot Dy^2(\theta) + y(\theta) + \beta \cdot y^3(\theta) = \cos \theta$$

$$y(\pi/2) = 0, \qquad Dy(0) = 0,$$

in two separate areas: first, to prove the existence of a a sequence of solutions tending to the solution of the "reduced" problem, $\gamma = 0$, in spite of the failure of the standard singular perturbation approach; and second, to rigorously show the nature of the principal solutions tions near several low-order resonances (γ near 1), including the divergence of the solutions into two separate branches in a region of resonance.

Detailed quantitative information is presented concerning solutions of the Duffing problem for various values of β and γ (particularly in the region $0 < \beta \leq 1$, $0 \leq \gamma \leq 1$) and the numerical procedure for obtaining these results is described. Data is given to substantiate the theoretical results by (a) illustrating the behavior of solutions for small values of γ, and (b) exhibiting the solution and the divergence into branches in low-order resonance regions.   *Abstract*

⊖Moler, Cleve B.　　　　　　　　　　13,876
Finite difference methods for the eigenvalues of Laplace's operation. (Thesis)
Stanford Univ., Stanford, Calif., 1965.

[*Editorial note:* A paper based on this was reviewed when published as *Finite difference methods for the eigenvalues of Laplace's operator*, Stanford Univ., Stanford, Calif., Tech. Report C522 (May 1965), 142 pp.; *CR* **7**, 3 (May-June 1966), Rev. 9767.]

Let G be a bounded, two-dimensional domain with piecewise analytic boundary Γ. Let Δ denote the Laplacian $(\partial^2/\partial x^2) + (\partial^2/\partial y^2)$. The kth eigenvalue of Δ over G is a number, λ^k, for which there exists a nonzero function, u, defined on $\overline{G}$, such that

$$\Delta u(p) + \lambda^k u(p) = 0, \quad P \in G,$$

$$u(P) = 0, \quad P \in \Gamma.$$

We are interested in finite difference methods for approximating these eigenvalues. We denote by $\Delta_{h,m}$ a difference operator which approximates Δ. Here h is the size of a square mesh covering the plane and $m = 0, 1,$ or 2 is the degree of an extrapolating polynomial used to define $\Delta_{h,m}$ near the boundary. The operators are all based on a five-point difference approximation to Δ. The corresponding eigenvalues are denoted $\lambda_{h,m}^k$. The operators $\Delta_{h,0}$ and $\Delta_{h,1}$ are positive definite and hence have real eigenvalues. We denote by $\Delta_{h,s}$ the self-adjoint operator obtained by averaging $\Delta_{h,2}$ with its adjoint.

The main content of the paper is a study of the rate of convergence of $\lambda_{h,m}^k$ to λ^k as h goes to zero. An example is given in which $\lambda_{h,0}^k - \lambda^k$ and $\lambda_{h,s}^k - \lambda^k$ are of order h, while $\lambda_{h,1}^k - \lambda^k$ and $\lambda_{h,2}^k - \lambda^k$ are of order h^2 as $h \to 0$.

The structure of the domain G and boundary Γ plays an important role. We say that G has no re-entrant corners if, at all the points of Γ where distinct analytic arcs meet, the interior angles are less than π. We say that G requires no interpolation at the boundary if it can be oriented so that there is a sequence of mesh widths for which Γ intersects the mesh lines only at mesh points. If G requires no interpolation at the boundary then all four difference operators reduce to the same operator which we denote by Δ_h. . . . 　　　　　*From the Abstract*

Sweet, Roland A.　　　　　　　　　　13,669
Properties of a semi-discrete approximation to the beam equation. (Thesis)
Purdue Univ., Lafayette, Ind., 1967.

The solution of the equation

$$w(x)u_{tt} + [p(x)u_{xx}|_{xx} = 0, \quad 0 < x < L, \quad t > 0,$$

where it is assumed that w and p are positive on the interval $[0,L]$, is approximated by using the method of straight lines. The resulting approximation is a linear system of differential equations with coefficient matrix S. The matrix S is studied under very general boundary conditions which result in a conservative system. In all cases the matrix S is either an oscillation matrix or possesses nearly all the properties of an oscillation matrix.

The computation of eigenvalues and eigenvectors of the quidiagonal matrix S is discussed. A recursive relation for the computation of the determinant of a quidiagonal matrix is given.

Some numerical examples are given to indicate that this method is an accurate technique for obtaining information on the eigenvalues and mode shapes of the equation.　　　　　　*Abstract*

⊖Whiteman, John Robert.　　　　　　　13,668
Numerical treatment of elliptic boundary value problems involving singularities. (Thesis)
Royal Military College of Science, Shrivenham, England, 1967.

This thesis is concerned with the numerical treatment of elliptic boundary value problems in which the regions of definition contain reentrant corners. . . . Cases in which the governing partial differential equation is either harmonic or biharmonic are considered. The thesis consists of three parts followed by short concluding remarks.

An introductory survey of methods for obtaining numerical solutions of elliptic boundary value problems together with fairly comprehensive references to the literature is given in Part I. Formulas relevant to the later work are included in this survey.

Part II deals with harmonic boundary value problems for reentrant regions. The work of Motz and Woods is discussed and extended with reference to a particular problem of this class. A new dual series method which produces an extremely accurate approximation to the exact solution of this problem and a bound for the truncation error is given. The methods of collocation and of conformal transformation are also demonstrated on this problem. The relative merits and the possibility of extension of all these methods are discussed.

A biharmonic problem for a reentrant region is considered in Part III. Variants of the Motz and Woods methods are applied to this problem, and the results produced are compared with those obtained with the standard finite-difference method and with others derived previously using a collocation technique.　　*From the Abstract*

⊖GRACE, DONALD WAYNE.   13,880
Computer search for non-isomorphic convex polyhedra.
   (Thesis)
Stanford Univ., Stanford, Calif., 1965.

   This dissertation is concerned with the solution of
the enumeration problem on a digital computer.
   A trilinear polyhedron is one in which each vertex
is incident with exactly three edges. Two polyhedra
are *isomorphic* if a one-to-one correspondence can be
established between the vertices, edges, and faces
of one with those of the other, so that the incidence
relations between elements are preserved. Two polyhe-
dra are called equisurrounded if a one-to-one corre-
spondence can be established between the faces of
one and the faces of the other so that each pair of
corresponding faces has equivalent surroundings. . . .
A polyhedron of F faces can be made from a poly-
hedron of F-1 faces by *partitioning* one face into
two. . . . If the partition line does not pass through
an existing vertex, and the $(F-1)$-hedron is trilinear,
then the F-hedron created is also trilinear. . . . The
dissertation contains a program in the "Extended
ALGOL" language for the Burroughs B5000 computer
which starts with the tetrahedron, performs all
possible partitions of faces to form pentahedra, but
saves only a set of pentahedra, no two of which are
equisurrounded. Then it uses the pentahedra as in-
puts, partitioning their faces to form hexahedra of
distinct surroundedness, and so on to heptahedra
and further. The original program enumerated in
this way the convex trilinear polyhedra of up to
eleven faces. The a modification was introduced
which limited the faces of the polyhedra accumulated
to no more than six sides. With this restriction, sub-
classes of polyhedra of up to 15 faces were enumerated.
The computer program and the list of the enumerated
polyhedra are included *in extenso* in the appendix.
The relation between isomorphy and equisurround-
edness is clarified, although not exhaustively. Also
the combinatorial nature of the problem is touched
upon, and a connection with the dissertation of
polygons into triangles is discussed.
                              From the Abstract

⊖RABIN, MICHAEL O.   13,671
Recursive unsolvability of group theoretic problems.
   (Thesis) *Ph D*
Princeton Univ., Princeton, N. J., 1956.

   This study deals with questions concerning the
existence of effective decision procedures for certain
problems in the theory of finitely presented groups.
   As a preliminary we introduce and study, in Chapter
I and Section 0.1, the concept of a recursive algebraic
system. A recursive group is, roughly speaking, a
group in which multiplication is an effectively com-
putable function. The behavior of recursive groups
under passage to quotient groups and subgroups is
studied. The work problem of a presentation is recur-
sively solvable if and only if the group defined by it is a
recursive group. It follows that a group defined by a
presentation with an unsolvable word problem cannot
be faithfully represented by matrices over any field.
The algebraic closure of a recursive field turns out to be
a recursive field. The main theorem is stated and
proved in Chapter II. . . .
   It follows (Chapter III) from the main theorem that
there does not exist a general effective procedure for
deciding, for every given presentation, whether the
group defined by it is 1) trival; 2) cyclic; 3) finite; 4)
locally infinite; 5) free; 6) commutative; 7) solvable;
8) simple; 9) decomposable into a direct product; 10)
decomposable into a free produce; 11) a free product of
finite groups; 12) definable by a single relation; 13) a
group with a solvable word problem; and 14) a knot-
group.
   We also show that the isomorphism problem for
f.p. groups is not effectively solvable. Furthermore, it
is impossible to solve the isomorphism problem even
by a bountably infinite system of computable iso-
morphism invariants, i.e., any such system is neces-
sarily incomplete.

   All these results clearly indicate that though an f.p.
group is uniquely defined by a given presentation, in
general, very little information about the group can
be obtained from the presentation.
                              From the Abstract

5.2 METATHEORY

5.21 FORMAL LOGIC

ΘABRAHAMS, PAUL WILLIAM. *5.21* 13,672
Machine verification of mathematical proof. (Thesis)
M.I.T., Cambridge, Mass., 1963. *Ph D*

This dissertation describes some investigations into the possible use of a digital computer to check mathematical proofs of the type that normally appear in textbooks. A computer program called the Proofchecker was written that verifies proofs written in a specified input format. A two-step process is involved in checking a proof within this framework: the proof is first translated from the language of the textbook proof into the input language of the Proofchecker, and the Proofchecker then attempts to translate the input proof into a rigorous proof, i.e., into a sequence of steps in a formal logical system. The work described here included not only the construction and application of the Proofchecker, but also the investigation of the formal system upon which the Proofchecker was based, and the development of a set of methods for translating from textbook proofs to input proofs.

The Proofchecker was programmed in LISP and operated on the IBM 7090. An input proof is given in the form of a list of LISP S-expressions, each of which represents a macro-step. Macro-steps bear a relationship to rigorous proof steps much like the relationship that macro-instructions in a macro-assembler bear to machine instructions in that assembler. The mechanisms by which the Proofchecker attempts to translate the macro-steps of the input proof into rigorous proof steps are described.

The Proofchecker was applied to 67 propositional calculus theorems from Chapter II of *Principia Mathematica*. It succeeded in checking the proofs of 63 of these. The requirements for translating from the textbook proof to the rigorous proof are discussed and the particular macro-steps used are specified. The causes of the failures of the Proofchecker are examined in detail. Although the Proofchecker was logically equipped to handle much more advanced proofs, machine limitations prevented it from proceeding further. ... The chief conclusion is that it is indeed possible to check textbook proofs on a digital computer, but the process is a laborious one, and serious practical and mathematical problems arise sooner than one would expect. *From the Abstract*

ΘARNOLD, RICHARD FAIRBANKS. *5.21* 13,673
Group methods in combinatorial switching theory. (Thesis)
Univ. Michigan, Ann Arbor, Mich., 1963. *Ph D*

This thesis develops a unified treatment of several problems in combinatorial switching theory. The determination of properties of switching functions related to physical realization of those functions is reduced to certain computations in the Boolean algebra of switching functions and an "operator" group.

Problems treated include the following:
1) The representation of switching functions as sums of invariant implicants. This is a generalization of the classical method of Quine, and enables one to take advantage of various symmetries, when they occur.
2) A treatment of group invariance for families of functions. Methods are developed to represent sets of functions, and techniques are given for determining the subset of invariant functions of a given set.
3) "Algebraic" criteria are given for the existence of decompositions of functions of the type studied by Ashenhurst and others. Techniques are developed which are suitable for computation with normal forms as well as with truth tables.

ΘDAVIS, MARTIN DAVID. *5.21* 13,496
On the theory of recursive unsolvability. (Thesis)
Princeton Univ., Princeton, N. J., 1950. *Ph D*

The theory of functions recursive in other functions is discussed as a generalization of Kleene's theory of recursive functions. The development thus obtained is shown to be equivalent to a similar one of Post.

The methods thus arrived at are employed to extend Kleene's hierarchy of predicate forms into the constructive transfinite.

The relation between recursive processes and arithmetic processes is investigated, and a simple unsolvable arithmetical problem is obtained. A new normal form for recursively enumerable predicates is also derived. *Abstract*

ΘFRIEDMAN, JOYCE BARBARA. *5.21* 13,495
A new decision procedure in logic with a computer realization. (Thesis) *Ph D*
Harvard Univ., Cambridge, Mass., 1964.

In this thesis we consider a partial decision procedure for the first-order predicate calculus from the point of view of efficiency and applicability. A partial decision procedure for validity of formulas with prefix

$(x_1) \ldots (x_k)(\exists y_1) \ldots (\exists y_m)(z_1) \ldots (z_n)$ is presented and proved to be a decision procedure for the subcase $m = 2$. A solution is then given to the amplification problem, so that the procedure becomes applicable to unsaturated formulas. Feasibility and efficiency are demonstrated by the construction of a computer program which applies the decision procedure.

... Chapter 1 of this thesis is a general introduction providing definitions and background material. The decision table method described there is that of Church. In Chapter 2 the new material of the thesis begins with application of our method to obtain a decision procedure for saturated formulas of the $\exists_2 V_n$ case. This material is covered more generally in later chapters, but Chapter 2 provides an illustration of the methods. ... Rules for a partial decision procedure for prefix $V_k\exists_m V_n$ are given in Chapter 3. These rules provide a decision procedure for saturated formulas of the two subcases $m = 2$ and $n = 0$.

In Chapter 4 we return to the simple case $k = 0$, $m = 2$ and give a solution of the amplification problem for dyadic predicates. Four amplification rules are given and it is proved that no one of them can be omitted, and that together they are sufficient. A corresponding computer program is described briefly in Chapter 5.

... The more general case $V_k\exists_2 V_n$ is considered in Chapter 6. Additional amplification rules are given and are proved sufficient. Chapter 7 then describes the computer program which carries out the procedure. The chapter is concluded with a discussion of the advantages and limitations of the method and some comments on possible extensions.

The appendices give examples of output and listings of the program cards for Program Two. *From the Abstract*

ΘHarrison, Michael Alexander. 14,095
Combinational problems in Boolean algebras and applications to the theory of switching. (Thesis)
Univ. Michigan, Ann Arbor, Mich., 1963.

In recent years, the techniques of enumerative combinatorial analysis have been applied to Boolean algebras. It was Polya who first showed that a natural group classifies Boolean functions into symmetry types. Thereafter, Shannon described how these symmetry types can be used in the theory of switching.

In this thesis, some new permutation groups on Boolean functions will be considered. The reasons for selecting these groups come from the motivations of switching theory. In each case, the cycles index, a multivariate generating function for the cycle structure of the group is derived. An approach to combinatorial analysis which is capable of generalization is adopted in the presentation. In particular, it is the representation of a group as a permutation group (not as an abstract group) which determines the combinatorial properties of the group. The need for a structural theory of permutation groups is demonstrated and some results obtained. It is necessary for the purposes of combinatorial analysis to be able to decompose a group into suitable constituents and to construct the cycle index of the group in terms of the cycle indices of the component groups.

The cycle indices derived for the new groups provide new classification results for Boolean functions. The recent theorems of DeBruijn are applied to obtain refined results and to enumerate various new objects such as invertible Boolean functions, networks, and self-complementary classes of functions.

Finally, generalizations to Post algebras and other systems of interest are indicated in the paper.

Abstract

Cycles in logical nets. (Thesis)
Univ. Michigan, Ann Arbor, Mich., 1959.

The methods of logic are used in this paper to analyze the effect of feedback in discrete systems. The analysis is carried out by using logical nets as abstract representations of discrete systems with the feedback loops being represented by cycles in the logical nets. . . . Part 1 of the paper introduces the problem and Part 2 gives rigorous definitions for the concepts just mentioned and related concepts. Part 3 makes direct use of the fact that a periodic input-state sequence produces a periodic net-state sequence. It considers the spectrum of nets in which all net cycles are simple (have no subcycles). The results indicate the oversimplification present in the idea that the main function of cycles in a system is to provide storage of information. It is shown that although a net may have arbitrarily many net cycles of arbitrary lengths its behavior will be severely limited if the net cycles are limited in the complexity of their feedback patterns. Part 4 considers various characteristics of the state cycles of input-independent net cycles, beginning with simple cycles and working step-by-step to the general input-independent case. The procedure is such that after each step one or more definitions and operations are introduced to enable the extension to be the next step. Part 5 extends the results of Part 4 to the general case of net cycles with input. . . . Part 6 summarizes the definitions and operations connecting the case of input-independent simple cycles with the general case of cycles with input. . . .

From the Abstract

ΘKornfield, Nathaniel Richard. 13,882
Boolean matrices and their application to fault reduction in switching networks. (Thesis)
Univ. Pennsylvania, Philadelphia, Pa., 1964.

A Boolean transfer matrix is simply a Boolean matrix with exactly one unit element per column. These matrices form the basic method employed in this dissertation for the analysis of faults and their effect since any combinational switching network, correct or faulty, can be represented by the matrix product of Boolean transfer matrices. The individual matrices used in forming this product are called section transfer matrices and each of these is formed through the star product of internal transfer matrices. The inverse operation to the star product is called decomposition. Detailed theory is developed for each concept and is further illustrated by examples. . . .

Fault order is defined precisely by the allowed fault transitions in the transfer matrices and is shown to correspond roughly to the number of component faults. Transition tables which specify the allowed fault transitions for a given correct element location and fault order are developed for several different cases. First-order fault masking is investigated in detail and several special cases became evident from the matrix equations. These concepts are applied to individual AND and OR gates and yield simple first-order fault masking. Partial masking, which allows some first-order faults to remain unmasked, is also introduced. When efficient partial masking is obtained through selective redundancy reduction methods, the unmasked faults occur only for predetermined input combinations. Examples are discussed for all the concepts introduced, and utilize two and three input diode AND and OR gates for which the fault matrices are tabulated in the Appendix. . . .

From the Abstract

⊖ALTMAN, EDWARD B.

The concept of finite representability. (Thesis) *Ph D* 13,681
Case Inst. Tech., Cleveland, Ohio, 1965.

A subclass of the context-free grammars is developed which is based solely upon the structural properties of the grammars. This subclass is utilized in the development of a partial hierarchy of the entire class of context-free grammars. In turn, this hierarchy makes possible the extension of certain information theory measures beyond the classical finite state limitations. Various restrictions upon the method of generating sentences are introduced and the consequences of these restrictions studied, in a general way, using mainly the introduced notion of production indexing sets.

Abstract

⊖BAHNSEN, RALPH JACOB. 14,101

An approach to synthesis of bilateral iterative systems. (Thesis)

M.I.T., Cambridge, Mass., June 1965.

Bilateral, one-dimensional, iterative systems which produce an input-pattern-to-output-pattern transformation that can be realized by some regular bilateral system are studied. The equilibrium behavior of systems of this type can be described by means of a state graph (nondeterministic machine state diagram) in which the states correspond to intercell states that can occur in a network of the system in equilibrium. Properties of these state graphs are studied (in the context of finite-state machine theory) with the aim of determining a minimal state equivalent of a given state graph. A general (but enumerative) method for obtaining a minimal-state equivalent of a graph A and a simple procedure for obtaining a near minimal-state equivalent of A are described. Sometimes the simple procedure yields a minimal-state solution as may be determined from some bounds which are developed for the number of states in a minimal-state equivalent of A. Some aspects of the cascade combination of a deterministic machine followed by a nondeterministic machine are also considered.

It is found that the state graph that describes the equilibrium behavior of a bilateral iterative system can be used in formulating sufficient conditions for stability. In the case of regular bilateral systems (which may have mutual interaction between the left to right and right to left signals) that meet the stability conditions, the time required to reach equilibrium in an n-cell network is a linear function of n. Also, for regular systems, there exist tests to determine if the sufficient conditions are met.

Given a regular state graph N, which defines a desired input/output transformation a synthesis procedure is described for obtaining a cell structure which 1) has as its state graph either N or N modified by the introduction of redundant states; and 2) satisfies the sufficient conditions for stability mentioned above. Finally, for a class of input/output transformations, a comparison is made between the systems that result from the given synthesis procedure and the folded forms for the same input/output transformations.

Abstract

⊖BALZER, ROBERT M. 13,678

Studies concerning minimal time solutions to the firing squad synchronization problem. (Thesis)

Carnegie Inst. Tech., Pittsburgh, Pa., 1966.

This paper presents a description of a general outline for a minimal time solution to the firing squad synchronization problem, and a solution of this form which is composed of machines with only eight states. The paper then discusses the verification of this minimal time solution by computer simulation, and gives a mathematical induction proof that the solution works for any length.

The paper then discussed some efforts to determine the minimal number of states needed for a minimal time solution. No four state minimal time solution exists. A reasonable set of conditions are presented for which no five state minimal time solution exists. Also, various eight state minimal time solutions exist. The final part of the paper demonstrates the equivalence of one-dimensional iterative arrays and Turing machines, and shows how the techniques used here apply to problems of optimizing Turing machines for a given computation.

Abstract

⊖BERGER, ROBERT. 13,683

The undecidability of the domino problem. (Thesis)

Harvard Univ., Cambridge, Mass., 1964.

The domino problem was first proposed by Wang in connection with his search for a decision procedure for the satisfiability of first-order predicate calculus formulas with AEA prefixes. Later Kahr, Moore, and Wang showed that there exists no such decision procedure. Furthermore, they made use of a restricted form of the domino problem to show that the (satisfiability) decision problem for the whole first-order predicate calculus reduces to that for the class of AEA formulas. Kahr and Dreben, Kahr, and Wang then defined more sharply the borderline between decidable and undecidable AEA subclasses. Wang proved that the class of formulas of the form F, $F: (x)(Ex')(y)[U(G_1xy, \ldots, G_kxy; G_1x'y, \ldots, G_kx'y)$ $V(G_1yx, \ldots, G_kyx; G_1yx', \ldots, G_kyx')]$, where U and V are truth functions, has an undecidable decision problem if and only if the domino problem (which Wang called the "unrestricted domino problem") is undecidable. Therefore, the undecidability proof for the domino problem in this paper implies the undecidability of the class of formulas of form F, and sharpens the borderline a little more. In addition, this paper adds yet another undecidable system to the many in the literature.

The undecidability proof consists of showing that, were the domino problem decidable, a known-undecidable halting problem for Turing machines would be decidable. In particular, the proof is largely an algorithm for constructing—given an arbitrary member of a certain class of Turing machines—a domino set that will be solvable if and only if the Turing machine never halts.

... However, the crucial part of the paper is Part 3, which presupposes no knowledge of Turing machines, and it answers an interesting question ... concerning the periodicity of solutions of domino sets.

From the Abstract

⊖BLUM, MANUEL. 13,679
A machine-independent theory of the complexity of recursive functions.
M.I.T., Cambridge, Mass., 1964.

The complexity of recursive functions is measured by associating with the list of all partial recursive functions $\varphi_0, \varphi_1, \varphi_2, \ldots$ another list of partial recursive functions $\Phi_0, \Phi_1, \Phi_2, \ldots$ having the properties: 1) for all i and n, $\varphi_1(n)$ converges if and only if $\Phi_1(n)$ converges; 2) there exists a total recursive function M such that

$$M(i, n, m) = \begin{cases} 1 & \text{if } \Phi_i(n) = m \; ; \\ 0, & \text{otherwise} . \end{cases}$$

For instance, $\Phi_i(n)$ may be the number of steps required to compute $\varphi_i(n)$ or the amount of tape used in the computation. *Theorem:* Let r be a total recursive function of 2 variables. Then there exists a 0–1 valued total recursive function f such that to every index i for f there corresponds an index j for f such that $\Phi_i(n) > r(n, \Phi_i(n))$ for almost all n. *Theorem:* There exists a total recursive function h such that to each Φ_i there corresponds a 0–1 valued partial recursive function f with the same domain as Φ_i such that 1) if f is any index for f then $\Phi_i(n) < \Phi_i(n)$ for all n; 2) there exists an index k for f such that $\Phi_n(n) < h(n, \Phi_i(n))$ for almost all n; and 3) there exists a total recursive function τ which maps the index i for Φ_i into the index k above for f. Both theorems are proved using double diagonalizations. *Abstract*

⊖BRAINERD, WALTER S. 13,674
Tree generating systems and tree automata. (Thesis)
Purdue Univ., Lafayette, Ind., 1967.

$\langle A, \sigma \rangle$ is a stratified alphabet iff A is a finite set and $\sigma : A \to N = \{0,1,2,\ldots\}$. Let $A_n = \sigma^{-1}(n)$. α is a tree (or term) over $\langle A, \sigma \rangle$ iff $\alpha = a \in A_0$ or $\alpha = a\alpha_1 \cdots \alpha_n$, where $a \in A_n$ and each α_1 is a term, $1 \leqslant i \leqslant n$. Let T_A be the set of trees over $\langle A, \sigma \rangle$.

$G = \langle B, \sigma', P, \Gamma \rangle$ is a regular tree grammar over $\langle A, \sigma \rangle$ iff 1) $\langle B, \sigma' \rangle$ is a stratified alphabet such that $A \subseteq B$ and $\sigma' | A = \sigma$; 2) P is a set of production rules of the form $\phi \to \psi$, where $\phi, \psi \in T_B$; and 3) Γ is a finite subset of T_B, called the axioms of G. ... Let $T(G) = \{\alpha \in T_B | \exists \gamma \in \Gamma \ni \gamma 1 - \alpha\}$ be the set of trees produced from the set of axioms Γ, and call $L(G) = T(G) \cap T_A$ the language generated by G.

Theorem: $L(G)$ is always a context-free language. Since each regular tree grammar can be interpreted to be a semi-Thue system, this shows that an interesting class of semi-Thue systems generate only context-free sets.

Theorem: Let $\langle B, \sigma', P, \Sigma \rangle$ satisfy all requirements to be a regular tree grammar except the one that requires Σ to be finite. If $\Sigma = L(G)$ for some regular tree grammar G, then a regular tree grammar G' can be effectively constructed such that $L(G') = L(\langle B, \sigma', P, \Sigma \rangle)$.

Tree automata have been defined and studied by Doner and by Thatcher and Wright. Each tree automaton determines a subset $L(M)$ of trees in a manner analogous to ordinary finite automata.

Theorem: Given a tree automaton M, one can effectively construct a regular tree grammar such that $L(G) = L(M)$ and vice versa.

Theorem: Given a tree automaton M, one can effectively construct a unique (up to isomorphism) automaton M', such that $L(M') = L(M)$ and such that of all automata accepting $L(M)$, M' has the fewest states. ... *From the Abstract*

⊖CODD, EDGAR FRANK. 13,886
Propagation, computation, and construction in two-dimensional cellular spaces. (Thesis)
Univ. Michigan, Ann Arbor, Mich., 1965.

This work is based on von Neumann's pioneering research into automata theoretic models of self-reproduction and, in particular, his cellular model. . . . The main objective of this work is to extend our knowledge concerning cellular spaces with considerably fewer states per cell than von Neumann's and to obtain a necessary condition for computation universally applicable to all two-dimensional cellular spaces. . . .

The principal results developed in this paper are as follows. There exists a strongly rotation-symmetric, 8-state, 5-neighbor cellular space which is computation-construction-universal. In this space all two-dimensional completely passive configurations can be read and erased (as well as written) by other configurations. As a consequence, this space may well be strictly more powerful than von Neumann's (weakly-) rotation symmetric, 29-state, 5-neighbor cellular space. A necessary condition for computation universality is that, by choice of initial configuration, it is possible to obtain boundable propagation arbitrarily far from its source. There does *not* exist a computation-universal, 2-state, 5-neighbor cellular space with a neighborhood which is 90°-rotation-symmetric. However, there does exist a 2-state cellular space which is computation-construction-universal.

In addition to the development of these results, several new techniques are described: the three-phase development of organization when one machine is constructing another, starting with the development of a (0,1) configuration, followed by sheathing and activation; a new set of commands, which is universal with respect to computation and construction, and at the same time does not depend on the existence in the space of a distinguished direction; experimental techniques for exploring propagation, computation, and construction by means of on-line interaction with a general-purpose, digital computer; and others. *From the Abstract*

ΘCole, Stephen Nisson.   13,504

Real-time computation by iterative arrays of finite-state machines. (Thesis) *PhD*

Harvard Univ., Cambridge, Mass., 1964.

An n-dimensional iterative array of finite-state machines is called an nD and consists of a set of finite-state machines indexed by z_n (z is the set of integers); all of the machines are identical except the machine indexed by the n-tuple$(0,0,\ldots,0)$ (the machine at the origin). Each machine receives a finite number of internal vocabulary symbols from neighboring machines in the array. The machines are synchronized to perform each step of computation simultaneously. The nD is treated as a real-time tape acceptor, and the external inputs are applied to the machine at the origin. A $1D$ that uses at most m symbols in the internal vocabulary is called an m-restricted $1D$. The major results which have been obtained are described below.

1) The set of tapes of the form $\tau\tau$ (where τ is any tape) is accepted by a $1D$. Since this set of tapes is not a simple phrase-structure (context-free) language, the class of sets of tapes accepted by $1D$'s is not a subclass of the simple phrase-structure languages.

2) The set of palindromes is accepted by a $1D$.

3) The set of palindromes is not accepted by any deterministic pushdown store machine. Thus there exist simple phrase-structure languages that are accepted by $1D$'s and not accepted by deterministic pushdown store machines.

4) For each integer m, and any input alphabet with at least two symbols, there exists a set of tapes accepted by an $m+1$ (-restricted $1D$ that is not accepted by any m-restricted $1D$.

5) A $1D$ can be designed to stimulate any n-tape, real-time Turing machine. Thus the sets of integers countable in real-time by multitape Turing machines (Yamada's real-time counters) are also real-time countable by $1D$'s.

6) A length-k encoding from input alphabet $\sum_1$ to input alphabet $\sum_2$ is a 1–1 function mapping symbols of $\sum_1$ into tapes of length k in $\sum_2{}^*$. Any length-k encoding f has a natural extension that maps sets of tapes in $\sum_1{}^*$ into sets of tapes in $\sum_2{}^*$. For any length-k encoding f and any set of tapes X, X is accepted by an nD if and only if $f(X)$ is accepted by an nD. The statement also expresses the fact that the speed of computation of an nD can be increased or decreased by a factor of k.

7) The class of sets of tapes accepted by nD's is a Boolean algebra with the set-theoretic operations.

8) The class of sets of tapes accepted by nD's is not closed under concatenation product or reflection.

9) The class of sets of tapes accepted by nD's is a proper subclass of the class of sets of tapes accepted by $(n+1)D$'s. More specifically for each n and any alphabet with at least two symbols, there exists a set of tapes accepted by a pushdown store machine, accepted by an $(n+1)D$, and not accepted by any nD.

From the Abstract

ΘDauber, Philip S.   14,100

Errors in finite automata. (Thesis)

Univ. Michigan, Ann Arbor, Mich., 1965.

The purpose of this research is to study the correctability properties of errors in a finite automaton driven by a random source. An error is defined to be a pair of states and is corrected by a tape if the tape takes both coordinates of the pair into the same state. Errors are then classified as one of four types: correctable, finite, definite, and noncorrectable. A correctable error is an error for which there is a correcting tape. The error is finite if the probability of the set of correcting tapes approaches one as the length of the tapes gets longer. A definite error is an error for which all tapes, of length greater than some fixed length, are correcting tapes. A noncorrectable error is one for which there does not exist a correcting tape.

We show that the set of finite errors induces a partition, called the finite error partition, on the set of states. Also, for a restricted class of random sources, this partition can be obtained from the set of correctable errors independent of the statistics of the source.

The notion of the semigroup of the automaton is then introduced. It is shown that many of the error properties of the automaton can be studied in terms of its semigroups. In particular, necessary and sufficient conditions are given for the automaton to have errors which are correctable but not finite and for the automaton to have only definite or noncorrectable errors.

Further results are then given on analyzing the error properties of finite automata which have a large number of states but can be decomposed into a series, parallel connection of smaller automata.   *Abstract*

ΘEven, Shimon.   13,503

On information lossless automata. (Thesis) *PhD*

Harvard Univ., Cambridge, Mass., 1963.

Chapter 1 is an introduction to the subject and lists the results of the thesis. In Chapter 2 a general theory of information lossless coding graphs is discussed. Sections (a) and (b) are original and Section (c) is based on a suggestion made by Philip K. Hooper. In Chapter 3 the theory of Chapter 2 is applied to finite state synchronous sequential machines, and the construction of an inverse for an information lossless automaton is discussed. All parts of Chapter 3 are original. In Chapter 4 the theory of Chapter 2 is applied to variable length codes, and it is shown that the Sardinas and Patterson test produces the same results. Sections (a) and (b) are original, and Section (c) is a demonstration of the Sardinas and Patterson test. In Chapter 5 the theory of Chapter 2 is applied to generalized automata, and all sections are original. In Chapter 6 the synchronization problem of variable length codes is discussed, and synchronizable codes are defined. It is shown how to test a finite code for synchronizability. All parts of Chapter 6 are original.   *From the Abstract*

ⵙEvey, R. James.   13,505

The theory and applications of pushdown store machines.
  (Thesis) *Ph D*
Harvard Univ., Cambridge, Mass., 1963.

    This thesis is a study of some aspects of the problem
of machine translation; particularly of the use of push-
down stores in such processes.

    A more detailed outline of the thesis is given in
Chapter 1. Chapter 2 contains the basic definitions of
which the most important are those of grammars and
machines. A hierarchy of six sets of machines, bounded
at the top by a Turing machine, is defined by adding
pushdown stores and counters to finite state machines.
Each set of machines is then partitioned in two ways:
1) into accepters (machines with only inputs) and
transducers (machines with both inputs and outputs);
and 2) into deterministic and nondeterministic ma-
chines. The set of all inputs (outputs) of a machine is
called its input (output) language. The main theorem
of the chapter states that the set of input languages of
all nondeterministic accepters of a given type is the
same as the set of output languages of all deterministic
transducers of the same type.

    In Chapter 3 it is proved that the set of output lan-
guages of all pushdown store transducers is the set of
all context-free phrase structure languages. In Chapter
4 a more detailed look is taken at the use of pushdown
store machines in the translation of languages (both
artificial and natural). Algorithms developed by Oet-
tinger and by Samelson and Bauer for translating from
one artificial language to another are shown to be com-
binations of machines in the hierarchy. Then results
pertaining to the generation of natural language sen-
tences (Yngve) and to the analysis of such sentences
(Kuno and Oettinger) are related to deterministic and
nondeterministic pushdown store machines, respec-
tively.   *From the Abstract*

ⵙGreibach, Sheila Adele.   13,502
Inverses of phrase structure generators. (Thesis) *Ph D*
Harvard Univ., Cambridge, Mass., 1963.

    Chapter 1 introduces the subject of the thesis and
lists the main results of the thesis.

    In Chapter 2, directed production analyzers are in-
troduced and inverses are defined. Section 2.4 gives a
normal form theorem for phrase structure generators
(Lemma 2.4.9). The main result of Chapter 2 is that
every context-free phrase structure generator has a di-
rected production analyzer as an inverse (Theorem
2.4.1). The definition of directed production analyzers
was suggested by study of the Kuno/Oettinger multi-
ple-path syntactic analyzer. The admissible systems
of Section 2.2 are equivalent to the reduced simple-
phrase structure generators of Bar-Hillel.

    Chapter 3 discusses p-systems, d-systems, and the
hidden ambiguity problem. The main result of Chapter
3 is the undecidability of the two-way correspondence
problem (Theorem 3.4.2). This is used to prove as un-
decidable the ambiguity problem for p-systems. The
definition of d-systems and Theorem 3.2.2 are due to
Gaifman. The one-way correspondence problem was
defined and proved undecidable by Post. The use of
the correspondence problem was suggested by the work
of Rabin and Scott.

    In Section 4.1, bounded and strongly bounded di-
rected production analyzers are defined and various
undecidability results are given. Section 4.2 discusses
inductive phrase structure generators and directed
production analyzers; truncated directed production
analyzers are the subject of Section 4.3. Whether a
phrase is simple is decidable, but whether a phrase is
independent is undecidable (Theorems 4.4.3 and 4.4.5);
this is the main result of Section 4.4. All of Section 4.4
is new and original. The definition of inductive phrase
structure generators is due to Evey; otherwise, Section
4.2 is original. Section 4.1 strengthens results of Chom-
sky and Parikh.

    Chapter 5 discusses linear phrase structure genera-
tors and uses the results of Section 4.3 to prove various
problems undecidable. . . . Some of the definitions of
Sections 5.1 and 5.4 were suggested by work of Even.
Lemma 5.1.2 is due to Even and Fischer.

    The theory developed in Chapters 2–5 is applied to
the Kuno/Oettinger multiple-path syntactic analyzer
in Chapter 6. In addition, some further results on
phrasing languages are obtained in Section 6.3.
                                          From the Abstract

ΘHADLOCK, FRANK OWEN.   13,507
Realization of sequential machines with threshold ele-
    ments. (Thesis)
Univ. Texas, Austin, Texas, 1966.

    This paper presents an algorithm which, given a se-
quential machine with completely specified state and
output tables, yields all code assignments for which the
state-variable and output-variable functions are 2-
asummable. . . . It is easily verified that a Boolean
function is 2-asummable iff it induces no ES (equal
sum) set-pairs. Let $S \times I$ be the set of state-input
pairs. It must first be determined as to which $S \times I$
set-pairs are encodeable as ES set-pairs. (A coded
$S \times I$ set-pair is obtained from an $S \times I$ set-pair by
replacing states and inputs by their codes.) Secondly,
which code assignments actually carry them into ES
set-pairs? Finally, it is necessary to know for which
assignments a state-variable or output-variable func-
tion induces a coded set-pair.

    The answers to these three questions make it possi-
ble to characterize the acceptable code assignments.
. . . Once they are characterized, it is a straightforward
matter to outline an algorithm yielding all acceptable
assignments.

    An assignment is taken to be a set $\mathcal{P} = \{\mathcal{A}, \mathcal{B}, \mathcal{C}\}$
where $\mathcal{A}, \mathcal{B}, \mathcal{C}$ are respectively zero-product sets of 2-
block partitions on the input, state, and output sets,
I, S, and O. . . . The first step of the algorithm consists
of rejecting certain 2-block partitions of S and of O as
being unusable in any assignment $\mathcal{P}$ which is accept-
able for the machine under consideration. Next, for
each of the remaining partitions of S or of O, a series
of lists is compiled. Each list is a list of partitions of
I or a list of partitions of S. If π is used in an assign-
ment $\mathcal{P}, \mathcal{P}$ is acceptable only if a partition from each
list in the series for π is also used in $\mathcal{P}$. At this point, a
discriminant function Δ is defined. If $\mathcal{P} = \{\mathcal{A}, \mathcal{B}, \mathcal{C}\}$
where $\mathcal{A}, \mathcal{B}, \mathcal{C}$ are respectively partition sets of I, S, and O
and if ψ is the set of all such $\mathcal{P}$, the function Δ is de-
fined from ψ into $\{O, I\}$. Δ is defined in such a way

that $\Delta(\mathcal{P}) = I$ iff $\mathcal{P}$ is acceptable. Thus Δ yields the
acceptable assignments.   *From the Abstract*

ΘHARING, DONALD RUSSELL.
Some aspects of the state assignment problem for sequen-   13,500
    tial circuits. (Thesis)   Ph D
Harvard Univ., Cambridge, Mass., 1962.   M. I. T.

    . . . The point of view is taken here that the greatest
lack in promoting an understanding of the state assign-
ment (SA) problem is a knowledge of the structure of
the relationship between the properties of the sequen-
tial machine (SM) and the properties of the logic re-
quired by its sequential circuit (SC) realization. Con-
sequently, a large part of this report is devoted to de-
veloping and using some new techniques for studying
the structure of this SM/CS relationship.

    In the first part of this report a new algebraic model
for the SM is introduced. With this model a set of al-
gebraic equations is derived which represent the SM/
SC relationship. Using these equations plus matrix
theory and group theory, some general algebraic prop-
erties of the SM/SC relationship are derived.

    Since single-column SM's play an important role in
understanding the SM/SC relationship, they are stud-
ied in depth. Using the new SM algebraic model, it is
proved constructively that the set of all 1-column, r-
state SM's forms a semigroup that is generated by
three of its members, thus proving the existence of a
type of "universal finite-state SM." Using linear
graph theory, an algorithm is derived to construct all
canonical forms of the state diagrams for the semi-
group.

    Another new technique introduced here to study the
SM/SC relationship is the theory of "restricted parti-
tions" of an SM, that is, partitions that are valid for
only parts of the SM, such as a single column of the
flow table for an m-column SM. It is shown that re-
stricted partitions are sometimes useful for finding de-
sirable unrestricted partitions of an SM, as well as for
selecting "good" SA's for both asynchronous and syn-
chronous SC's. Restricted partitions are particularly
useful in the SA problem because as is shown in this
report, the properties of the SC logic are very much a
function of the detailed properties of the SM, which
can be conveniently studied by such partitions.

    The remainder of the report is devoted to using the
results of the first part to establish methods for cal-
culating bounds on the amount of combinational logic
required by synchronous SC's, and to select economi-
cal SA's for such circuits.   *From the Abstract*

⊖Harlow, Charles Alton.   13,677
On the structure of sequential machine realizations.
 (Thesis)
Univ. Texas, Austin, Texas, 1967.

In most studies of the structure of sequential machines there has been a tacit assumption that the machine was to be realized with unit delay memory elements. In this dissertation we consider sequential machines that are realized with either trigger or set/reset flip/flop memory elements.

It is shown that the relation called a partition pair which predicts the dependence of the input functions to unit delay memory elements does not predict the dependence of the input functions to trigger or set/reset flip/flop memory elements. In this paper we define relations called t-pairs and r-pairs which characterize the dependence of the input functions to trigger and set/reset flip/flop memory elements, respectively. It is found that these relations do not have all the algebraic properties that partition pairs possess.   *Abstract*

⊖Jones, Neil Deaton.   13,676
Formal languages and rudimentary attributes. (Thesis)
Western Ontario Univ., London, Ont., Canada, 1967.

This thesis develops a number of properties of several classes of formal mathematical languages, using tools from Mathematical Logic and Automata Theory. A new logical operator, transitive closure, is introduced. It is shown that if the class RUD of rudimentary attributes due to Smullyan is extended by the

addition of transitive closure, the entire class of RE of all recursively enumerable attributes is obtained. Further, by restricting the application of transitive closure, two new attribute classes RR and DRR are obtained, and it is shown that these completely characterize the acceptance powers of nondeterministic and deterministic linear bounded automata.

The properties of RR and DRR are investigated, and it is shown that the operation of transitive closure is sufficiently powerful to eliminate the need for quantifiers in the definition of these classes.

Finally, the hierarchy $RE \supset RR \supseteq DRR \supseteq RUD$ is compared to the Chomsky hierarchy of classes of formal languages. It is shown that RE and RR completely characterize the type 0 and context-sensitive classes, and partial results are given for the context-free and regular languages classes.   *Abstract*

⊖Krohn, Kenneth Bruce.   Ph D   13,501
Algebraic theory of machines. (Thesis)
Harvard Univ., Cambridge, Mass., 1962.

This paper is an attempt to present an algebraic theory of nonprobabilistic sequential machines. The first part consists of an algebraic formulation similar to that of Rabin and Scott from which previous noncombinatorial results on automata follow easily. One sequential machine is said to "divide" a second if, by the use of pairs of "memoryless" codes (one input code and one output code to a pair), the second machine can do any calculation that the first one can. The division is called "uniform" if one pair of codes suffices. These properties are shown to have simple interpretations with respect to the semigroup naturally associated with each machine.

. . . Motivated by the corresponding electrical engineering circuit operations, the definitions for series and parallel composition of machines are introduced, permitting one to construct new machines as "networks" of others. Some composition properties of semigroup machines are derived, yielding, as a byproduct, a unique (up to type) factorization theorem for finite semigroups (i.e., a semigroup is called "irreducible" whenever it is a homomorphic subimage of a semidirect product of two semigroups). . . . Analogously, a machine is called irreducible if whenever it divides some composition of semigroup machines, then, it uniformly divides one of them. Further, it is shown that each machine can be represented as a network of the following machines: a certain two-state machine

whose semigroup is irreducible but not a group, an arbitrary machine whose semigroup contains a nonsingleton subgroup, and the prime machines (irreducible ones whose semigroup is a prime) which divide the machine of the given machine's semigroup. This constitutes a unique (up to type) prime factorization theorem for sequential machines.   *From the Abstract*

ΘLANDWEBER, LAWRENCE H.   13,883
A design algorithm for sequential Machines and definability in monadic second-order arithmetic. (Thesis)
Purdue Univ., Lafayette, Ind., 1967.

The automatic design of sequential machines (or sequential circuits) is among the most practical problems of automata theory. This paper considers algorithms for synthesizing machines to satisfy design requirements expressed in a formal language.

Monadic second-order arithmetic or sequential calculus (SC) is the interpreted formalism which makes use of individual variables ranging over the natural numbers; monadic predicate (set) variables ranging over arbitrary sets of natural numbers; the individual symbol 0 standing for zero; the function symbol ′ denoting the successor function, propositional connectives, and quantifiers on both types of variables.

Let $\phi(X, Y)$ be a well-formed formula of SC where $X = (X_1, \cdots, X_n)$ and $Y = (Y_1, \cdots, Y_m)$ are vectors of free set variables. . . . A solvability algorithm for SC decides, for any ϕ, whether it is solvable. In addition, a synthesis algorithm constructs a solution if one exists.

Definability by formulas $\phi(X)$ of SC where X is a free set variable, is investigated. Each such formula defines a set of sets which is in the Boolean algebra of the Σ_2 sets in the arithmetic hierarchy. $\phi(X)$ also defines a subset of the Cantor ternary set

which is in the Boolean algebra of the G_δ sets with respect to the Borel hierarchy. This, together with results of Davis on 2-player infinite games, yields an alternate proof that for every finite state game one of the players has a winning strategy. However, the proof is nonconstructive and the strategies need not be finite automata.   *From the Abstract*

ΘLEVIEN, ROGER ELI.   13,499
Studies in the theory of computational algorithms. (Thesis)
Harvard Univ., Cambridge, Mass., 1962.

The central notion in the current theory of computation is that of an algorithm. An informal definition of algorithms which is more general than many in current use is presented in the Introduction. . . . In Chapter I, the formal definitions of set, relation, function, ordered set, tuple, and product set, which are the only mathematical preliminaries to the remainder of the thesis, are presented. . . . The formal characterization of computational algorithms is considered in Chapter II. Functional systems, consisting of a set S and a function f from S to S (said to be in S) are defined and it is shown how each may be used to compute a function f which is also in S. . . . In Chapter III the class of functions computable by functional systems is determined. It is shown that under the original definition of the computations of functional systems, introduced in Chapter II, only a vanishingly small portion of all the functions in an arbitrary set S are computable. Since this result agrees neither with intuitive notions nor with the results of previous formalisms, it is concluded that the original formalization of the functions computed by computational algorithms is inadequate. A new notion, that of the functions R-computed by functional systems, is also introduced. . . . In Chapter IV a concise and precise algorithm language, especially intended for the description of operations on structured tuples, is defined. It is a modification of a language developed by Iverson. An attempt has been made to keep the number of different elementary statements as small as possible without at the same time making algorithm representations unwieldy. . . . In Chapter V, six common analysis problems arising with respect to computational algorithms are treated.

. . . The emphasis in this investigation, in contrast to that of many previous studies of these questions, is on the development of solvability, rather than unsolvability, results.   *From the Abstract*

ΘMaurer, Ward D.   13,682
On minimal decompositions of group machines. (Thesis)
Univ. California, Berkeley, Calif., 1965. *Ph D*

This paper examines the question of uniqueness in the main (discrete input, deterministic, sequential) machine decomposition theorem of Krohn and Rhodes. In the terminology of the above authors a machine is a collection of functions $f: \Sigma A \to B$, where A and B are finite sets and ΣA is the set of all non-empty sequences of members of A; the collection must be closed under composition with the maps $L_t: \Sigma A \to \Sigma A$, the left translations by elements $t \in \Sigma A$. A function f, which is a member of a finite machine, represents a state of some sequential circuit, and, by the above theorem, is decomposable into a series-parallel composition of units, delays, and the primes which divide it. . . .

It is readily shown that any decomposition may be reduced, in some sense, to a serial composition of functions of semigroups of the form $G \times A^r$, where G is a nontrivial simple finite group and A^r is a right zero semigroup, i.e., $xy = y$ for all $x, y \in A^r$. . . .

The remainder of this paper is devoted to the analysis of decompositions whose circuit analogs have the minimal number of states. As a byproduct of the work, a classification theorem has been derived for transitive subgroups of the wreath product $G_1 \wr \ldots \wr G_n$, considered as a permutation group over $G_i x \ldots x G_n$. In Chapter 8, this theorem is generalized to cover transitive subgroups of the wreath product $V_1 \wr \ldots \wr V_n$ of arbitrary permutation groups. A group having a subnormal series with factors $G_1, \ldots, G_n$, in that order, may be embedded isomorphically in $G_1 \wr \ldots \wr G_n$, up to conjugation. Likewise, any group having a subgroup chain with permutation factors (in a suitably defined sense) $V_1, \ldots, V_n$, in that order, may be embedded isomorphically in $V_1 \wr \ldots \wr V_n$ in a constructible manner. By Theorem 8.1, a generalization of this construction gives all transitive subgroups of $V_1 \wr \ldots \wr V_n$, up to conjugation.   *From the Abstract*

ΘOtt, Eugene H.   13,498
Theory and applications of stochastic sequential machines. (Thesis) *Ph D*
Harvard Univ., Cambridge, Mass., 1966.

This thesis treats several problems associated with the theory of stochastic sequential machines. The formulation of the concept of a stochastic sequential machine is identical to that employed by Carlyle and others.

In Chapter II we formalize the problems treated in the following two chapters and present the relevant known results of other researchers. The only original concept presented in Chapter II is that of dominance. . . .

In Chapter III . . . we present a procedure for solving the minimal dominant representation problem in the case where there exists a minimal dominant whose rank equals that of the given system. . . . We illustrate how the theory developed in the first section can be applied to improve the efficiency of the test developed in Chapter II for the dominance relation.

We begin Chapter IV by introducing a new concept of matrix systems which is intrinsically related to the theory of stochastic sequential machines. . . . In Chapter V we treat the problem of encoding the outputs from a controllable rate source of discrete information whose output statistics can be accurately described as a stationary finite-state Markov Process. . . . We present a uniquely decodable scheme in this class which minimizes the ensemble average length of the transmitted message corresponding to any number of outputs from the source, i.e., a compact encoding scheme. The code used will vary with time as a function of the entire past history of the source. . . . The future encoding of the outputs from a sample source with any given past history will be compact also. . . .

From the Abstract

ΘPepe, James T.   14,341
A procedure to determine by observation the state diagram of a Turing machine. (Master's Thesis)
M.I.T., Cambridge, Mass., 1967.

This thesis presents a solution to the problem of determining the state diagram of a Turing machine that is viewed as a black box. That is, the Turing machine is looked upon as a computing machine which one watches in operation without knowledge of its internal states. While research has been done on this same problem for finite state automata, the two problems are different. To be specific, when working with automata, certain input patterns can be fed into the machine, from whose output the state diagram is determined. However, a Turing machine controls its own input. One must therefore arrive at a state diagram only by observing how the Turing machine acts upon its tape.

This thesis presents a procedure to solve the above stated problem of finding the state diagram. To achieve this goal a Turing machine's computation is given a mathematical structure. Then, by proving some results about the pseudo-periodicity of such a computation, the above stated problem is solved depending upon the computational properties that a Turing machine in question exhibits. Finally, the results of implementing this solution on a digital computer are presented.   *Abstract*

⊖Page, Carl V.   14,102

Equivalences between probabilistic sequential machines. (Thesis)

Univ. Michigan, Ann Arbor, Mich., 1965.

This report introduces new definitions of behavioral equivalences and shows relationship among the various notions of behavioral equivalence between probabilistic machines. Four basic problems are discussed for several different behavioral equivalences between machines. In what follows we use the symbol "$\equiv$" as a variable to denote one of the several behavioral equivalences considered in this report. Given an arbitrary probabilistic sequential machine A:

1. Is there an input-state calculable machine A' (a machine with deterministic switching and random outputs) such that $A \equiv A'$?
2. What are the machines A' with minimal number of states such that $A \equiv A'$?
3. How does one obtain all stable modifications of A, i.e., all machines A' such that the switching probabilities of A' and A differ but $A \equiv A'$?
4. Is there a finite bound on the length of experiments required to establish whether $A \equiv A'$ holds?

The four basic problems are solved completely for some equivalences between machines and are left open for other equivalences. Some applications are made to optimal control problems.   *Abstract*

⊖Rosenberg, Arnold Leonard.   13,497

Nonwriting extensions of finite automata. (Thesis)

Harvard Univ., Cambridge, Mass., 1965. *PhD*

Chapter 1 contains an introduction to the problems considered, including a survey of related work in the literature and a summary of the major results reported. Chapter 2 introduces the models studied and demonstrates the equivalence of alternative definitions of certain models. All of Chapter 2 is original. In Chapter 3 various projection and mapping theorems are proved. ... Chapter 4 considers various closure and characterization theorems. The theorems asserting the nonclosure of the class defined by deterministic multitape automata under the Kleene operations are original. The section on nondeterministic multitape automata is original, but was proved independently, and at an earlier date, elsewhere in the literature. The proofs presented are, however, original. The remainder of Chapter 4 is original.

In Chapter 5, various decision properties of the models studied are considered. The emptiness, finiteness, and disjointness problems for the class of deterministic multitape automata have been considered in the literature. The proof of the unsolvability of the problem of deciding whether or not a set definable by a nondeterministic multitape automaton is, in fact, definable by a deterministic multitape automaton is due to Professor P. C. Fischer. The proof of the unsolvability of the emptiness problem for 2-head finite automata is due to Professor S. A. Greibach. The remainder of Chapter 5 is original.   *From the Abstract*

⊖Thatcher, James W.   13,884

Decision problems and definability for generalized arithmetic. (Thesis)

Univ. Michigan, Ann Arbor, Mich., 1964.

1. Introduction. Let N_k denote the set of words over the alphabet $\Sigma_k = \{1, \cdots, k\}$. N_k contains the null word which is denoted. We consider decision problems for various first-order interpreted predicate languages in which the variables range over $N_k (\geq 2)$. Our main result is that there is no decision as its only nonlogical primitive. This, together with known results summarized in Section 4, settles the decision problem for any language constructed on the basis of the relations and functions listed below:

Concatenation	$\widehat{uv} = uv$
Subword	$uv \leftrightarrow \exists x \exists y[v = xuy]$
Prefix	$u \leq v \leftrightarrow \exists x[ux = v]$
Suffix	$v \geq u \leftrightarrow \exists x[xu = v]$
Reflection	$c(\sigma_1 \cdots \sigma_n) = \sigma_n \cdots \sigma_1 (\sigma_i \in \Sigma_k)$
Right successors	$r_\sigma(u) = u_\sigma \qquad (\sigma \in \Sigma_k)$
Left successors	$l_\sigma(u) = \sigma_u \qquad (\sigma \in \Sigma_k)$
Equal length	$L(u, v) \leftrightarrow u$ and v have the same number of symbols.

    Abstract

⊖Tixier, Vincent.   13,684

Recursive functions of regular expressions in language analysis. (Thesis)

Stanford Univ., Stanford, Calif., 1967.

A theory of language analysis is developed in the framework of an algebraic theory of systems of equations. These equations belong to Kleene's algebra of regular expressions and to a novel extension of it, the algebra of conditional regular expressions.

An axiom system for the unrestricted algebra of regular expressions is introduced and its completeness proved. A theorem for the equality of regular expressions and new proofs of known theorems on finite state automata are given.

The notion of separability of sets of strings is defined. The class of regular context-free (RCF) languages is defined by applying this notion together with previous results. It is shown that EULER, a generalization of ALGOL due to Wirth and Weber, is RCF; that RCF languages can be defined compactly and legibly; and that a high-speed analyzer can be derived from their definition.

Alternate characterizations of the class of RCF languages are given, one of which is automaton/theoretic. This class is related to other classes; its closure properties are investigated, results on left and right cancellation established, solvability and unsolvability questions studied.

Eventually, as a natural extension to the class of RCF languages, conditional regular expressions are defined and axiomatized and systems of recursive functions of regular expressions are introduced. It is argued that these systems offer a convenient metalinguistic tool for language analysis by computer.   *Abstract*

ΘYAMADA, HISAO.   13,887
Counting by a class of growing automata. (Thesis)
Univ. Pennsylvania, Philadelphia, Pa., 1960.

The present work is, in essence, the fusion of the generalized notion of counting a set of integers with the idea of a multitape Turing machine. For the purpose of counting, Turing machines are used as real-time devices. The real-time study of Turing machines has, as far as we know, not been attempted before. In particular, the only counters studied have been finite-state devices, which count only in a periodic (or ultimately periodic) fashion.

The notion of counter is defined as follows: let A be an infinite set of positive integers. Also let M be an automata with one binary input $I(t)$ and one binary output $U(t)$ in the domain of quantized time $t - 1, 2, 3, \cdots$. Then M is said to be a *counter* of A if and only if

$$(U(t) - 1) \equiv (I(t) = 1) \text{ and } \left(\left[\sum_{x-1}^{t} I(x) \right] \in A \right). \quad (1)$$

In other words, U is in state 1 at time t if and only if I is 1 at time t and the number of times I has been in state 1 is a member of the set A, for any input sequence on I and for any t. . . .

With A we associate a function $f(x)$ such that

$$A - \{f(x); x \in I \quad \text{and} \quad f(x) > 0\},$$

where I is the set of all positive integers. Intuitively, the ith time the output is 1 is the $f(i)$th time the input is 1, if the function is monotonic and everywhere positive. (Later we introduce two-argument functions.) Call this $f(x)$ a *defining function* of A. Then A or its defining function $f(x)$ is said to be *countable* if and only if there exists some M (of the class described above) to satisfy condition (1). . . .

General properties of machines, restricted by the definition of M, are discussed. Also some problems for future research are indicated.   *From the Abstract*

ΘZEIGER, HOWARD PAUL.   13,680
Loop-free synthesis of finite state machines. (Thesis)
M.I.T., Cambridge, Mass., 1964.   *Ph D*

Techniques are developed for synthesizing a finite state machine as a loop-free interconnection of simpler machines. Methods are given for:

1) Constructing any machine from machines (hereafter called P/R machines) whose inputs either permute the states or reset them all to one state.
2) Constructing any P/R machine from other P/R machines whose state permutations contribute simple groups.
3) Constructing any P/R machine from a machine whose inputs only permute the states plus a machine whose inputs either a) leave the state unchanged; or b) reset all states to one state.

The above methods provide a new way of reaching the result that for any given machine the minimum set of groups arising in its loop-free construction is uniquely determined.   *Abstract*

5.24   THEORY OF PROGRAMMING

ΘEVANS, ARTHUR, JR.   13,510
Syntax analysis by a production language. (Thesis) *Ph D*
Carnegie Inst. Tech., Pittsburgh, Pa., 1965.

This dissertation presents proofs that two specific translation algorithms operate correctly. Suggestions are given for the application of the techniques developed to translation algorithms considerably more complex than those given.

The plan of the work is as follows: We start with a Chapter 0 in which we define the fundamental concepts of characters, alphabets, and strings which will be used. We define also our notation and conventions for writing strings. . . . We then consider the concept of a Backus Naur Form grammar. After a brief introduction, BNF grammar is defined quite carefully. Other concepts are introduced, and then a specific grammar, the A-grammar, is exhibited. . . . Finally, the concepts are put to use by showing that the A-grammar is unambiguous.

We then introduce Floyd-Evans Productions. The notation is described informally and then defined formally. A specific set of productions is introduced to clarify the concepts—the A-productions. . . .

The notation of a Backus Naur Form Grammar is expanded to include translation rules. This is done for the A-grammar given in Chapter 1. . . .

We then show the relation between the A-Grammar (with translation rules) and the A-productions. We show that the algorithm defined by the productions produces precisely the translation given by the translation rules . . . and then we carry out the program for the B-productions and B-Grammar. . . .

The A-productions are equivalent to another set of productions in that both accept the same set of input strings and produce the same output. The new productions are in a form more useful for certain applications. . . .   *From the Abstract*

5.29 Miscellaneous

Θ Songster, Gerard F. 13,888
Some representation systems. (Thesis)
Univ. Pennsylvania, Philadelphia, Pa., 1962.

This paper is concerned with the development of an algorithm to generate representation sequences with negative n in systems that are of the residue-class type. . . . The systems are generalized by 1) allowing β_n to be a function of n with domain in the nonzero integers; and 2) allowing R_n to be a function of n with domain in the sets that form complete sets of residues modulo β_n.

Concentration is placed on R_n that form integer intervals, i.e., $R_n = \alpha_n, \alpha_n + 1, \cdots, + |\beta_n| - 1\}$,

where α_n is the minimum-valued member of the set.

Whether or not $\{d_n\}$ represents x is decided by the criterion

$$x = \sum_{n=-1}^{-\infty} d_n \prod_{i=-1}^{n} \beta_i^{-1} + Q,$$

where Q is an integer. This relationship is recognized as a generalization of the "expansion in negative powers of the base" common to constant-base systems.

The algorithm used to generate $\{d_n\}$ for nonintegral x in systems such as the decimal is given recursively as follows

$$\mu_0 = x$$
$$\mu_n = \beta_n \mu_{n+1} - d_n$$
$$d_n = \overline{R}_n([\beta_n \mu_{n+1}]) ,$$

where $n < 0$. The sequence of u_n generated in the process is an auxiliary sequence of remainders and it is not part of the representation. The function $\overline{R}_n$ maps the integers onto R_n, the set of residues modulo β_n, and the brackets within the scope of $\overline{R}_n$ indicate that the greatest integer of the contents should be taken. . . .

The algorithm can be considered to be a mapping between the real numbers and the sequences and is one-to-one under certain conditions and many-to-one (numbers-to-sequences) under other conditions. Rules for multiplication and addition of sequences are given and this mapping is shown to be isomorphic or homomorphic under certain conditions. The group structures of the sequences with the operations of addition and multiplication are also investigated. . . .

From the Abstract

5.3 COMBINATORIAL & DISCRETE MATHEMATICS

5.32 GRAPH THEORY

Θ Anger, Arthur L. 13,685
An algorithm for the genus of a graph. (Thesis)
Harvard Univ., Cambridge, Mass., 1965.

The genus of a graph is the minimal complexity of surface in which it may be mapped. The algorithm described here operates by successive installations of paths in partial maps, and is an extension of the work of several investigators [1, 2, 3]. Although equivalent to an exhaustive search, completion of most nonminimal maps is avoided by partial prediction of complete map genus during construction; some strategies for quickly finding near-minimal maps are also suggested. The algorithm has been implemented in Fortran by representing the map faces as lists of vertices, and results for some simple cases are given. Similar aspects of printed-circuit design are explored, but no direct application is seen. Finally, several topological questions are proposed for further study.

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Abstract

Θ Hedetniemi, Stephen Travis. 5.32 13,889
Homomorphisms of graphs and automata. (Thesis)
Univ. Michigan, Ann Arbor, Michigan, 1966.

. . . In this thesis the concept of a homomorphism of a graph is extensively studied. . . . In Chapter I the basic definitions relating to homomorphisms of graphs are presented. It is shown that colorings of graphs are essentially homomorphisms, and on the basis of this observation a number of fundamental results are obtained which relate homomorphisms to the chromatic number of a graph. In Chapter II several schemata for constructing critical graphs from other critical graphs are presented, which generalize and improve those of Hajos, and indications are given of the important

role that homomorphisms can play in further developments along these lines.

In Chapter III various classes of homomorphisms of graphs are defined and discussed. . . . In Chapter IV three areas of research in automata theory are introduced: regular events in directed graphs, homomorphisms of finite automata, and decompositions and complexity of finite automata. Solutions to problems in these areas are shown to involve homomorphisms of finite automata, and indications are given that by representing automata by state transition graphs, further studies of homomorphisms of graphs can be very useful in solving many of these problems.

From the Abstract

Θ**HOLT, ANATOL WOLF.**   13,890

A mathematical and applied investigation of three structures for computer syntactic analysis. (Thesis)
Univ. Pennsylvania, Philadelphia, Pa., 1963.

This paper consist of two major parts: mathematical and applied. The mathematical part is an investigation of trees—or more exactly, of finite, rooted, oriented and ordered trees; a variety of graph-theoretic structure which is frequently encountered in computer and language related fields of study. The applied part deals with the problem of mechanizing the analysis of written English sentences into transformational constituents.

The mathematics consists of the following. There is defined for trees (of the sort considered) a group of tree operators. The group, taken at its most general, is shown to be isomorphic to the infinite dihedral group; the operators restricted to finite families of trees generate finite dihedral groups. It is shown that the generators of these groups are naturally interpreted as tree reflections and rotations.

Relative to these transformations there are defined a family of tree node mapping functions which are naturally regarded as "directions" in a tree. Rotations and reflections of geometrical objects transform directions, and the rotations and reflections of trees are seen to do the same in a strictly analogous fashion. The direction functions lead to the definition of a particular subgraph of a tree, called the tree "outline," which is shown to represent the tree uniquely and which exhibits particularly simple behavior when subjected to rotations and reflections as defined.

Finally, it is shown how tree outlines can be utilized to construct a "tree memory" with properties that are especially suitable to the linguistic application, though by no means restricted to the latter. The construction addresses itself to definitions of "memory system," "memory accessing function," and "memory modifying function" which are proposed in this paper. Flowcharts for a set of tree memory modifying functions are given in an appendix. . . .

From the Abstract

Θ**MOWSHOWITZ, ABBE.**   13,511

Entropy and the complexity of graphs. (Thesis)
Univ. Michigan, Ann Arbor, Mich., 1967.

This study is addressed to the problem of measuring the relative complexity of graphs. . . . The principal aim of the study is to demonstrate the usefulness of the entropy function as a measure of the relative complexity of graphs. This objective is pursued in two ways. First, a detailed, systematic treatment of an entropy measure defined with respect to the automorphism group of a graph is presented. In so doing, some tools for studying entropy measures in general are developed; and a basis for a complete classification of graphs in terms of this one particular measure is established. Second, a measure defined in terms of a class of chromatic decompositions is examined, largely for the sake of comparison with the first measure. The comparison is intended to highlight those peculiar structural characteristics of a graph which are reflected in the behavior of each of the respective measures.

. . . One general conclusion can be drawn from the study. It is mathematically feasible to use the entropy function to characterize the structure of an object. . . . Moreover, the notion of structural information explored in the study is applicable to more general objects than graphs.

From the Abstract

Θ**RAMAMOORTHY, CHITTOOR VIJAYARAGHAVALU.**   13,686

Generating functions of abstract graphs with systems applications. (Thesis)   *PhD*
Harvard Univ., Cambridge, Mass., 1964.

This thesis is concerned with the concept, properties, and applications of generating functions of abstract graphs. Many practical problems like code generation, path enumeration, shift register sequences, samples data systems, discrete Markov processes, and certain connectivity considerations in automata can be handled in a unified manner using these techniques.

The generating function of a graph is a function of the complex variable z which has the property that interesting attributes of the graph can be extracted from it by numerical operations.

The computation of the generation function involves either matrix inversions or application of formulas that take into account the topological characteristics of the graph. When the graph has certain orderly topological features, the topological method gives the generating function explicitly even when the graph contains an extremely large number of nodes. However, if the graph has been chosen at random, often no advantage can be derived from a topological characterization. The matrix method can then be applied, but computational complexity restricts the size of graphs which can be analyzed.

Abstract

5.4 MATHEMATICAL PROGRAMMING

5.40 GENERAL

Θ**THOMAS, JAMES HENRY.**   14,781

An investigation into the output distributions of GERT networks by the use of simulation. (Ph.D. Thesis)
Lehigh Univ., Bethlehem, Pa., 1967.

The purpose of this research was to further the investigation into GERT (Graphical Evaluation and Review Technique) output distributions. From the family of GERT networks containing only *exclusive-or* nodes, a generally applicable network form was chosen for simulation. A generalized computer program was written to simulate any specific network of this form.

Various networks consistent with the chosen network form were simulated. These ranged from relatively simple networks with constant times associated with the simulations showed that the output distribution could always be represented by an exponential distribution which had been transposed a certain distance in the positive direction. This distance, as well as the parameter of the exponential distribution, could be determined with a certain degree of confidence from the first two moments of the output distribution.

Since the shape and placement of the distribution can be determined from the GERT analytical results, confidence limits can now be placed on the GERT results with relative ease, and without the need for sophisticated mathematical manipulation of GERT moment generating functions.

Abstract

Investigations on a time-table problem. (Thesis)
Univ. Toronto, Toronto, Ont., Canada, 1965.

In this thesis a mathematical model of time tables based on their representation by arrays of zeros and ones, is examined. A scheduling is defined. The classical Konig-Hall theorem on distinct representatives plays a basis role. Feasible matrices and three-dimensional availability arrays are introduced as tools. The structure of these matrices and arrays are revealed. A method (the long-range feasibility method) for the construction of time tables is presented.

A special case of the time-table problem, the so-called tight time-table problem, is introduced. By a constructive proof it is shown that every time-table problem can be embedded into a tight problem. Tight time-table problems have much simpler structures than problems which are not tight. The relationship between the time-table problem and the theory of doubly stochastic matrices is established. The original formulation of the time-table problem is extended.

It is shown that the problem of completing a Latin square is equivalent to a special case of the tight time-table problem. The term-rank and coverance of matrices are generalized for arrays with more than two dimensions. Although the term rank is not equal to the coverance in these cases, many results regarding matrices can be carried over.

The time-table problem without preassignments is completely solved. Two algorithms are given for constructing schedulings in generalized doubly stochastic matrices.

The application of the long-range feasibility method of the construction of high school time tables is briefly indicated.   *Abstract*

5.5 MATHEMATICAL STATISTICS; PROBABILITY

ΘBirdsall, Theodore Gerald.   13,688
The theory of signal detectability: ROC curves and their character. (Thesis)
Univ. Michigan, Ann Arbor, Mich., 1966.

The first problem in the theory of signal detectability deals with the decision between two alternative responses, corresponding to two possible classes of causes of an observation. When the goal of a decision

process is to achieve the highest quality of terminal decision, the Receiver Operating Characteristic curve (ROC curve) contains all of the information necessary for the evaluation of the decision process. This present work introduces the ROC character, which is isomorphic to the ROC curve.

The formal development is based on two key facts. The first is the fundamental theorem: if $l(X)$ is the likelihood ratio of an observation, the likelihood ratio of l is l itself. The second is the main theorem on ROC characters: each ROC character is isomorphic to a univariate probability distribution that possesses a moment generating function. The character convolution theorem and the character addition theorem follow directly from these.

Families of ROC curves are developed from the main theorem on ROC characters. . . . Additional families are generated from these by use of the metastatic relation, and the convolution and addition theorems.

ROC curves contain information about the performance of other two-cause decisions besides the two-response decision. Several are considered that are used in the testing of human perception; namely, the symmetric forced choice decision, type II decisions, the rating scale procedure, and the analysis of a decision based on the reports of multiple observers.
     From the Abstract

ΘGentleman, W. M.   13,522
Robust estimation of multivariate location by minimizing pth power deviations. (Thesis)
Princeton Univ., Princeton, N. J., 1965.

The sensitivity of the mean to deviations from normality such as outliers or long tails is well known. In one dimension various cures have been suggested, but in k dimensions nothing very satisfactory exists. We propose here that the estimator which minimizes the pth power of the deviations (where the deviations are measured with Euclidean distance) for some p between one and two, rather than minimizing the square, provides a useful alternative to the mean.

We demonstrate that, for each of the three parts of the problem—one-dimensional, k-dimensional (metric given), and k-dimensional (metric estimated)—reasonable computational algorithms can be developed. Through consideration of the asymptotic properties, we show how these estimators may be expected to behave for various underlying distributions. For example, we look at what happens when the metric has been specified, but wrongly. Finally, we indicate how a modified form of jackknifing can be used to obtain studentized estimates, and to estimate the metric.

Extensive use is made of Monte Carlo to evaluate the algorithms, to compare asymptotic and small sample properties, and to study the distributions of the studentized statistics in order to help choose critical values.   *Abstract*

ΘRosin, Robert Fisher. 14,126

An algorithm for concurrent random walks on highly parallel computers. (Thesis)

Univ. Michigan, Ann Arbor, Mich., 1964.

The purpose of this research is to propose and evaluate an algorithm for concurrent simulation of absorbing boundary random walks in any two-dimensional space on a highly parallel computer.

The algorithm to be studied is presented and compared with the conventional nonconcurrent algorithm and with other concurrent algorithms. There follows a definition of G, which is a measure of effectiveness of the new algorithm as compared to the conventional one, and definition of several other parameters which describe simulation according to the new algorithm.

A two-part theoretical discussion is then presented. In the first part, the algorithm is analyzed for one-dimensional spaces with the source in the center. Then a lower bound is established for the general two-dimensional case. While it is true that $G \leq 1$ for the one-dimensional spaces, the proof in the second part of this theoretical study shows that $G \leq \frac{1}{2}$ in general, and that $G \leq 1$ subject to two intuitively reasonable assumptions.

An experimental study of G for simulation of symmetric random walks in two-dimensional spaces is then presented. First considered are random walks in spaces with irregular boundaries. The results of these experiments support the conclusions that (1) $G < 1$ for any two-dimensional space; (2) when the objective is to determine the absorption probability for a very small set of boundary points, G increases linearly with the number of nonabsorbing points near the source; and (3) a stated prediction formula for G is valid.

The main conclusions to be drawn from this work are 1) the proposed algorithm is at least as effective as the conventional algorithm for simulating absorbing boundary random walks on highly parallel computers for one- and two-dimensional spaces; (2) in many cases (e.g., small target sets), the algorithm is much more effective than the conventional one and a measure of this effectiveness, i.e., G, can be predicted without random walk simulation.   - *Abstract*

5.6   INFORMATION THEORY

ΘLeiter, Myron. 13,524

Error probabilities for a general class of phase-shift keying communication systems. (Thesis)

Harvard Univ., Cambridge, Mass., 1965.

The objective of this study is to analyze the error performance of phase-shift keying data transmission. The analysis takes as the channel model a random phase-shift, a constant or slow Rayleigh gain, and additive-white-Gaussian noise. The test statistic for the maximum likelihood receiver with post-detection diversity combining is derived and implementations are obtained. Furthermore, the performance of this receiver is analyzed when the channel model contains additional disturbances (e.g., varying path delay, intersymbol interference, etc.), although the receiver is no longer optimum.

The approach taken in this investigation of m-phase transmission is to derive probabilities involving the choice between two of the m possible transmissions. These probabilities are then related, through geometric arguments, to probabilities involving the choice of one of m transmissions. This technique is useful because probabilities associated with the two-decision problem are relatively easy to compute.

A number of phase-shift keying systems are examined including one, termed clairvoyant phase-shift keying, which exhibits maximum achievable performance. In addition, this study attacks several problems of practical importance to communications systems design. One problem involves the relative effect of the number of transmitted phases m on error performance. In an m-phase system, large m may be desirable since the bandwidth requirement, at equivalent binary digit data rates, is proportional to $1/\log_2 m$. Other problems include the computation of error correlations, important to the application of error detecting or correcting codes, and the optimum selection of system parameters (e.g., power division between reference and data signals) in order to minimize error rate. . . .   *From the Abstract*

⊖Neumann, Peter Gabriel.   13,899
Efficient error-limiting variable-length codes. (Thesis)
Harvard Univ., Cambridge, Mass., 1961.

[*Editorial note:* A paper based on this was reviewed when
published as "On a class of efficient error-limiting variable-
length codes." *IRE Trans.* IT-8, 5 (Sept. 1962), 260–
266; *CR* 4, 3 (May-June 1963), Rev. 4167.]

... The purpose of this thesis is to develop codes
which surmount the practical difficulties often en-
countered in employing variable-length codes, namely,
the destructive propagation of errors and the com-
plexity of the encoding and decoding processes. ... A
compromise is developed in this thesis between the
error stability and decoding simplicity of the spaced
codes and the "efficiency" of the optimum codes
(which minimize the overall number of code digits).
Surprisingly, it is found that this compromise di-
minishes only slightly the advantages of the spaced
codes while coming very close to the optimum
efficiency.

The first chapter of the thesis presents the theory
of variable-length codes having a finite number of code
words. ... The second chapter represents the heart
of the thesis. ... After a brief introduction to se-
quential processes in Section 2.1, a study is made of
prefix codes with infinitely many code words defined
by means of a deterministic sequential process; these
codes are called *systematic prefix codes*. ... A general
theory of the desired sequential processes and of the
resulting codes is developed in Section 2.2. ... In Sec-
tion 2.3 binary systematic prefix codes are considered,
with equivalence relations among the next-state func-
tions of the sequential processes being defined in order
to classify the codes efficiently according to the sets
of code-word lengths. Sections 2.4 and 2.5 are devoted
to a special class of binary systematic prefix codes
whose defining sequential processes may be completely
specified by certain combinational switching functions
of a finite number of code digits. ... The third chapter
formulates the ... difficulties which restrict the use of
optimum prefix codes. ... It is demonstrated that
systematic prefix codes may be used to overcome these
difficulties. ... The fourth and concluding chapter of
this thesis investigates the applicability of the sys-
tematic prefix codes for encoding natural languages
and other large systems. ...
From the Abstract

6. DESIGN & CONSTRUCTION

6.1 Logical Design; Switching Theory

⊖Bargainer, James Daniel, Jr.   13,699
Redundancy in threshold logic networks. (Thesis)
Univ. Texas, Austin, Texas, 1966.

In this paper, methods are presented for designing
error correcting capabilities into threshold gate net-
works so that the logic gates themselves correct errors
of the system. A method is first presented which is
based on the tree method of Coates and Lewis for the
realization of threshold gate networks. In this method
the error correcting network is designed from the
Boolean function to be realized. ...

It is shown that a realization obtained by the tree
method will correct t errors of gates in the system if and
only if all primary realizations are selected so that they
will correct t errors of gates in the primary realization.
Relations are then presented for selecting the primary
realizations.

In the second part of this paper, three methods are
presented for adding redundancy to a given realization
f so that errors of gates are corrected by the level of
logic immediately following the occurrence of the
error. ...

Cameron's method for obtaining minimal realiza-
tions is then modified to yield, from the Boolean func-
tion, a minimal realization such that errors of gates in
the system are corrected. It is also shown in this section
that, if a Boolean function is m summable, then a
realization of this function, which corrects t errors,
must have at least $2t + t/(m - 1) + 1$ gates.

In the final section it is shown that correcting errors
in the logic gates, themselves, requires fewer levels of
logic and, for many realizations, fewer gates than when
majority gates are used to correct the errors.
From the Abstract

⊖BLAAUW, GERRIT A.   13,698
The application of selenium rectifiers as switching devices
   in the Mark IV Calculator. (Thesis) /4 D
Harvard Univ., Cambridge, Mass., 1952.

   Selenium rectifiers . . . can be combined in circuits
which perform the logical AND operation or the logi-
cal OR operation. It is possible to use the output of an
AND circuit as an input to an "OR" circuit and vice
versa. This kind of switching circuit is generally
known. An analysis of the circuit which is obtained
when small selenium rectifiers are used shows that the
application of this kind of rectifier to switching circuits
is limited by the speed of the rectifier circuits.
   . . . The output of a rectifier circuit differs in ampli-
tude, waveform, and impedance from the input sup-
plied to the circuit. In order to be able to use the signal
output again as an input to other circuits, an amplifier
and cathode follower are added to the rectifier circuit.
The circuit thus obtained can be considered the basic
unit of a switching circuit. This unit is very powerful
in representing the logical conditions which occur in
large switching circuits. Such a circuit can be consid-
ered as a large network of signal wires. Each signal
originates from a basic unit and is used in turn to con-
trol other units. A system of this kind will contain
several closed loops. An investigation of small systems
with a feedback loop shows that it is possible to com-
bine two basic units in a circuit with two stable states.
. . . In general, n units can be combined in a circuit with
nCm stable states, where m is the number of outputs
which is low in each state. The expression nCm repre-
sents the number of combinations m at a time of n

quantities. These circuits are called multiplets and can
be used to store information.
   . . . The application of multiple state circuits which
use selenium rectifiers is limited by the speed with
which the circuit can change its state. It has been
verified experimentally that for small multiplets a time
of 2 microseconds is required to perform the change
over. An application of the circuits which have been
developed is given in the description of the Sequence
Unit and the Slow Storage Unit of Mark IV. The major
parts of these units consist of rectifier switching cir-
cuits. . . . The possibility of using selenium rectifier
circuits is an important argument in favor of switching
systems which use a medium speed.
                                    From the Abstract

⊖CALINGAERT, PETER.   13,695
Multiple-output relay switching circuits. (Thesis) /, D
Harvard Univ., Cambridge, Mass., 1955.

   Various aspects of multiple-output relay switching
circuits are considered in this thesis. A systematic pro-
cedure is presented for reducing the problem of synthe-
sizing a single-impulse circuit for r binary functions of

n binary variables to that of synthesizing a single-im-
pulse circuit for a single function of $n + r$ variables.
The procedure is applicable to all combinations of
binary functions, and can be used to synthesize both
constant-voltage and constant-current circuits. The
number and classification of multiple-output combina-
tions are also discussed. A method is presented for re-
ducing, at the cost of time, the amount of equipment
required to produce a given set of functions. This is
accomplished by the synthesis of a multiple-output cir-
cuit whose operation is sequential.
   A comprehensive class of circuits is defined, and it is
shown that the synthesis of a minimal multiple-output
circuit belonging to that class is reducible to the syn-
thesis of a minimal single-output circuit of that class.
The problem of minimization is also considered from
the viewpoints of simplifying circuits designed by the
synthesis procedure and of selecting optimum formula-
tions of a given problem for that procedure.
   The dual of a circuit is defined, and it is demon-
strated that the same output functions are produced by
a single-impulse circuit and its dual.
   Finally, matrix representations of both constant-
voltage and constant-current circuits are presented. By
means of two kinds of Boolean determinants, the ma-
trices are used to evaluate the functions produced by
the circuits.   *Abstract*

⊖Cohn, Martin.   13,904
Switching function canonical forms over integer fields.
  (Thesis)
Harvard Univ., Cambridge, Mass., Dec. 1960.

In the Δ-canonical forms considered in this thesis, switching functions are expressed as modulo-2 sums of products of complemented and uncomplemented variables. Chapter 1 begins with an introductory section, followed by definitions and notational conventions. Next, the Boolean canonical form and the Δ-canonical forms are introduced and the representation of switching functions as vectors is discussed. The chapter ends with the definition of a cost function for Δ-form expressions.

Chapter 2 is devoted to the definition and investigation of the class of composition matrices over the finite field of integers modulo-2. . . . it is shown that they are nonsingular. . . . The class of consistent Δ-forms is then considered. . . . The matrices which relate consistent Δ-forms to each other and to the Boolean form are all shown to be composition matrices, hence nonsingular. From this it follows that all the consistent Δ-forms are canonical.

In Chapter 3 all the inconsistent Δ-forms are proved to be canonical, and by the use of this result an upper bound is derived for the cost of a Δ-form expression for an arbitrary function. The matrices which relate inconsistent Δ-forms to the Boolean form are then examined, . . . expedient methods of inverting the matrices are devised, and upper bounds on the cost of inversion are established.

The concepts of the Boolean form, Δ-forms, and composition matrices, as well as many of the theorems concerning them, are generalized in Chapter 4 to the case of an arbitrary prime modulus. . . . The final section of Chapter 4 treats the evaluation of the proportion of nonsingular matrices and the proportion of composition matrices over the field of integers modulo p.

Chapter 5 returns to the case $p = 2$ and considers the topic of incompletely specified switching functions. . . . Three problems deemed by the writer to be worthy of future attention, are described in Chapter 6. . . .
From the Abstract

⊖Coolidge, Charles Allerton, Jr.   13,531
Design of an automatic digital calculator. (Thesis) *PhD*
Harvard Univ., Cambridge, Mass., 1953.

. . . In the first two chapters of this thesis, principles governing the organization of large-scale digital calcutors are presented with as little reference to technical matters as possible.

The next topic considered is the design of switching circuits in order to use a minimum amount of equipment. Any general solutions to this problem will not be forthcoming for many years. Several practical techniques which are useful in the design of complicated switching circuits are described, with particular reference to the design of circuits for decimal arithmetic units.

The second part of the thesis is devoted to the application of the principles set forth in the first part. Plans are presented for the construction of a low-cost general-purpose calculator. . . . In the design of the proposed calculator every effort has been made to make the task of problem preparation as simple as possible. Much simplification is accomplished by the use of ten special control registers which bear a close resemblance to the indices associated with the algebraic symbols $\prod$ and $\sum$. Further simplification is achieved by the facts that there is only one internal number storage; and no problem preparation time need be spent to accomplish perfunctory transfers from one internal storage to another.

Further design effort is made to reduce the amount of equipment necessary for the construction of the calculator. This aim is accomplished by the use, in a relatively slow machine, of fast circuits performing serial operations. The use of such techniques reduces both the initial and maintenance costs of the calculator.
From the Abstract

⊖Dertouzos, Michael L.   13,536
Threshold-element synthesis. (Thesis)
M.I.T., Cambridge, Mass., 1964.

This report treats the combinatorial design of switching networks in terms of threshold elements. The problem of threshold-element synthesis consists of two parts, namely, the synthesis of a single threshold element and the synthesis of threshold-element networks.

Single-threshold-element synthesis is approached through correlation of the required output Boolean function with the available input variables. A necessary and sufficient condition for single-threshold-element realizability is derived in terms of these correlation coefficients. This condition gives rise to three test-synthesis techniques for effecting single-threshold-element synthesis.

Threshold-element network synthesis is approached through an augmented vocabulary of correlation coefficients. This approach makes possible three procedures for effecting this type of synthesis. One procedure, in particular, permits the synthesis of networks in the presence of reliability constraints. The networks resulting from all these procedures are in two-level form or degenerate variants of such a form. Moreover, bounds are given for the relative optimality of these networks.

Certain peripheral aspects (e.g., the reliability of threshold elements, don't-care synthesis, etc.) and the necessary supporting material for developing the above procedures are also presented.   *Abstract*

⊙DWYER, THOMAS F.   13,533
Bipolar magnetics for digital information processing.
  (Thesis) *PhD*
Princeton Univ., Princeton, N. J., 1966.

    This thesis is an analytical and experimental in-
vestigation of the bipolar operation of square-loop
magnetics for digital information processing, following
the work initiated by Newhall.
    In the first chapter the operational behavior of the
bipolar elements is examined with respect to the
generalized requirements of elementary digital net-
works. This qualitative evaluation shows that digital
information can be handled adequately by networks
composed of bipolar elements and connecting wires
only.
    The switching characteristics of the bipolar elements
are analyzed in detail in the second chapter. . . . Ap-
propriate equivalent circuits of the bipolar element in
its various operational flux states are developed.
    A representative elementary digital network com-
posed of the bipolar elements and low-resistance con-
necting wires only is analyzed in the third chapter.
The analysis reveals that the timing of the pulse
energization of the bipolar network is not as critical as
one might expect. The operational behavior of the
elementary network in a three-phase shift register is
determined experimentally and it appears to agree
well with the analysis. Some design and operational
considerations of the bipolar network are elaborated.
The operational characteristics of the bipolar network
and a similar unipolar network are compared, showing
the advantages of the bipolar elements over the con-
ventional unipolar elements.
    Power amplification for logical fan-out is treated in
the last chapter. Several approaches to realize power
amplification are evaluated. An analytic expression
for energy gain per transfer is developed. . . .
                                From the Abstract

⊙EICHELBERGER, EDWARD B.   13,534
Sequential circuit synthesis using hazards and delays.
  (Thesis) *PhD*
Lehigh Univ., Bethlehem, Pa., 1963.

    This dissertation describes a new type of circuit
realization for fundamental mode sequential circuits
(level input signals and level output signals). This
new type of circuit realization, called a "delayed-input
circuit," contains static hazards and delays which
enable input level changes to produce hazard pulses.
These pulses are then used to change the internal state
of the circuit.
    A general model is proposed for delayed-input
circuits, and a new flow table is used to describe its
operation. Making use of this flow table, a general
synthesis procedure is developed. It is shown that
delayed-input circuits are inherently free of critical
races, and contain an absolute minimum number of
feedback loops.
    The problem of how to design combinational (loop-
free) networks that generate output pulses for input
level changes is considered, and two synthesis tech-
niques are described.
    A modified type of delayed-input circuit, called an
R.D. circuit, is also considered. It is shown that any
fundamental mode sequential circuit can be realized
by an R.D. circuit that does not contain any delays
in its feedback loops.   *Abstract*

⊙GOULD, RODERICK.   13,532
The application of graph theory to the synthesis of contact
  networks. (Thesis) *PhD*
Harvard Univ., Cambridge, Mass., 1957.

    In this thesis the application of the mathematical
theory of graphs to contact network design is dis-
cussed. The theory of graphs is concerned with sys-
tematizing the relationships of sets of points connected
in some fashion by line segments. Any contact network
may be considered to correspond to a graph; through
this correspondence results obtained in the study of
graphs may be applied to contact networks.
    Chapter 1 is devoted to an exposition of certain
aspects of graph theory which are especially pertinent
to the study of contact networks, and in particular to
two-terminal contact networks. . . . In Chapter 2 the
class of monotone functions is defined; this class in-
cludes all graph functions. . . . Some further structural
properties of two-terminal graphs are studied in
Chapter 3. In the course of the development, "series-
parallel" and "bridge-type" graphs are defined, and it
is shown that every two-terminal graph is of one of
these two types. . . . The first section of Chapter 4 is
devoted to a description of an alternative graph
synthesis procedure, which utilizes vector space prop-
erties possessed by the loop-sets and cut-sets of
graphs. In the remaining sections of the chapter, the
problem of synthesizing any graph from a basis matrix
of its loop-set vector space is considered in more detail.
. . . In Chapter 5 the incidence matrix is proposed as
an alternative model. The representation and analysis
of various types of multiterminal networks are
discussed. The use of oriented graphs and their cor-
responding matrices for the representation of net-
works containing bilateral elements is described
briefly. . . . In Chapter 6 it is shown that the methods
of graph synthesis previously developed have ap-
plications to the synthesis of contact networks for
arbitrary switching functions. Some techniques are
outlined which appear to point the way toward a
practical general method for the synthesis of two-
terminal networks.   *From the Abstract*

ΘHENDERSON, DEREK S.   13,538
Logical designs for arithmetic units. (Thesis)

In this thesis methods are proposed for the logical design of various types of arithmetic units for high-speed digital computers. Except where expressly indicated, attention is confined to binary systems. After an introductory chapter, the design of general and special purpose counters is discussed in Chapter 2. In Chapter 3 two main types of adders are developed, and special comparator circuitry for use in sorting operations is described. An analysis of maximum carry propagation lengths for various radices is provided. Finally, the question of the simultaneous addition of several numbers receives attention.

The carry storage adder developed in Chapter 3 is applied in Chapter 4 to a short-cut method of multiplication. Other methods of multiplication based on multiple adders and on the use of counters are presented. Two methods of table look-up multiplication are investigated, and a method is indicated for reducing the computation time of the frequently occurring sequences of arithmetic operations embodied in vector product and polynomial evaluations.

In Chapter 5 various proposals for performing the operations of division and square root extraction are discussed. An efficient algorithm for programmed division and a process of square root extraction based

on Horner's method are the main features of this chapter.

No examination of high-speed arithmetic systems should omit an exposition of the residue class number system. This is the subject of Chapter 6. Methods based on modular arithmetic are derived for detecting and correcting errors in the arithmetic operations of both radix and residue class systems.

In Chapter 7, comparisons and conclusions are drawn from the material of the thesis, and areas in which further research is likely to be profitable are suggested.   *From the Abstract*

ΘHOPKINS, ALBERT LAFAYETTE, JR.   13,529
An investigation of non-ohmic resistive switching networks. (Thesis)   *Ph D*

The primary purpose of this investigation is to determine whether non-ohmic resistances other than crystal diodes have useful switching applications in which they may offer economic advantages over diodes.

Chapter 1 is an introductory chapter describing the basic form of the resistive electrical circuits which are used to realize conjunctive and disjunctive operations on binary variables. . . . In Chapter 2, the separation and widths of the output voltage ranges are used to define figures of merit for the steady-state outputs of a switching network. These figures can be evaluated analytically or experimentally, and are used throughout this investigation. A number of simplified examples are used to show that resistive switching networks operate best with highly non-ohmic elements and few inputs. In addition, it is seen that algebraic evaluation of the figures of merit is extremely complicated for all but the simplest cases. Numerical techniques developed for the calculation of network output voltages are presented in Chapter 3. A method is derived for the calculation of two-level network outputs, and is applied to an example. A more satisfactory method, however, utilizes the output voltages calculated for one level at a

time . . . In Chapter 4, selected solutions are presented graphically to illustrate the influence of each of the parameters on the output voltages and the figures of merit. The solutions are further utilized in studying the effects both of non-uniformity of the elements and of the loading of the second level on the first. A method of calculating the second level output voltages is presented, which uses the results of the one-level analysis. It is demonstrated that useful switching networks can theoretically be made from non-ohmic resistances other than crystal diodes . . .

One type of non-ohmic element whose switching properties have been studied previously is made from silicon carbide granular aggregates, similar to those used in making "Thyrite" and "Globar" resistors. The advantages and disadvantages of such elements are discussed in Chapter 5 . . .

In Chapter 6, the experimental behavior of switching networks made with these crystal assemblies is described.   *From the Abstract*

Θ HOWE, ALFRED BART.   13,697
A study of hazards in threshold networks. (Thesis)
Univ. Texas, Austin, Texas, 1966.

This paper is concerned with the study of logic hazards in threshold gate networks.

. . . A method is first presented for determining if a given threshold realization contains any logic hazards within a particular prime implicant. This technique is an extension of McCluskey's work and requires determining a function of the realization which is referred to as the transient function $F^\dagger$.

A procedure is then given for obtaining a realization from the given realization, such that the latter realization will have the same hazard conditions as the given realization. By using the latter realization, it is possible to determine, without the calculation of $F^\dagger$, if a given realization contains any logic hazards. But even more important, the second method provides the fundamental ideas needed for synthesizing hazard-free threshold logic.

The first two methods for detecting logic hazards are based on either the transient function $F^\dagger$ or the input/output relations of the realization. Two additional methods are then presented for detecting logic hazards which are based upon the gates of the realization. The latter two methods are needed to prove a theorem for synthesizing logic hazard-free threshold networks.

A method is then presented for synthesizing logic hazard-free realizations directly from the Boolean function to be realized. This method is based on the tree method for synthesizing threshold gate networks.

. . . In the last part of the paper a set of algorithms are given for modifying a given realization such that the modified realization will not contain any logic hazards.   *From the Abstract*

Θ KIMURA, IZUMI.   13,696
Extensions of asynchronous circuits and the delay problem.
 (Thesis)
Univ. Tokyo, Tokyo, Japan, 1967.

Delays of signal propagation inherent in the wires interconnecting the elements of an asynchronous switching circuit often cause unexpected behavior of the circuit. This problem is known as the delay problem, of which this paper attempts to find a general solution. It is the purpose herein to clarify the true nature of the problem and to provide a mathematical framework applicable not only to the delay problem itself but also to a number of problems such as of finding an easily realizable combination of logical elements usable in an asynchronous circuit as a substitute for another element, of which physical realization is difficult. Basic to the theory is the concept of extensions. An extension C^+ of a circuit C is another circuit having hidden nodes in addition to the nodes of C. Some requirements are introduced for C^+ to be "practically identical" to C, and conditions are derived for these. A model for the delays within the wires is established and the significance of the requirements relative to this model is investigated. A study is made in search of test procedures for checking whether the delays under a given circuit configuration are harmful or not.
                    Abstract

Θ LECHNER, ROBERT JOSEPH.   13,530
Affine equivalence of switching functions. (Thesis)
Harvard Univ., Cambridge, Mass., 1963.

The subject of this thesis is a study of equivalence relations induced on functions whose domain $D = J_p^n$ and range $R = J_p^m$ are both finite-dimensional vector spaces over the same finite field J_p of (residue classes of) integers modulo, p. . . . The focal point of this thesis is the systematic study of cyclic subgroups of RAG $(n/1)$ by rational algebraic methods. The initial inspiration for this research was Ninomiya's pioneering study of equivalence relations induced by transformation groups on $D R = J_2^n$ which leave invariant the unordered set of Fourier coefficients of a switching function.

. . . Chapter 1 is devoted to the generalized definition and analysis of equivalence between two sets of m functions of n arguments under the group RAG(n/m) over J_p. . . . Chapter 2 develops rational canonical forms for elements of AG(n) and RAG$(/1)$ over J_p and effective methods for transforming an arbitrary element of either group into canonical form. Chapter 3 analyzes the structure and determines the order of the centralizer group for a cyclic subgroup of AG(n) or RAG$(n/1)$ whose generating element is in canonical form. . . . Chapter 4 applies the theory developed in Chapters 2 and 3 to the problem of counting the number of equivalence classes of switching functions of n binary variables under RAG$(n/1)$ over J_2.

. . . In conclusion, this thesis may be summarized as an attempt to lay down a firm algebraic foundation for further research on both the theoretic and computational aspects of the analysis of functional equivalence under the group RAG(n/m). Three major problem areas are suggested as worthy of future research effort. The first of these is a computational evaluation of the practicality of a synthesis procedure which generates a set of functions by applying restricted affine encodings to the domain and range of one or more canonical representatives of the equivalence classes to which the set of functions belongs. The second problem is the development of rational canonical forms for elements of RAG(n/m) with m 1. . . . The third problem area . . . is an exploration of the interrelationships among the rational algebraic and harmonic analytic methods of functional classification in this thesis and that of Ninomiya, and existing computational approaches to the synthesis of switching circuits, most of which are based primarily on combinatorial analysis and Boolean operations on prime implicants.
                    From the Abstract

ΘLiu, Ming-Tsan. 13,903
The triquare map method for realization of threshold
  functions. (Thesis)
Univ. Pennsylvania, Philadelphia, Pa., 1964.

... An objective of interest is the problem of devis-
ing a simple test and synthesis procedure for a given
Boolean function to be realized as the output of a
single threshold element. This paper, after an intro-
duction giving various approaches to this problem,
divides into four chapters.

By introducing the concept of *dual-monotonicity* as
a dual to that of *monotonicity*, a chain of conditions,
called dual-comparability, 1-dual-monotonicity, 2-
dual-monotonicity, etc., and their union, *complete
dual-monotonicity*, is established. The mutual relation-
ship between monotonicity and dual-monotonicity is
explored in detail. Complete dual-monotonicity is
shown to be equivalent to complete monotonicity as a
necessary condition for threshold functions.

A Triquare (*TRI*angle-s*QUARE*) map is obtained
by developing a unit n-dimensional cube on a 2-
dimensional plane diagram composed of triangles and
squares. The recognition of various order dual-mono-
tonicities, as well as monotonicities on a Triquare
map plot for a given function is clear and easy. A prac-
tical synthesis procedure, suitable to a map method,
to find the integral-minimal realization of a threshold
function without directly solving a set of inequalities,
is given. As with any map method, the Triquare map
utilizes the ability of people to recognize patterns and
the relation between patterns. Experience plays a role
here.

Two sets of parameters, to be called *eigenvalues*, are
derived to completely characterize threshold func-
tions, and to yield their integral-minimal realiza-
tions. A list of 135 representative classes of self-dual
threshold functions with up to seven variables, in
terms of these parameters, has been prepared to
facilitate the identification and realization of all
threshold functions of up to six variables, amounting
to more than 15 million functions. ... However, the
questions about what can be expected in general and
what procedures are likely to lead to a better solution,
still remain to be answered.   *From the Abstract*

ΘMeisling, Torben H. 13,537
The translation of arithmetic operations into switching
  operations in digital computer design. (Thesis)
Univ. California, Berkeley, Calif., 1952.

Functionally, an electronic digital computer con-
sists of networks of electronic two-position switches.
The synthesis of these networks gives rise to design

problems in which the physical nature of the switches
is of secondary importance. Such problems, classified
as logical problems, appear prominently in the design
of the arithmetic element. The subject of this study is
the translation of arithmetic operations on numbers
into the operations of switching networks.

Digital computers have for some time been recog-
nized as devices capable of storing, moving, inter-
preting, and modifying information. This point of view
is adopted and a suitable mathematical information
concept is found in the mathematical theory of com-
munication. It is shown how this concept can be
applied both to arithmetic operations on numbers and
to switching operations. From the analysis it appears
that the essential characteristic of an arithmetic
operation is its distribution of symbols. Any physical
process capable of bringing about a particular
distribution of output symbols over input symbols
may be used as an arithmetic element for that par-
ticular arithmetic operation.

When the information concept is applied to the
switching operations use is made of the symbolic logic
representation of these operations. It is shown how the
operations of Boolean algebra represent information
filters capable of realizing the distribution of symbols
required in arithmetic operations.

The symbols dealt with in Boolean algebra are com-
binations of values of binary variables. Arithmetic re-
quirements can be expressed in Boolean symbols as
well as in the common arithmetic symbols, and the
translation leads to new and more comprehensive and
systematic methods for the design of arithmetic ele-
ments.   *Abstract*

ΘMERWIN, RICHARD EUGENE. 14,594
A calculus of injective-covers. (Ph.D. thesis)
Univ. Pennsylvania, Philadelphia, Pa., 1965.

... The development of a Calculus of Injective-Covers proceeds from the cubical calculus used in synthesis. The elements of this calculus are presented as background material. Next a mathematical model based on a set of recursive rules is presented, which restricts the switching networks considered to combinational nets. This model employs a directed-graph representation with injective and logic nodes. A system of input and output labeling is developed for the injective nodes along with a functional description of the recursive rules.

Having defined in a rigorous fashion a combinational net as a directed graph, a translation algorithm from the mathematical model to a set of cubes called an injective-cover is required. ... With the injective-cover defined, the calculus operations on network structures are developed. The first of these is the analysis transformation, which converts a structural description of a net into a behavioral description. ... To complete the calculus, the intersection and subtraction (sharp product) operation between combinational nets is described. A method for multiplexing the injective-covers for two or more nets is presented, to permit operations between the nets in terms of cubes. The intersection and subtraction procedure is developed in terms of the analysis procedure previously described for a single injective-cover. These operations are then employed in design confirmation and fault location as practical applications of the calculus.

In conclusion, several possibilities for future research in this field are presented. These mostly follow from restrictions adopted in the development of the calculus which are not inherent limitations of the injective-cover, but were adopted to simplify the presentation. *From the Abstract*

ΘSEMON, WARREN LLOYD. 13,701
The application of matrix methods in the theory of switching. (Thesis) *PhD*
Harvard Univ., Cambridge, Mass., 1954.

In this thesis a new mathematical model for the representation of switching networks is introduced based on the notion, proposed by Professor Howard H. Aiken, that the circuit element between two terminals i and j may be taken as an element a_{ij} of a matrix. It is shown that such a matrix completely describes the network in the sense that the circuit diagram may be immediately inferred from the matrix; that this is true for general networks, series-parallel or bridge-type, planar or nonplanar, single or multiple output, and including unilateral or bilateral elements or both. The matrix also acts as a criterion for minimization in that it specifies the number of switching elements in the circuit.

The matrices for certain elementary circuits are examined in detail, canonical form matrices are developed, and various transformations which leave the outputs of the circuit invariant are described. Finally, a sequence of theorems is presented, leading to a theoretical solution of the problem of designing a network using the minimum number of relay contacts while producing a prescribed output. *Abstract*

ΘSINGER, THEODORE. 13,700
A class of time-sequential circuits. (Thesis) *PhD*
Harvard Univ., Cambridge, Mass., 1954.

The design of sequential circuits is widely regarded as the most difficult problem in the field of circuit synthesis. This thesis attacks one aspect of this problem through the medium of a detailed study of a certain class of relay circuits operated in a sequential manner; to them is applied the term *rattle circuits*. The term *rattle functions* is applied to the switching functions which occur as their outputs.

A very diverse range of application of the rattle circuit idea is possible, and in the present study of rattle circuit operation, two main avenues of thought are chosen for special investigation. The first of these is particularly appropriate for use in connection with the switching functions associated with reiterative networks, and it is discussed in the second and third chapters, with special attention to symmetric functions in Chapter 2. In the fourth chapter the second line of investigation is begun. In it, the systematic use of circuit algebra plays a large role. In order to gain some insight into the nature of the circuits and the functions, this part of the investigation begins with the study of a somewhat overspecialized rattle circuit, but the class is extended in the following chapters by the use of devices of various kinds. The circuits through which these devices may be realized are described, and the classes of output functions are studied in great detail. Indications are given of possible further extensions of the class. A method is developed for identifying a given switching function as a rattle function, and for specifying more precisely the nature of the rattle circuit required for the function. *Abstract*

Θ WINDER, ROBERT O.
Threshold logic. (Thesis) *PhD* 13,702
Princeton Univ., Princeton, N. J., 1962.

. . . This paper, after an introduction giving defin-tions, simple properties, and some general discussion, divides into two sections: Properties and procedures. The first of these sections includes discussion of a doubly infinite chain of properties of threshold functions, the second limit of which characterizes such functions. The first two properties, which are the most useful as "necessary conditions," are given special attention; they yield interpretations in algebraic ex-pressions for the function and provide a natural order-ing of the function's arguments. Relations between the families of properties are given, and their independence shown. Some other conjectured characterizations of threshold functions are shown invalid. The number of threshold functions, as a function of n, is given a rela-tively good upper bound.

The procedures include first a practicable method of enumerating symmetry classes of threshold functions, and several synthesis procedures. The problem of determining whether, for a given function, a's as above exist, and if so, what values are possible, yields a sys-tem of linear inequalities. Reduction of the system and its solution are treated. Generalization to the case of partially specified functions, and restriction to the case of minimal integral solutions, are given. The very dif-ficult problem of realizing a given function as a com-position of just two nontrival threshold functions is completely solved. Two approaches to synthesis under restrictions on the set of allowable threshold functions are given. In the first, an appropriate axiomatization of the algebra of simple majority functions ($x_1 x_2 = x_1 x_3 = x_2 x_3$) is described and shown complete; in the sec-ond, practical compositions are given which allow any threshold function to be composed efficiently from sim-pler threshold functions.   *From the Abstract*

6.2 COMPUTER SYSTEMS

6.21 GENERAL PURPOSE COMPUTERS

Θ SHIPKOVITZ, SAMUEL.   14,806
An asynchronous look-ahead digital simulation language. (M.Sc. Thesis)
Case Inst. of Technology, Cleveland, Ohio, 1967.

ALAS (Asynchronous Look-Ahead Simulator) 1107 is an implementation of a digital systems simulation language. This implementation uses and notes only the changes of states of the system and resultant effects. By contrast the usual method re-evaluates all nodes. The system demonstrated here is an asychro-nous ("interrupt driven") look-ahead system and thus the electronic timing (internal delays) of the simulated devices is considered. The simulator was written in a combination of ALGOL 60 and SLEUTH II (UNIVAC 1107 assembly language). The description of a digital system in this language is described with its input and output nodes in a single statement, the order of these statements being unimportant, Coding in this digital simulation language is simple, enabling any engineer to learn to program its use in a matter of minutes. Provision is made for adding additional devices and/or internal delay parameters to the system.   *Abstract*

Θ STURMAN, JOEL N.   13,704
An iteratively structured digital computer. (Thesis)
Cornell Univ., Ithaca, N. Y., 1966.

This work is an investigation of a general-purpose digital computer composed entirely of small sequential machines. The sequential machines, or cells, are iden-tical in structure, each cell having fewer than 2^{11} states.

The one-dimensional iterative array of cells which constitute this computer is similar to the distributed logic associative memory originally proposed by C. Y. Lee. A significant difference in the machine's structure, however, arises from the fact that instructions are stored within, and are under the control of other cells rather than a central processing unit. Sufficient logic must be incorporated into this iterative array to store and interpret instructions, to find and perform arith-metic and other manipulative operations on the data stored elsewhere in the array, and to perform the se-quencing and branching of instruction control as per-formed in a more conventionally structured computer. No specific area of this machine acts solely as a mem-ory, an arithmetic unit, or a control unit; but rather one or more cells within the iterative array perform all of the above tasks.

The logical structure of a typical cell is described, and programming techniques peculiar to this machine are investigated. Rapid instruction execution is possi-ble because of the asynchronous machine operation, the simplicity of the cells, and the transmission line properties of the computer.

This concept of machine structure yields benefits of an associatively organized memory structure and pos-sesses useful properties of repetitive construction and asynchronous timing.   *Abstract*

6.3 COMPONENTS & CIRCUITS
6.31 CIRCUIT ELEMENTS

⊖MINNICK, ROBERT CHARLES.   13,907
The use of magnetic cores as switching devices. (Thesis)
Harvard Univ., Cambridge, Mass., 1953.

[*Editorial note:* A paper based on this was reviewed when published as "Magnetic core access switches." *IRE Trans.* *EC*-11, 3 (June 1962), 352–368; *CR* 4, 4 (July–August 1963); Rev. 4356.]

The purpose of this thesis is to develop on a logical and experimental basis switching circuits using magnetic cores having rectangular hysteresis loops. The principles used in these circuits were first suggested by Howard H. Aiken. Magnetic core switching circuits can be considered as generalizations of the static magnetic delay line. The three windings on a single magnetic core in a static magnetic delay line are used for 1) input of the information to be stored; 2) output of this information; and 3) control. By replacing the single input windings for the arbitrary number of windings, n, and by substituting two control windings for the single one on the magnetic storage device, it is shown in this thesis that logical operations may be performed on the binary input variables. Specifically, two such magnetic core switching circuits are developed which are equivalent respectively to the binary outputs of n triodes having a common plate resistor, and of n cathode-followers having a common cathode resistor; where binary inputs appear at the grids of these vacuum tubes.

These basic magnetic core switching circuits are combined into several alternate "two-level" circuits, and it is shown that each of these is capable of producing any switching (i.e., binary) function of any number of binary input variables.

. . . Several magnetic core switching circuits were built, and the experimental data regarding them are reported in the text. The logical behavior of these circuits is verified by oscillograms of the outputs for all possible combinations of the binary inputs. . . . The problem of synthesizing magnetic core switching circuits to produce given switching functions is considered in this thesis. Specific rules for synthesis are given, and a table of all possible magnetic core switching functions of three variables is included. . . . Practical construction techniques for magnetic core switching circuits are considered, and a method for simplifying the winding of the toroidal magnetic cores is suggested. . . .   *From the Abstract*

6.32 ARITHMETIC UNITS

⊖LEHMANN, M.   13,544
Parallel arithmetic units and their control. (Thesis)
Univ. London, London, England, 1957.

. . . Part One of the thesis considers the fundamental principles on which the design of binary arithmetic units may be based. It discusses and analyses the various methods by which the basic operations may be performed. In particular, a new and original method for the control of signed multiplication is developed, a proof is given that this method is the optimum multiplication method in a sense defined, and an expression is derived for the reduction in the number of additions during multiplication which the method achieves. A detailed comparison is made of the relative speeds—as a function of circuit constants—of the various multiplication methods discussed. Proposals are similarly made for the provision of a fast division order using "short-cut" techniques.

Part Two describes an arithmetic unit based on the fundamental design concepts outlined in Part One, but not including the newly developed process. This machine was built of two valve-packages in the Department of Mathematics, Imperial College, London. In Part Three, new designs for two packages, one of which is based on original logical concepts, are outlined. As an illustration of the application of these packages, the design of an original arithmetic unit and its control built up from these two circuits and gating and decoding circuits only, is developed. The main requirement of this design is that the resultant unit and the machine of which it is a part shall achieve high order and program speeds, but the attainment of this shall be subject to reasonable economic restrictions.
. . .   *From the Abstract*

⊖RATZ, ALFRED G.   13,545
The design of the arithmetic unit of an electronic digital computer. (Thesis)
Univ. Toronto, Toronto, Ont., Canada, 1951.

The thesis deals with the design of the arithmetic circuits of an electronic digital computer. Factors influencing the design are examined and of these, reliability is seen to be of prime importance. Reasons are given to show that a parallel binary Arithmetic Unit is the most reliable.

Two types of Arithmetic Unit are considered. The first uses pulses to represent digits and computes by counting these pulses. The circuits of the second type are over-drive and direct-coupled, and in them digits are represented by voltage amplitudes.

The second type is indicated as the more reliable and most of the thesis is concerned with its design. Its component circuits (static links, adder networks, and register flip-flops) are investigated, and design procedures outlined. Ease of design, circuit speed, and the number of vacuum tubes required are important in evaluating circuit designs.

Finally, the Arithmetic Unit of the University of Toronto Model Digital Computer is described. Direct-coupled circuits typical of those investigated are incorporated in the Unit. Its high speed and reliable operation indicate that the decision to base the design on such circuits was a wise one.   *Abstract*

ΘASHENHURST, ROBERT LOVETT.   13,709
The structure of multiple-coincidence selection systems.
(Thesis)   *PhD*
Harvard Univ., Cambridge, Mass., 1956.

Since the use of coincident-current selection for mag-netic core information storage was first proposed by J. W. Forrester in 1950, much effort has been expended on the practical development of this type of storage. The two-dimensional "digit plane" array has been the basis of most proposed systems. The nature of coin-cident-current selection in storage arrays, however, suggests the possiblity of more general designs.

In this thesis the abstract structure of such designs is investigated and mathematical methods are pre-sented for the synthesis of multidimensional "coordi-nate-access" arrays with redundant selection. The use of such arrays can lead to considerable savings in input switching equipment, or alternatively, permit faster and more reliable operation than otherwise possible.

The design methods developed are based on modern algebra, and a concise self-contained presentation of the relevant algebraic theory has been included. The technique of applying the algebraic tools to the syn-thesis of storage arrays is discussed and illustrated in detail. The related questions of output disturbance and input switching are also investigated. . . .

Chapter 1 is an introductory description of existing magnetic storage systems. The basic principles of coin-cident-current selection are set forth in Chapter 2. . . . Chapter 3 is devoted to the development of algebraic tools for use in designing coordinate-access arrays. . . . The application of the tools developed in Chapter 3 to the synthesis of multidimensional magnetic core arrays with redundant groups of selection wires is pre-sented in Chapter 4. . . . Chapter 5 deals with the prob-lem of output disturbance in storage arrays. . . . The question of input switching is treated in Chapter 6. A model of an input switching network is developed, fol-lowing A. W. Burks and his collaborators.

. . . The results indicate how the multidimensional

approach facilitates the construction of large arrays with substantial savings in associated equipment.
                                        From the Abstract

ΘSMITH, KENNETH C.   13,549
Flux reversal in ferrites. (Thesis)
Univ. Toronto, Toronto, Ont., Canada, 1960.

Existing measurements of switching properties of magnetic materials are inadequate to discriminate between theories of various switching mechanisms. It was felt that further progress would only be possible after an extensive study of switching properties under comparable conditions. For this work a detailed study of a single material seemed most useful.

The purpose of this thesis has been to provide such a set of experimental results and to compare them with the theories which may be expected to apply to the material selected, a common variety of magnesium manganese ferrite.
                                        Abstract

6.35 INPUT/OUTPUT EQUIPMENT

ΘGRONEMANN, URI FRITZ.   13,550
Coding color pictures. (Thesis)   *PhD*
M.I.T., Cambridge, Mass., 1964.

A computer-simulation study of efficient coding for color pictures has been undertaken. Two typical color transparencies were resolved into three primaries, sampled in a square array, and recorded digitally on magnetic tape. The computer program transformed these data into luminance and chrominance quantities, performed certain parameter modifications, recon-verted them into primary-color quantities, and wrote the latter on an output tape. The parameters modified were the effective number of samples per picture and the number of quantum values each for the luminance and for the chrominance. The output tape was played back through the recorder/reproducer to produce images of the coded pictures on the face of the CRT, which were then photographed through appropriate filters on color film.

. . . The results show that while the best monochro-matic reproduction achievable in the experimental system required a transmission rate of 5 bits per sample (using logarithmic quantization), the best color reproduction in the same system (having the same luminance sample density) required an average of at most 5.55 bits per sample. This is achieved by quantizing chrominance to about 1,000 values and reducing the spatial density of chrominance samples to 1/18 of that of luminance. The results also indicate that the luminance sample density of a color picture can be reduced by a factor of from 1.5 to 18 or more, and still be equal in quality to the monochromatic reproduction, depending on the subject matter and on the criterion used for comparison.

Two major conclusions were drawn from this study: 1) a normal monochromatic picture can be converted into a dull color picture of the same apparent sharp-ness by transmitting additionally only a fraction of a bit per sample; and 2) for many purposes inclusion of color may result in an overall lower transmission rate requirement than would the same picture coded

monochromatically; for some purposes, such as recog-nizing objects, this reduction can be substantial.
                                        From the Abstract

Ⓗ Kates, Josef. 13,551
Space charge effects in cathode-ray storage tubes. (Thesis)
Univ. Toronto, Toronto, Ont., Canada, 1951.

In 1948 F. C. Williams and T. Kolburn disclosed that they had succeeded in using ordinary cathode-ray tubes for the storage of digital information in electronic computers. The above authors proposed a theory which neglected space charge influences.

When cathode-ray tubes are used for digital storage, there are a number of complicated phenomena which cannot be explained completely by the original theory. An analysis of these phenomena is difficult because of the geometry of cathode-ray tubes. In this thesis one-dimensional models of a cathode-ray tube are used to analyse the effects of secondary emission and space charge parameters. An improved theory of a cathode-ray storage tube action is developed and experimental evidence is given to support this theory. The important differences from the Williams and Kilburn theory which result are: a) the potential of a storage spot is negative with respect to the electrode collecting secondary electrons; b) the difference between the potentials denoting a "zero" and a "one" is, not due solely to initial secondary electron velocities, but depends to a considerable extent on space charge parameters; and c) the spot potential and spot charge density are functions of the bombarding beam current. The last effect may find application in a store designed to reduce the interference between different storage locations. *Abstract*

Ⓗ Engelbart, Douglas Carl. 13,557
A study of high-frequency gas-conduction electronics in digital computers. (Thesis) *Ph D*
Univ. California, Berkeley, Calif., 1955.

A new type of phenomenon, among those which have been proposed for application to digital computers, is the high/frequency glow discharge. Such discharges exhibit bistability, may be localized within a large gas-filled vessel, and may be transferred from point to point within that vessel under control of external electrodes. An exceedingly simple, serial shifting register may be constructed from a piece of glass tubing, which contains only low-pressure gas, upon which is fixed an iterative array of external electrodes. Appropriate sequential excitation of the electrodes by thirty-megacycle driver units will shift a pattern of discharges and no-discharges, in either direction, at speeds up to thirty thousand bits per second.

This dissertation presents this new phenomenon, and especially the shifting-register application, by a detailed analysis of the physical and functional aspects of high-frequency discharges and glow-transfer techniques. Study of basic gas-discharge mechanisms indicates that, for the discharge conditions being utilized, the losses due to volume recombination and attachment are relatively insignificant. During breakdown and equilibrium, the field-induced drift current to the walls dominates as a loss mechanism and ionization by electron/atom collision is the primary source of new charged particles. Decrease of losses with increased plasma density, and, for higher densities, a similar decrease in ionization, are the two factors which control the final equilibrium densities, the lower limit of the maintenance fields, and the "priming" characteristics of these discharges.

After termination of the excitation, ambipolar diffusion, down to the critical priming density, determines the "extinction" time of the discharge, which in turn sets the limits upon the shifting speed. Power requirements are typically of the order of one-tenth of a watt per discharge. . . . *From the Abstract*

ⵔSUTHERLAND, IVAN EDWARD.   13,911
Sketchpad, a man-machine graphical communication system. (Thesis)

[*Editorial note:* A paper based on this thesis was reviewed when published as "Sketchpad: a man-machine graphical communication system" in Proc. AFIPS 1963 Spring Joint Comput. Conf., 329–346. Spartan Books, Baltimore, Md.; *CR* 5, 4 (July-August 1964), Rev. 5951.]

The Sketchpad system uses drawing as a novel communication medium for a computer. The system contains input, output, and computation programs which enable it to interpret information drawn directly on a computer display. It has been used to draw electrical, mechanical, scientific, mathematical, and animated drawings; it is a general purpose system. Sketchpad has shown the most usefulness as an aid to the understanding of processes, such as the motion of linkages, which can be described with pictures. Sketchpad also makes it easy to draw highly repetitive or highly accurate drawings and to change drawings previously drawn with it. The many drawings in this thesis were all made with Sketchpad.

A Sketchpad user sketches directly on a computer display with a "light pen." The light pen is used both to position parts of the drawing on the display and to point to them to change them. A set of push buttons controls the changes to be made such as "erase," or "move." Except for legends, no written language is used.

Information sketched can include straight line segments and circle arcs. Arbitary symbols may be defined from any collection of line segments, circle arcs, and previously defined symbols. A user may define and use as many symbols as he wishes. Any change in the definition of a symbol is at once seen wherever that symbol appears. . . .

It is easy to add entirely new types of conditions to Sketchpad's vocabulary. Since the conditions can involve anything computable, Sketchpad can be used for a very wide range of problems . . . The Basic operations used in Sketchpad for manipulating the ring structure are described.   *From the Abstract*

ⵔVAN DAM, A.   13,912
A study of digital processing of pictorial information. (Thesis)

[*Editorial note:* A paper based on this was reviewed when published as "Computer driven displays and their use in man-machine interaction" in *Advances in Computers*. Vol. 8, 239–290; *CR* 8, 2 (March-April 1967), Rev. 11,691.]

The primary objective of the work described has been to establish a prototype of a storage and retrieval oriented, growing facility for graphic man/machine interaction. In particular, the aim was to provide a capability for encoding, storing, manipulating, retrieving, and displaying two-dimensional line drawings, which form a large subset of pictorial data. A system consisting of the Pictorial Encoding Language (PENCIL) and its processor was developed for the IBM 7040 computer and 1301 disk file at the University of Pennsylvania. The implementation of the PENCIL processor is based on an adaptation of the MULTILIST technique for simulating an associative memory with a threaded list structure.

One contribution of this work is the development of an efficient and compact pictorial data structure which takes advantage of the innate hierarchical nature of the type of drawings commonly produced, for instance in the engineering design process. In this scheme, the topology and geometry of a given picture are stored only *once*. If the picture is used as a subpicture in a higher-level assembly, a single, compact matrix accumulates all successive affine transformations which the subpicture may undergo, while its original description is left unaltered. Any number of transformed "instances" (copies) of a given picture may be used as subpictures in this manner, but only one description of the prototype, and one cumulative matrix per instance of the prototype, will exist.

Another objective of the work has been to perform an "in-depth" survey of the pictorial data processing field to provide background for the design of the picture-manipulating scheme. The aim of this survey was to structure the mass of available data, which is still highly dispersed and disorganized because of the newness of the field, and also to draw conclusions relevant to the particular design objectives.

Abstract

6.39 MISCELLANEOUS

⊖SKLAR, JAY ROBBINS.   14,147
Sequential measurement of multi-dimensional trans-
    ducers. (Thesis)
M.I.T., Cambridge, Mass., Sept. 1964.

Although the problem of decoding tree encoded
messages in communications and that of measuring
the parameters which describe a multidimensional
transducer appear very different at first, striking
similarities arise upon closer scrutiny. These similari-
ties are most evident when each successive transducer
output depends on an additional transducer pa-
rameter. Because of these similarities and because
sequential decoding has been so successful in decoding
tree-encoded messages, we are motivated to study the
application of sequential decoding algorithms to
measurements.

In this thesis we analyze a sequential algorithm due
to Fano and study its application to measurement

problems. From the analysis we obtain bounds to the
average number of computations needed to estimate
one parameter, and a bound to the probability of
estimating at least one parameter of a set incorrectly.
It will become apparent that when one tries to
differentiate between parameter values that produce
too small an effect on the output, relative to the
noise, the sequential method will fail. This difficulty
determines a limit to the precision obtainable with the
sequential method. This critical level may be likened
to the computational cutoff rate in the corresponding
communication problem.

A series of simulation experiments were performed
to test the hypotheses and results of the theory.
These experiments consisted of estimating the char-
acteristic impedance values of the sections of a
transmission line constructed of many short seg-
ments. This problem displays many of the features
characteristic of geophysical layer determination.
Although the theoretical and simulated measure-
ment problems were not identical, the theoretical and
experimental results agree, at least qualitatively.
Thus it appears further research is warranted on the
application of sequential decoding to actual measure-
ment problems.   *Abstract*

⊖LINCOLN, ANDREW JAMES.   13,914
Magnetic devices in sampled analog systems. (Thesis)
Harvard Univ., Cambridge, Mass., 1961.

The primary aim of this thesis is to show how . . .
sampled-data computers may be constructed from
circuits using rectangular hysteresis loop magnetic
cores. Toward this end, optimum controller organiza-
tion for magnetic realization is discussed, and the per-
tinent characteristics of rectangular loop cores are
investigated.

Chapter 1 serves as an introduction to sampled-
data control systems and to the use of magnetic cores
in information processing. . . . It is demonstrated in

this thesis that magnetic cores possess analog storage
properties adequate for the construction of low-
precision controllers capable of high-speed, drift-free
operation. These controllers store quantities in an
analog manner, but their operations are time-discrete;
therefore they are called *"intermediate controllers."*

Some error arises in magnetic intermediate control-
lers when information is transferred from one storage
location to another. In Chapter 2, after a brief review
of applicable sampled-data theory, it is shown that
the number of information transfers per sampling
period depends upon the controller structure and may
be reduced at the cost of increased controller com-
plexity. . . .

The magnetic cores proposed for use in intermediate
controllers have rectangular hysteresis loops. Storage
of a numerical quantity is accomplished by setting the
flux in a core to a level proportional to the quantity.
In Chapter 3, the existing theory of flux reversal in
rectangular loop magnetic cores is presented. . . .

In Chapter 4, various sampled analog magnetic
circuits are presented. . . . A model intermediate
controller employing the techniques presented in this
thesis was constructed. . . .   *From the Abstract*