"A marvelous and personal exploration of a poorly documented period in the history of data communication! I lived through it and re-lived it in these interviews and narrative."
- Vint Cerf, Internet Pioneer

Circuits, Packets, and Protocols

Entrepreneurs and Computer Communications, 1968–1988

James L. Pelkey, Andrew L. Russell, Loring G. Robbins

ASSOCIATION FOR COMPUTING MACHINERY

Circuits, Packets, and Protocols

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Circuits, Packets, and Protocols

Entrepreneurs and Computer Communications, 1968–1988

James L. Pelkey

Andrew L. Russell
SUNY Polytechnic Institute, New York

Loring G. Robbins

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List of Acronyms

ACM	Association for Computing Machinery
ACS	AT&T Advanced Communications Service
ADPCM	Adaptive differential pulse-code modulation
ADS	American Data Systems
AFIPS	The American Federation of Information Processing Societies
AMD	Advanced Microchip Devices
AMEX	American Stock Exchange
AMI	American Microsystems, Inc
ANSI	American National Standards Institute
ARCNET	Datapoint LAN product
ARD	American Research and Development
ARPA	Advanced Research Projects Agency
AT&T	American Telephone & Telegraph
ATTIS	AT&T Information Systems
BPO	British Post Office
BSD	Berkeley Software Distribution
CAD	Computer automated design
CAE	Computer-aided engineering
CATV	cable television
CBX	computerized branch exchange
CCB	Common Carrier Bureau
CCI	Concord Communications, Inc.
CCIA	Computer & Communication Industry Association
CCITT	International Telegraph and Telephone Consultative Committee
CDS	Concord Data Systems

CEO	Chief Executive Officer
CHM	Computer History Museum
CIO	Chief Information Officer
CLNS	Connectionless Network Service
CMC	Computer Machinery Corporation
CMU	Carnegie Mellon University
COO	Chief Operating Officer
COS	Corporation for Open Systems
CPE	Customer Provide Equipment
CPU	Central Processing Unit
CRT	Cathode-Ray Tube
CSC	Computer Science Corporation
CSMA/CD	carrier sense multiple access/collision detection
CTOS	Convergent Technologies Operating System
CVSD	continuously variable slope delta modulation
CXC	CXC Corporation
DAA	digital access arrangements
DARPA	Defense Advanced Research Projects Agency
DBMS	data base management system
DCA	Digital Communication Associates
DCE	data communications equipment
DDCMP	Digital Data Communications Message Protocol
DDN	Defense Data Network
DDP	digital data processing
DDS	Digital Data Service
DEC	Digital Equipment Corporation
DIS	Draft International Standard
DISOSS	Distributed Office Support System
DIX	DEC-Intel-Xerox
DOD	Department of Defense
DOS	Disk Operating System
DP	Draft Proposal
DSP	digital signal processor
DTE	data terninsal equipment
ECMA	European Computer Manufacturers Association
EDP	electronic data processing
EIN	European Informatics Network

ENE	Enterprise Network Event
ERISA	Employee Retirement Income Security Act
EVP	executive vice president
FCC	Federal Communications Commission
FDM	frequency division multiplexer
FDMA	frequency division multiple access
FIPS	Federal Information Processing Standards
FTAM	File Transfer Access Method
GDC	General DataComm Industries, Inc.
GE	General Electric
GI	General Instruments, Inc.
GM	General Motors
GOSIP	Government Open Systems Interconnection Profile
GTE	General Telephone Electronics
HAPC	Hush-A-Phone Corporation
HDLC	High-Level Data Link Control
HP	Hewlett-Packard
IAB	Internet Activities Board
IBM	International Business Machines
ICA	International Communications Association
ICBM	Intercontinental Ballistic Missile
ICC	Interstate Commerce Commission
ICCB	Internet Configuration Control Board
ICCC	International Conference on Computer Communications
ICST	Institute for Computer Sciences and Technology
IDCMA	Independent Data Communications and Manufacturers Association
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IFIP	International Federation of Information Processing
IMP	Interface Message Processor
INI	Industrial Networking Inc.
INWG	International Network Working Group
IP	Internet Protocol
IPO	Initial Public Offering
IPTO	Information Processing Techniques Office
ISO	International Organization for Standardization
ITT	International Telephone & Telegraph, Inc.

LACN	Local Area Communications Network Symposium
LAN	Local Area Networks
LANCE	Local Area Network Controller Ethernet
LATA	Local access and transport area
LCS	Laboratory of Computer Science
LISP	LISt Processor
LNI	Local Area Network Interface
LSI	Large-scale integration
MAC	media access control
MAP	manufacturing automation protocols
MBA	Master in Business Administration
MIS	management information systems
MIT	Massachusetts Institute of Technology
NARUC	National Assoc of Regulatory Utility Commissioners
NAS	National Academy of Sciences
NBS	National Bureau of Standards
NCC	National Computer Conference
NCP	Network Control Protocol
NCR	National Cash Register
NMC	Network Measurement Center
NPL	National Physical Laboratory
NRC	National Research Council
NSF	National Science Foundation
NWG	Network Working Group
NYSE	New York Stock Exchange
OEM	Original Equipment Manufacturer
OSI	Open Systems Interconnection
PARC	Palo Alto Research Center
PBX	Private Branch Exchange
PC	Personal Computer
PCA	Protective Connecting Arrangement
PCM	pulse-code modulation
PSTN	Public Switched Telephone Network
PTT	Postal, Telegraph & Telephone
PUC	Public Utility Commission
PUP	PARC Universal Packet
QAM	Quadrature Amplitude Modulation

RBOC	Regional Bell Operating Company
RCA	Radio Company of America
RFC	Request for Comments
RFNM	Request for Next Message
RFQ	request for quotation
RTL	register-transfer level
SAGE	Semi-Automatic Ground Environment
SBIC	a small business investment company
SBS	Satellite Business Systems
SC	Subcommittee
SDC	Systems Development Corporation
SDD	Systems Development Division
SDLC	Synchronous Data Link Control
SDS	Scientific Data Systems
SEC	Securities Exchange Commission
SNA	System Network Architecture
SNMP	simple network management protocol
SRI	Stanford Research Institute
SUN	Stanford University Network
TC	Technical Committee (ISO)
TCCC	Technical Committee on Computer Communications (IEEE)
TCP	Transmission Control Program
TCP/IP	Transmission Control Protocol/Internet Protocol
TDM	Time Division Multiplexer
TIP	Terminal Interface Processor
TOP	Technical Office Protocol
TP	Transfer Protocol
UART	Universal Asynchronous Receiver and Transceiver
UB	Ungermann-Bass
UCI	University of California Irvine
UCLA	University of California Los Angeles
UCSB	University of California Santa Barbara
UDS	Universal Data Systems
USAF	United States Air Force
USART	Universal Synchronous Asynchronous Receiver Transmitter
VAR	Value Added Reseller
VC	Venture Capital

VLSI	Very Large Scale Integration
WAN	Wide Area Network
WD	Working Draft
WE	Western Electric
WG	Working Group
XNS	Xerox Network System

Preface and Acknowledgments

It was the summer of 1987, and James L. Pelkey, a partner at the San Francisco investment bank Montgomery Securities, was perplexed. Three years earlier, Pelkey had joined Montgomery to take charge of its venture capital investments. He had a special interest in data communications and networking markets. The core enabling products of those markets—such as modems and local area networks—were relatively new innovations. The personal computer boom was under way, and internetworking hardware was available to purchase. Yet almost no one at this time saw the earth-shrinking changes that lay only a few years away, fueled by the commercialization of the Internet and the rapid adoption of the World Wide Web.

The internetworking products of the late 1980s worked well enough to demonstrate the vast potential for sharing information between computers and their applications. Pelkey and his peers knew that there was money to be made, especially if the futurists were correct in predicting that the global economy was moving from the Industrial Age to the Information Age. But it was increasingly difficult to see through the thicket of competing technologies, companies, and standards. Nobody had convincing answers to deceptively simple questions. For example, why were some entrepreneurs successful when most others failed? Which standards would get the fastest market acceptance? And how was it possible that established companies—including the American titans of computing and communications, IBM and AT&T—were failing to dominate this promising market?

Pelkey was well positioned to guide Montgomery's strategy in computer communications.[1] Before arriving at Montgomery, he spent 18 months as the chief

1. Pelkey first moved to San Francisco after earning a degree in engineering from Rensselaer Polytechnic Institute (1968) and an MBA from Harvard (1970). He initially worked in leasing and finance, and gained experience in management with several companies. In 1980, he moved to Santa Barbara to become president of the technology start-up Digital Sound. He then consulted for companies with a focus on communications, software, and graphics. Pelkey recalls, "One client, Communications Machinery Corporation (CMC), was a small engineering shop headed by Larry Green. They believed one of their projects could lead to real products. I had a hard time

executive of Sorcim, a company that sold SuperCalc, an early spreadsheet program that helped popularize desktop computing. When he arrived at Montgomery in 1984, Pelkey had established a strong record of success managing early-stage start-ups. Montgomery wanted his expertise to help turn around underperforming companies in its portfolio, and to find new companies to invest in. Paths to success in venture capital traveled through social networks, so Pelkey decided—some time in the summer of 1987—to make contacts with executives of leading companies in computer communications. Seeking introductions to some experts in the field, Pelkey called on Paul Baran, whom Pelkey had met after joining the board of Baran's start-up, Telebit. Baran was the co-inventor of packet switching, a highly respected figure in government and technical circles, an advisor to several start-ups, and an entrepreneur himself. Baran and Pelkey discussed various people that Pelkey should meet—scientists, engineers, regulators, and entrepreneurs who were widely considered to be key figures in computer communications. Baran generously made introductions to a handful of people, and Pelkey found they were willing to speak candidly.[2]

Pelkey interviewed these experts throughout 1988, part of an exhausting year when he traveled frequently from San Francisco to cities around the world. In Boston, London, Paris, Singapore, Tokyo, Melbourne, and many places in between, Pelkey met investors, served on corporate boards, and squeezed in time to interview experts. His purpose was to build relationships and look for opportunities that would benefit Montgomery—perhaps young companies with potential for a strong IPO, or others that needed a merger to realize their potential. Once he started interviewing people from the list that Baran had shared with him, some interviews led to others—an incremental approach that social scientists refer to as the "snowball method."

Pelkey's vision for these interviews was much broader than a typical process of market research and discovery. He decided to record these interviews—but only the parts about history, not industry gossip or investment strategies. His goal was to understand the industry better, to identify how populations of companies emerged, and to answer some big questions of broad interest: how do ideas become products, companies, and industries? How does this process generate economic growth and prosperity? Prevailing economic theories, presuming

understanding why or how. The project was an emulator for a new Ethernet semiconductor chip named LANCE. It took nearly a year of Saturdays for me to finally grasp its importance and, really, the importance of computer networking." James L. Pelkey, "About James L. Pelkey," http://www.historyofcomputercommunications.info/About/JimPelkey.html.

2. The initial list included Bernard Strassburg, Vint Cerf, Robert Kahn, Lawrence Roberts, Donald Davies, John Heafner, Leonard Klienrock, Johnny Johnson, Gordon Bell, Frank Heart, and David Farber.

a general tendency toward equilibrium, poorly described the dynamic conditions he observed in computer communications. Pelkey sensed that the experts he was meeting could provide some raw material to understand these old questions in new ways.

Pelkey decided that his interviews could be the basis for writing a history of computer communications for the years 1968 to 1988. In the end, he recorded 85 interviews that altogether fill 1,887 pages of printed transcripts.[3] Along the way, Pelkey concluded that a traditional, linear history could not do justice to the stories he heard. He wanted to present them in a format that could capture the uncertainty, stress, and rewards of the time. A hypertext format could give readers the opportunity to explore this history in the order they chose; it also could support links to the substantial source material that informed his analysis, such as the transcripts from his interviews as well as data on revenues, sales, market projections, and more.

The hypertext book took time to emerge. Pelkey decided to leave Montgomery Securities at the end of 1988 to form his own investment company. He moved to Santa Fe, NM, in 1989, and, among other things, found a new home amongst the economic theorists at the Santa Fe Institute. He became a Trustee in 1989, and served as Chairman of the Board of Trustees from 1992 to 1994. Through attending workshops and engaging in discussions with scientists from many disciplines such as Brian Arthur, Chris Langton, David Lane, Walter Fontana, and John Padgett, he learned about complex adaptive systems and the notions of emergence, self-organization, and punctuated equilibriums. These ideas helped Pelkey understand his experiences and interview data in a new light, and provided some theoretical underpinnings for his hypertext book, *Entrepreneurial Capitalism & Innovation: A History of Computer Communications, 1968–1988*.[4]

Published on-line as a series of linked webpages, *Entrepreneurial Capitalism & Innovation* fulfilled Pelkey's vision of providing fertile ground for reader exploration. But visitors to Pelkey's website regularly contacted him to request a version of the material as a traditional book. The first collaborative steps toward this book occurred in 2007, when the computer scientist John Day introduced Pelkey to Andrew L. Russell. At the time, Russell was a Ph.D. student at Johns Hopkins University, finishing a dissertation on the historical aspects of technical standards for communication networks. They struck up a friendship and shared ideas. Russell agreed to help finish the final chapter of *Entrepreneurial Capitalism & Innovation*,

3. These transcripts and recordings are now deposited at the Computer History Museum in Mountain View, CA.

4. James L. Pelkey, "*Entrepreneurial Capitalism & Innovation: A History of Computer Communications, 1968–1988*," http://www.historyofcomputercommunications.info.

an assignment that brought him to visit Pelkey on Maui for a week in March 2013. The pair agreed to work together toward the publication of a book, but progress was slow until Pelkey began to work with Loring G. Robbins in November 2017. Robbins quickly and enthusiastically threw himself into the research, revision, and writing necessary to complete the book—and utilized his skills in graphic design to create and update illustrations that provide visual depictions of some complex technologies described in several chapters.

As we bring this unusual project to completion, we believe it will be helpful to be explicit about the different types of readers we have imagined as we have crafted *Circuits, Packets, and Protocols*. One group is historians, professional and amateur alike, who are already familiar with the rise of Silicon Valley and the emergence of the ARPANET and Internet. We know that much of the material we present here cannot be found in existing published books, and we hope that these readers will discover our book to be a different take on a familiar story. In the Introduction, we go into some depth about how *Circuits, Packets, and Protocols* both overlaps with and departs from the existing literature.[5]

In addition, professionals who are not historians will find something of value in these pages. Those who are active in business and technology may find some lessons applicable to their own circumstances. For example, how do entrepreneurial ventures coalesce into populations of firms and products? How do these new collectives challenge—or become challenged by—incumbent firms? In contrast to the conventional business school case study, focused on a single firm, *Circuits, Packets, and Protocols* captures the experience of dozens of firms, interacting with one another, that eventually became more than the sum of their parts.

We also hope that general readers—such as ACM members—will appreciate our effort to illuminate the respective roles of individuals and collectives in history. We believe that the episodes detailed in the following pages illustrate the power, and at times decisive role, of individuals. And even more generally, we believe that our historical account of computer communications has captured the nascent stages of technologies that are widely regarded as transformational. In business, politics, and our personal lives, it seems that no aspect of modern life is untouched by networked digital communications—for better or worse. Digital data networks in general, and the Internet in particular, are remarkable (if imperfect) developments

5. For a condensed version of our arguments, with particular attention to standards in international business, see Russell, A., Pelkey, J., & Robbins, L. (2022). The Business of Internetworking: Standards, Start-Ups, and Network Effects. *Business History Review*, 1–36. doi:https://doi.org/10.1017/S000768052100074X.

in human history. The interviews that Pelkey recorded capture some inspiring stories about the origins of the information infrastructure that keeps the world connected, even as we all endure the terrible COVID-19 pandemic. Indeed, the ease with which the Internet has absorbed so much traffic—thereby sustaining unprecedented amounts of the world's economic and social life—should inspire readers to learn about the origins of the technologies that move data around the world.

Acknowledgments

Loring G. Robbins would like to thank both Jim and Andy for the opportunity to work on this project. The collaboration has been a great experience, not only for the understanding I have gained about this important period in history but also for the friendship I share with these two authors. Jim's patience and willingness to pass on his personal stories and knowledge of the business world has given me a deep appreciation for the challenges and the allure of the entrepreneur's journey. Andy's encouragement, sense of humor, and his deep knowledge of business and technology history have been invaluable throughout this process. I would also like to thank Rick and Kathy Kimball, Stu Greenfield, and Bob and Kathie Maxfield, whose generous gifts in support of this project made my work possible. A big thanks also to Manley Irwin, who generously gave me his time to answer questions in person at his home in New Hampshire as well as via phone and email. I would also like to thank my wife Gena and daughter Sophia for their support during my work on this project.

Andy Russell would like to thank John Day, the computer scientist who introduced Andy to Jim Pelkey. Day's passion for history—and for understanding the mix of contextual factors, technical details, and long-term consequences—has been a source of motivation over the past 15 years. I am likewise grateful to acknowledge encouragement and insight from Bradley Fidler, Louis Galambos, Massimo Petrozzi, Valérie Schafer, Marc Weber, and Joanne Yates. It's difficult to imagine where this project would be without Tom Misa's extraordinary advocacy and enthusiasm, as well as the diligence and intelligence of Loring G. Robbins. My wife and kids—Lesley, Reese, and Calvin Russell—have been the best writing partners and supporters anyone could ask for. Finally, I am profoundly grateful that Jim Pelkey welcomed me into his vast intellectual universe and allowed me the privilege of working with him to bring this project to completion.

James L. Pelkey would like to acknowledge the following people.

Paul Baran

I met Paul Baran shortly after I joined Montgomery Securities, in September 1984. I soon made a client solicitation call on Packet Technologies, also known as Packet Cable. Little did I know at the time that lifelong friendships would be formed with Paul Baran, William Houser, and Steve Millard, Packet Technologies' founder and Chief Scientist, CEO, and CFO, respectively. Paul Baran's creative mind soon conceived an innovative technology for high-speed modems that became the basis for another start-up—Telebit. Montgomery Securities' Venture Fund soon led the investment round and I joined the Board of Directors. My relationship with Paul blossomed and when, years later, I shared with him my desire to write a history book that would reconstruct computer communications for the years between 1968 to 1988, he could not have been more encouraging. In addition to a very frank interview, he willingly introduced me to many of the key people I interviewed, read early drafts of my text, and was always available to answer any questions or be of help.

Paul Baran was as fine a gentleman as it has been my honor to know. He essentially became my surrogate father. He was brilliant, gracious, humble, compassionate, always willing to lend a helping hand, and believed that the act of innovation was a team effort. I never heard him voice a critical word of anyone. In addition to co-inventing the seminal technology of "packet switching," by 1988 he had founded seven successful start-ups.[6] Paul passed away on March 26, 2011, from complications of lung cancer. The last meal I had before moving to Maui in 2004 was with Paul. Often called "the father of the Internet," the Computer History Museum (CHM) honored him "for fundamental contributions to the architecture of the Internet and for a lifetime of entrepreneurial activity." He was the most important person in helping me finish the on-line version of this book and it saddens me that he will not be able to read this version as well.

I can vividly recall the second meeting we had after I had further refined my thoughts. We were sitting at his desk at yet another start-up—Metricom—when he said I absolutely had to interview Vint Cerf and Robert Kahn who were engaged in starting a new firm themselves. I asked him how I could arrange interviews, when he picked up his phone and called Vint, who took the call and they began talking as if friends, which it turns out they were. Paul soon told Vint what I was up to and passed the phone to me; Vint introduced himself and said when I knew I was coming to Washington, DC, to call and they would meet me.

Montgomery Securities

Next must come Montgomery Securities, for without their support the 85 interviews would undoubtedly been just a dream. I joined Montgomery Securities

6. These companies were Packet Cable, StrataCom, Telebit, Institute for the Future, Metricom, Interfax, and Com21.

in 1984, reporting to Thom Wiesel, to assume responsibility for their struggling venture-capital operations. In 1985, I was promoted to general partner and had an office next to Thom's. I couldn't have been more fortunate for Thom took a keen interest in introducing me to many of the venture capitalists with whom I would work with over the next four years. Working for Thom was a gift, and I would not have resigned were it not for personal reasons.

Thom was the best manager I ever had, and he gave me the freedom to conduct the interviews essential to writing these histories. I am deeply indebted to Thom and his firm and partners for trusting me and seldom questioning my priorities.

In addition to Thom, one partner and his wife are due special mention. Rick Kimball joined Montgomery at the same time as I did and reported to me. He had just graduated with an MBA and proved to be an exceptional research analyst. He later went on to start his own successful venture capital firm. We stayed in touch over the years as his career took off and when, in 2015, I had exhausted my means to fund the book project, I called Rick, and without any hesitation he said Kathy and he would give me the money I needed. It was a very special moment in my life and was essential to completing the book project. I was deeply honored.

Early Book Reviewers

Six individuals deserve special mention for having taken an early and meaningful interest in this book project: Stu Greenfield, Harold Shattuck, Douglass North, Manley Irwin, Robert Maxfield, and Kathie Maxfield.

Stu Greenfield

Stu has been with me throughout the long history of first reconstructing the 20-year history of computer communications in the form of a hypertext on-line version capturing many lengthy excerpts from the 85 interviews. Then, after that had been accomplished, to more selectively answer questions that I had, he blocked out time for lengthy conversations, and finally continued in the role of one of my most trusted reviewers of drafts of the book. Stu worked for IBM for many years as a senior software engineer before assuming important staff roles as his career advanced. With Ed Glassmeyer he formed one of the most highly regarded East Coast venture capital firms, and as one of the firm's senior partners, Stu served on many boards of directors, including those of Ungermann-Bass, Micom, NET, and Equinox, and others important to this history, which clearly gave him a unique perspective to understand and critique my work. Stu and his wife Connie steadfastly encouraged and supported me throughout these many years. While I had never written a book, Stu assured me that was less important than what I knew, all the data that I had collected, and what I had experienced. Finally, Stu helped convince Gardner Hendrie, a CHM board member, to accept the gift I was proposing. He is a wonderful friend.

Harold Shattuck

Harold and I worked together at Montgomery Securities and his competence was as a talented computer scientist and engineer as well as having been president of a public and substantial company. Over the four years that we worked together we always traveled together when we held limited partner meetings, when we attempted to raise more capital, or when we were doing due diligence on potentially new investments, or to justify investing more in existing investments. We often discussed my idea to write a history book, so when I finally began to do so, I always passed drafts by him to make sure I had my technology descriptions correct. Frequently, he would come to my home with a bottle of wine and we talked outside for hours before going to a favorite restaurant. I totally trusted his contributions that unfortunately got fewer over time. He even came to Maui to continue our conversations. He will always be a friend for life.

Douglass North

I met Professor Douglass North at one of the frequent talks he gave on the Stanford campus in the late 1990s, after he had already won his Nobel Prize in 1993. Upon first meeting him I briefly told him a little about myself and invited him to have lunch. Unfortunately, I was so busy, and living alone, that I never studied up on Professor North even though I knew he had won the Nobel Prize in economic history. We had as I remember four lunches at the Il Fornaio restaurant in downtown Palo Alto. I was honored to be sitting and talking about institutions as if friends and for a few minutes as if equals and economic researchers helping each other, even if only a fantasy running in my mind. Most of what we said is lost with time, but I clearly recall his emphasizing the importance of population growth, a fact that I had overlooked in my work. He encouraged me to continue to send him my writings and he always edited them and returned them promptly. He might have gained little from our interchanges, but I always felt honored.

Professor Manley Irwin

I first heard about Manley when I interviewed Bernard Strassburg. Realizing how important his many contributions were, I initiated conversations that led to him providing a treasure trove of documents to our historical project. Unfortunately, I never interviewed Professor Irwin, but he met and talked at length with one of my co-authors, Loring G. Robbins. He has continued to provide critical insights into the history we are reconstructing, especially the early years. I am so very glad we have become friends, and thank him for so many important documents that he is trusting us to make public.

Robert (Bob) and Kathie Maxfield

In one of our final drafts, we realized we had overlooked the history of ROLM, so we did some additional research. In doing so we discovered a treasure of a book written by Kathie Maxfield, the wife of one of the founders of ROLM—the M in fact. Her book is a wonderful account of the evolution and culture of Silicon Valley. After learning that the Maxfield's have a home on Maui, I arranged to have them visit me in my home. We discussed Kathie's book and then asked Bob questions that he patiently answered.[7] Afterwards he sent us a diagram he had drawn of the ROLM CBX, which we used as the basis for the one in the book. When we needed some additional financial support, even though we had just met, they responded graciously. We are forever grateful.

Computer History Museum

John Toole and John Hollar

Both recent Presidents deserve thanks in supporting my efforts to gift my website and 85 interviews to the museum. Before I moved to Maui in 2004, I met with John Toole twice to hammer out the agreement that was then finalized soon after John Hollar became president in 2008. Both presidents committed the CHM to host both my website: (historyofcomputercommunications.info) and all my interviews in perpetuity.

I finally met John Hollar in July 2015 and had the opportunity to thank him personally. Then in 2017, I raised the issue that I was hoping that the Museum would make more of an effort marketing my completed website. Their response was that I needed to convert the website into a book that could more easily be marketed. I said I could not do it by myself and they said that did not matter as long as it became a book. The result was I asked the most ideal person I knew, Andy Russell, who agreed to partner the project with me. As time passes, I am ever more certain that the CHM is the best permanent home for my works.

Chuck House

Chuck was one of two longstanding CHM board members who facilitated my desire to gift my oral interviews and my on-line book to the museum. Chuck soon contacted me and explained that he was reconstructing the history of Cisco and wanted to come to Maui to get to know me and review the materials I had collected. I thought it was a great idea and invited him to stay with me. He did and we had a great time together. In addition to familiarizing himself with all of my materials,

7. Katherine Maxfield. *Starting Up Silicon Valley: How ROLM Became a Cultural Icon and Fortune 500 Company*. Greenleaf Book Group, 2014.

he left with a small suitcase of duplicated documents. I thought that was the last of our interchange until I received a letter from the NOVIM non-profit organization for science and global change on April 19, 2019, announcing that I had received the Science Inspiration Award for Historical Preservation for my computer communications project. As I cannot travel, a week later I received a sculptured glass award trophy. I was and will always be truly honored.

Gardner Hendrie

I have never met Gardner but have talked to him at length on the phone. I do know Stu introduced my project to Gardner, who, as a CHM board member, along with Chuck House, helped convince the two presidents of the value of the project, especially given the early date of the interviews.

Marc Weber

Once my gift had been given an initial approval, it was turned over to Marc Weber, the Founding Curator of the Internet History Program, to negotiate the final details. Marc and I began an exchange of letters in early April 2010 that quickly led to a satisfactory mutual exchange. Marc and I have enjoyed a productive and constructive relationship ever since.

Interviewees

My 85 oral interviews have resulted in 1,185 pages of transcriptions. It is an unenviable task to indicate that any interviews were better than any others. I would prefer the reader to conclude that I was blessed to have every one of the interviewees sit with me and record their thoughts for posterity. If you read any of them, I believe you too will conclude I was indeed very lucky. I will identify a few interviewees whose time with me was exceptionally noteworthy. But to everyone I say thank you and I hope the transcription captures both the content and spirit of our conversation.

Vint Cerf

Our time together was rescheduled a number of times, and a serious snowstorm cut our time together even shorter. But a very valued friend, Bill Houser, gave me a ride from the city out to Reston where Vint's office was. The last thing I wanted was for us to have an accident, so while my conversation with Vint was brief we had a great connection, and over the years we had many conversations that all proved valuable. After meeting Robert Kahn two weeks later, I could sense how they became lifetime friends.

Robert Kahn

Dr. Robert (Bob) Kahn is one of the smartest men I have ever met. I called on him right after lunch, and as I began questioning him, he could sense how little I knew about what I was hoping to learn from him. So he gently interrupted me and asked me why I was in a rush. He said he had set aside the afternoon for us, and thought it might be best if he started. He was so right. I knew so little of his history and experiences. Dr. Kahn was so patient, clear, and thorough with his descriptions. Hours later he said he needed an hour to finish up some work, but then how would I like to have dinner together? Knowing I had some time before I was to meet Dr. Kahn before dinner, I drove past the restaurant so I was sure not to get lost, and found a place where I could pull over and park and I began to reflect on all that I had just heard and reviewed what was written down. Before the interview I had felt overwhelmed and lost. But in listening to Dr. Kahn's explanations, I began to sense a glimmer of hope that there might be a way that I could organize my thoughts and communicate them so that others might see and understand the evolution and importance of computer communications. Later, we met at the restaurant and continued our conversation. We enjoyed a great French dinner together and ended up closing the restaurant many hours later. Indeed, Bob Kahn was a great person to interview.

Robert Metcalfe

When I called Bob to ask him if he was willing to be interviewed, without any hesitation he said yes and invited me to come by after dinner some agreed upon night. He was alone that night and we proceeded directly to his home office in his attic. I eyed a convenient couch with glass-topped table where I could set up my recording system and microphone. Bob sat across from me and waited for me to begin. Having learned the benefits of being prepared, I didn't act rushed, and we took a few minutes getting to know each other. I then turned my system on and, nevertheless, asked him an awkward question to begin. He seemed not to mind and thus began a lengthy and very enjoyable interview that could have gone on for much longer, but it was getting late and I felt I had overstayed his gracious offer. I highly recommend reading the interview and the great story of how Ethernet was birthed. I left having absolutely no doubt that Bob was a heroic entrepreneur in Schumpeter's best sense of the word.

Jay Hill

I first met Jay at Doelz Networks Inc. board meetings. I was attending as an observer and potential investor in my role with and for Montgomery Securities. At the time

Doelz was considered a "hot" investment and I was not the only observer attending. One member of the board was Stu Greenfield's partner, Ed Glassmeyer. When it came time for the vice president's report, in came Jay Hill, who was the best dressed executive I had ever seen in business. His report also bore the signs of his time working for IBM. Afterwards, I asked Jay if I could buy him dinner. He said yes and it soon became a standing practice with others often joining us, including Frank Conners, the company president.

I learned a lot during our meals together, not only about Doelz but the industry in general and even the practices of marketing and sales. Jay became a friend and often visited me. It was during these times together that we were inexorably drawn to sharing our personal lives. It was then that I learned Jay's wife was a minister in their faith, and the incredible commitment they made, and the extended time spent with Alaska Natives in outer Alaska. During this period, Jay was no longer with Paradyne and was a consultant and our conversations became more spiritual than business, and frankly more meaningful, and Jay became a close friend.

Louis Pouzin

Unfortunately, Louis Pouzin's schedule and mine never overlapped when I was in Paris; as mine had with Hubert Zimmerman's. But we were persistent, and finally on November 28th, when I had only two more scheduled interviews left to complete the list of interviewees, Louis and I finally arranged to meet in Florida, for dinner. We both had had busy days; I had two interviews in Huntsville, Alabama, before flying into Atlanta on my way to our dinner in Tampa Bay. Louis had had a similar busy day, so we were glad to finally have met so that he could share his unique and important story in the history of global packet switching. He was a gracious, open, and forthright interviewee.

Bernard (Bernie) Strassburg

Bernard Strassburg had retired from the Common Carrier Bureau (CCB) years earlier. But he arranged for our interview to be conducted in his old office in the CCB's department. As I walked down the large hallways, I could almost sense the history that had been made therein. When I reached the CCB's offices, I pushed on the large oak paneled doors, and entered the magisterial chambers. Before me were a series of wood railings and gates and I could see Mr. Strassburg beckoning me forward. We shook hands and before I could say anything, he said to call him Bernie. We began the process of introducing ourselves as I set up my recorder and he finished by telling me that his office, together with the adjacent conference room was where the future of the telecommunications industry had been negotiated. I said I was hoping to hear his views and feelings of those times, and I believe I did.

One important fact coming from the interview was Bernie mentioning the name of Dr. Manley Irwin, who has proved to be a remarkable source of documentation and very willing contributor to our historical reconstruction. I consider Bernard Strassburg to be one of the unsung heroes of the *information economy* and he was acting as a social entrepreneur. It was a huge honor to spend an hour and a half with him.

Dan Lynch

I will never forget the day I called on Dan Lynch for an interview. I found his street address in Cupertino and pulled up a steep driveway and stopped before the garage. I could see a covered picnic table in the backyard with people milling about. Dan was in the kitchen, which was anything but a kitchen. It looked more like a crowded office with computers, fax machines, and copiers and stacks of Connexions magazines.

Dan began by explaining how he became responsible for the computer facilities at a number of important institutions that led to his being responsible for the important task of the conversion of the ARPANET from NCP to TCP/IP. Although our conversation was very interesting, it ended with a brief discussion of OSI versus TCP/IP when I had to unfortunately end the interview as I had another engagement I had to attend.

We agreed to meet again, but the year slipped away. Then one day I got a call from Dan and he wanted to come visit. On arriving, we began talking aside my backyard pool when he suddenly pulled at a gift and proceeded to inflate a three-foot long dirigible that once inflated could be steered since it was powered by a small fan at one end of the football-like balloon. We then began taking turns racing it around a course we set up around the pool. We soon discovered we were enjoying being competitive and couldn't stop laughing. It was a moment of sheer joy and I'll never forget it, knowing we would always be friends.

There would be other days of racing and discussing his history and the success of the tradeshow Interop, an organization dedicated to the importance of TCP/IP. Months later in 1990, Dan even sought advice on his decision of whether to sell Interop or not. Years later he remains a dear friend through our time together on the board of Santa Fe Institute and this book project. Finally, we owe Dan many thanks for the photo that is on the cover of this book.

Joseph Carl Robnett (J.C.R., or "Lick") Licklider

It was a rainy afternoon in June 1988, when I pulled up in front of Dr. Licklider's home in Arlington, MA. I sat hoping the rain would let up, but not wanting to be late, I finally decided to get wet and walk up his pathway to his front door. When the door opened, I said "Dr. Licklider?" And he replied: "Just call me Lick." He took my raincoat, then guided me to his living room. As I began to set my recorder up, he pulled a well-worn chair up to the table between us, and his wife, Louise, came in and asked if we want anything, to which we replied: "no, thank you." Lick then began by saying he was not sure he could help me, but what questions did I have? If I was nervous before, and I should have been, I was now dumbstruck. He broke the silence and asked where he should begin. For anyone who knows who Lick is, my being a bit nervous is understandable. But as I would soon learn, it was totally inappropriate, for Lick was warm-hearted, gracious, and as interested in me and my project as I was in him and his indelible imprint on the history of computing and computer communications. This interview is a casual walk through Lick's career and accomplishments. He was open and humble, and an absolute joy to be with.

Art Carr

Art Carr resisted the idea of sitting for an interview. When I told him who else had already agreed to be interviewed, he said that was even more reason that he did not need to be interviewed. But it was essential that I interview Art, so he finally agreed if I kept it short. I arrived on time and sat outside his office until his door opened. He was polite but not particularly friendly. The process went reasonably well until he realized that very day, April 6, was the day 18 years ago when he had learned that Jim Cryer, the president of Codex, had died, setting in motion events that would forever change Carr's fortunes at Codex. On realizing the serendipity of the moment, he asked that I turn the recorder off, then leaned back, remembering that time in his career. He then dialed his secretary, asked her to clear his schedule, asked if I wanted a coffee, then turned to me and said: "where were we? There is no need to rush, for I have all the time we need." From that moment on, I could not have asked for a more patient and thorough interviewee. It had felt like a seminal moment and I never second guessed any question I had, I just asked them. It was the most enjoyable interview I conducted. Equally important, when I reflected on the experience afterwards, I realized I had had a profound shift, from questioning the value of what I was doing to feeling excited about meeting others on my list.

G. David Forney

I interviewed Dave in July, well after my time with Art Carr, who was president of Codex while Dave was vice president of research. I will never forget meeting Dave Forney for he was such a gentleman who never asserted his obviously superior intelligence. When I reached his office, which was in the engineering section but a few steps up from the floor level, he greeted me graciously. As I followed him into his office, I could see most of the four walls had floor to ceiling shelves stuffed with technical books. The floor behind his desk was stacked high with magazines and papers, creating the impression of a very busy man engaged in many projects and managing many engineers and scientists. This proved to be true. I was concerned as I set up my recorder because I was intimidated about how to interview such an accomplished individual. But when it was transcribed, the interview turned out to be only five pages shorter than the one with Art Carr. This wasn't because I was a skilled interviewer, it was indicative of how easy he was to be interviewed.

By the end of our time together, it was crystal clear that the history of Codex owes much to the engineer from MIT with a doctoral degree who took a job with a 12 person company in a second-story office above a tailor shop on Mass Ave. to gain some practical experience.

I and another co-author, Loring G. Robbins, reached out to Dave on many occasions when writing *Circuits, Packets, and Protocols* for help for many reasons, and Dave was always of expert assistance. As with Art, it seemed as if I had made two new wonderful friends.

John Day

John was a very unexpected surprise on many accounts. First of all, he was not on my initial list of people I felt I needed to interview but was added because others strongly encouraged me to talk to him. John proved to be an essential read if one wants to understand the early days/years of the Open Systems Interconnection (OSI) history. In addition, John as a graduate student began participating in the ARPANET Network Working Group, and after receiving his M.Sc. in computer science in 1976, went to work for a local company in Illinois and participated in the International Network Working Group, or INWG. Furthermore, John became a leader in the evolution of the OSI standards. If that wasn't enough, John was an avid and accomplished collector of ancient maps, a habit I have indulged in since meeting John.

When John and I discussed why I wanted to interview him, it devolved into both the longer story of my project and his excitement of how he wanted to affect my conclusions, as well as the fact that I was a venture capitalist and that he had hopes to start a company. For various reasons his schedule brought him to the Bay Area roughly once a month, and when it did, he always looked me up. For years before I moved to Santa Fe, we were developing an intense relationship around his arguments that the ARPANET and therefore the Internet were fundamentally flawed and his intellectual aim to prove that fact. He hoped I would be persuaded by him and would document it in my project. I wanted to understand him, but it went against what I was learning from others I had interviewed and that created problems. John was dogmatic and enjoyed the give and take, however. When I had to go to Boston, we always had dinner and continued our conversations. I always believed his "educating" me helped me write a better history.

My Co-authors:

Andy Russell

I first learned of Andy Russell shortly after I moved to Kula, Hawaii, in early 2007. One night I decided to go out to dinner and, as was my habit, took a stack of reading material with me. On this occasion in my stack of material was an article by Andy Russell titled: "'Rough Consensus and Running Code' and the Internet–OSI Standards War," *IEEE Annals of the History of Computing* 28 (2006): 48–61. I loved the article and couldn't wait to call Andy and introduce myself and hopefully engage him in a conversation. It would be a couple of days before I called only to learn that one of the scientists I had interviewed, John Day, had called Andy on February 4th, a week earlier, recommending that the two of us talk. We did and I shared the historical reconstruction project I was engaged in, and we decided we wanted to collaborate if and when possible.

An opportunity came up in early 2013 when I was in a fix writing one of the last sections of a final chapter, so I called Andy and he was willing to come help me. He proved more than capable and as the week passed, we had time to get to know each other. One of the ideas we discussed was turning my on-line book into a real book, but I didn't think I had the energy or focus. Then in 2017 the CHM requested that to market my website required that I produce a book, I said I could not do it by myself. The president wanted to know whom I would choose, and I said Andy if he could make the time. He wholeheartedly approved, and Andy did as well. Andy then took on the task of finding a publisher and connected us to Tom Misa and ACM. I can't imagine anyone being a better partner, unless if we lived near each other so that we could find the time to work together in person as opposed to using telecommunications. We have not had one argument or rough spot, all the while becoming closer friends. Thank you, Andy, for I am one lucky co-author.

Loring G. Robbins

Not long after I moved to Kula, I concluded I needed to retain a personal trainer to work with me two or three days a week. It wasn't long before I found Loring, and we settled into a wonderful working friendship. Then in 2017 when I took on the project of writing a book with Andy Russell, and I reluctantly concluded that I could no longer hold up my end of our agreement and I needed to find someone to help me, I naturally asked Loring. After a few days of asking questions and reflection, he agreed. The truth is it is a partnership that has turned out better than I think either of us ever imagined, and I can assert has turned out better than I could have ever hoped. Loring has, without doubt, earned his way from helping me to being a co-author with Andy and me. It has been a profoundly wonderful journey, and I know I speak for Andy when I say Loring has contributed his full share in getting this book birthed! It has been fun, with a little stress thrown in, and it is going to be a book we will be very proud of. Thank you my and our friend.

Introduction

Your presence in a global, digitized society depends on modems and routers. These are devices—in every home and business—that, at first glance, may come across as modest and unremarkable. Typically, they are black plastic boxes with a few blinking lights, no larger than a book or small box of chocolates. These unassuming devices sustain and enable the global economy of the 21st century—but you won't find them heralded in most accounts of the digital age.

The purpose of *Circuits, Packets, and Protocols* is to shed some light on the historical origins of today's modems and routers, and the multiplexers and local area networks (LANs) they connect. Although there are many books about the creation of the Internet, the World Wide Web, and digital culture in an age of ubiquitous search and social media, the story of the devices and systems that make it all possible—networking, specifically internetworking—has not yet been told.

The background of our story begins just after World War II, with events that catalyzed the convergence of telecommunications and computing. Our story takes off in 1968 with the Carterfone decision, ARPA's funding of the ARPANET, the first 9,600 bps modem and time division multiplexer, and a rush of minicomputer start-ups.

Our story ends in 1988, for several reasons. First, in 1988 two trade shows—the Enterprise Networking Event and Interop—successfully demonstrated internetworking hardware and software. Computers from different vendors running different operating systems could now share data over diverse communication networks. This had been the goal of networking specialists for nearly two decades. It was accomplished in 1988. Second, 1988 was when one of the authors of this book, James L. Pelkey, began to interview industry and technical leaders in the field. He was interested in understanding this recent history, not predicting the murky future. And he wanted those interviewed to know that he was only interested in the past—a condition readily agreed to by the interview subjects.

Later in this introduction, we further expand on our decision to end our story in 1988—when internetworking had been demonstrated publicly and when the global market for computer communications equipment reached $5 billion, setting the stage for the commercialization of the Internet and the emergence of the World Wide Web. But first, let's preview the most important themes in the extraordinarily dynamic field of computer communications.

Three Themes

The theme of entrepreneurship is front and center. Entrepreneurs, as the economist Joseph Schumpeter described, were the people who were able to transform a new idea into a successful innovation—whether a new product, a new method of production or distribution, a new market, or, in the widest sense, a new industry structure. Schumpeter observed that entrepreneurs had three types of motivations:

> First of all, there is the dream and the will to found a private kingdom... Then there is the will to conquer: the impulse to fight, to prove oneself superior to others, to succeed for the sake, not of the fruits of success, but of success itself... Finally, there is the joy of creating, of getting things done, or simply of exercising one's energy and ingenuity.[1]

Throughout this book, we emphasize two aspects of entrepreneurship. *Vision* involves seeing latent opportunity within a new technology or new way of doing things. *Leadership* is the ability to establish a shared vision and persuade others to work in pursuit of it. When entrepreneurs are effective, it is because they are able to harness the spirit of creativity—that is, to bring a fresh approach to established problems. But as the historian Louis Galambos has pointed out, not all entrepreneurs embody Schumpeter's grandiose, heroic role. Entrepreneurs face confusing, frustrating, and often unresolvable obstacles. Entrepreneurs can work on modest, small-scale problems. And, crucially, not all entrepreneurship is synonymous with starting a business from scratch. Entrepreneurship occurs within existing institutions and it can also take root within non-profit settings, such as in government agencies, academic institutions, professional societies, and technical organizations.[2]

1. Joseph A. Schumpeter. 1983 [1934]. *The Theory of Economic Development: An Inquiry into Profits, Capital, Credit, Interest, and the Business Cycle*. Transaction Publishers, 93.

2. Louis Galambos. 2018. The entrepreneurial culture and the mysteries of economic development. *Essays in Economic & Business History* 36, 290–320; Louis Galambos. 2020. The entrepreneurial culture and bureaucracy in twentieth-century America. *Enterprise & Society* May 12, 2020, https://doi.org/10.1017/eso.2020.15; Louis Galambos. 2020a. The entrepreneurial culture: Mythologies, realities, and networks in nineteenth-century America. *Academy of Management Perspectives* 7 February 2020, https://doi.org/10.5465/amp.2019.0132.

Entrepreneurship tends to refer to individuals, but, paradoxically, entrepreneurship in computer networking required the collaboration of many people working together as teams and in loosely coupled networks. In many cases, acts of entrepreneurship also inspired imitators, which in turn created a critical mass of activity that generated swarms, flurries, and communities of individuals all working on varied aspects and approaches to one big overarching challenge—like the challenge of connecting computers into networks. Our focus on entrepreneurs should not be read as an attempt to diminish the contributions of all kinds of other people—such as managers, executives, administrators, scientists, and engineers. Rather, by featuring entrepreneurs we are highlighting the challenging nature of bringing new technologies to profitable use, and some obstacles that may await those who try to transform existing institutions.

Another of Schumpeter's foundational contributions to the study of business is his memorable insight that entrepreneurship and innovation fuel the "perennial gale of creative destruction." Entrepreneurs trigger these gales through their ability to attract support (in the form of capital) for their ideas. Many chapters in *Circuits, Packets, and Protocols* detail these abilities, typically in the form of venture capital, initial public offerings, and mergers, acquisitions, and divestments. The entrepreneurs in our story worked in a different era than Schumpeter's, and, accordingly, gathered capital in ways that he did not fully anticipate. An important phase of growth and expansion in the availability of venture capital occurred at the same time as the technological developments in our story. Indeed, these developments were connected—evident in the accumulation of wealth among those who led and financed successful corporations in California's Silicon Valley. In addition, regulatory changes in the late 1970s and early 1980s—such as reductions in the capital gains tax and the 1980 Small Business Investment Act—provided further impetus for investment at a crucial phase of transition in the networking industry. Our history shows the many ways that success in business and technology depended upon success in attracting capital, and how increasing returns accrued to successful firms.

Like Schumpeter, our central focus is not the wreckage that is the inevitable consequence of "creative destruction"—although readers will notice how many companies and individuals fall by the wayside in the chapters that follow. The most notable examples of these are the titans of telecommunications and computing at the beginning of our book, IBM and AT&T, which were pale shadows of their former selves by the late 1980s.[3] Rather, our chapters document the "creative" side

3. The literature on these two companies is vast. Two useful starting points are Richard H. K. Vietor. 1994. *Contrived Competition: Regulation and Deregulation in America*. Harvard University Press; James W. Cortada. 2019. *IBM: The Rise and Fall and Reinvention of a Global Icon*. MIT Press.

of the equation—a progression in business development that demonstrates how entrepreneurship can catalyze the growth of individual companies, then multiple companies interacting within a dynamic market-structure that, in turn, generates economic growth and therefore prosperity.

In anticipation of the dozens of entrepreneurs you will meet in the pages that follow, we want to highlight three individuals who played outsized roles in the convergence of telecommunications and computing.

The first is a lawyer, Bernard Strassburg, who spent three decades with the Common Carrier Bureau (CCB) of the Federal Communications Commission. He was named bureau chief on November 22, 1963. At that time, the responsibility of the CCB was largely the regulation of the circuit-switched telephone industry, which meant the regulation of AT&T. Working with a staff economist, Dr. Manley Irwin, Strassburg took aggressive steps to steer the convergence of telecommunications and computing in a way that would serve the public interest—and that ultimately led to the breakup of AT&T.

Second is Paul Baran, an engineer celebrated as the co-inventor (along with Donald Davies) of the packet switching technology that is the foundation of digital networks. While working at RAND, Baran conceived of packet switching as part of a design for a communications system that could survive an attack by nuclear weapons. Throughout his subsequent career, Baran was widely respected as an expert on packet switching and computer communications more generally. He also was an energetic figure in the business world: he was comfortable in social networks and founded seven companies that applied packet-switching technologies to wired and wireless communications and home networking. Baran's career accomplishments were recognized with prestigious awards such as the IEEE Alexander Graham Bell Medal, the Marconi Prize, and the National Medal of Technology and Innovation.

Robert Metcalfe is the third entrepreneur you'll encounter in this book. In 1969, as a graduate student in applied mathematics, he connected MIT's minicomputers to the ARPANET. He quickly became an important member of the ARPANET community. Upon graduating, he worked as a research scientist for Xerox PARC and co-invented Ethernet, a design that enabled local area networking. Metcalfe spent years proselytizing the superiority of Ethernet including the formation of the DEC–Intel–Xerox consortium known as DIX. Afterwards he co-founded 3Com, a computer networking equipment manufacturer that would grow to $251 million in revenue by 1988.

Strassburg, Baran, and Metcalfe illustrate the rich and multifaceted meanings of entrepreneurship that we highlight throughout the book. While Baran and Metcalfe are more in the Schumpeterian heroic mold, Strassburg was a public servant who did not form companies but who was nevertheless profoundly influential.

After entrepreneurship, a second major theme of this book surrounds the tensions that arise at the *boundaries of markets and governments*. In some cases, governments seek to constrain market actors—such as the antitrust suits that the US federal government pursued against AT&T and IBM over several decades. In other cases, government agencies often subsidize or even coordinate market activity, as with Department of Defense funding for the development of the ARPANET and standards setting activities overseen by the National Bureau of Standards. And in still other cases, governments establish and enforce rules that market participants must follow, such as protection for intellectual property, conditions for market entry, immigration and labor policies, tariffs for international trade, and rules for corporate governance and taxation. The boundaries of markets and governments change over time and across state, national, and international jurisdictions.[4]

A third theme that recurs throughout this book is *learning*. Formal educational institutions played crucial roles, and this era was an important phase of growth for some important computer science programs such as at MIT, Stanford, UCLA, and University of Utah, among many others. Equally important are informal processes such as learning by doing, market research and discovery, and the retraining of engineers and technical staff. Membership on corporate boards sometimes permitted cross-fertilization of ideas, expertise, and tacit knowledge. Successful high-tech firms have access to teams of expert researchers—typically postdocs or graduates of elite universities—who keep abreast of changes in computer science and technology. Additionally, researchers, managers, and investors need their own continuing education. As we will see, learning occurs within *communities* that form, sometimes organically, when students and employees socialized or attended parties together. Experts form insights and knowledge about technology and markets in these venues, outside the typical domains studied by economists, such as market exchanges governed by price mechanisms.[5]

4. Stuart W. Leslie. 2000. The biggest 'angel' of them all: The military and the making of Silicon Valley. In Martin Kenney, ed., *Understanding Silicon Valley: The Anatomy of an Entrepreneurial Region*. Stanford University Press; Mariana Mazzucato. 2013. *The Entrepreneurial State: Debunking Public vs. Private Sector Myths*. Anthem Press, London; Lee Vinsel. 2019. *Moving Violations: Automobiles, Experts, and Regulations in the United States*. Johns Hopkins University Press; Margaret Pugh O'Mara. 2019. *The Code: Silicon Valley and the Remaking of America*. Penguin Press.

5. There is a vast literature on organizational learning and communities of practice. Some good starting points are Naomi R. Lamoreaux, Daniel M. G. Raff, and Peter Temin, eds. 1999. *Learning by Doing in Markets, Firms, and Countries*. University of Chicago Press, Chicago; Urs von Burg. 2001.

Trade shows, demonstrations, professional conferences, and public expositions arguably were the most important sites for learning. These meetings provided opportunities for the public to learn about new technologies and products—and for companies to learn about their competitors. The outsized import of these kinds of meetings is clear at almost every step of our story—from the ARPANET demo in 1971, to the National Computer Conference of 1980, to the Interop expo founded by Dan Lynch starting in the mid-1980s. Our cover image was taken at Interop ’88, a meeting that, as we describe in Chapter 13, was a tipping point for the victory of TCP/IP in the international competition to establish internetworking protocols.

These different forms of learning provide the best insurance against the pervasive uncertainty and the chance of failure that are permanent fixtures of high-tech industries. Uncertainty reigns in the early phases of market development, when knowledge and technologies are changing fast, firms have yet to establish organizational capabilities, and customer wants and needs are unknown. The experience gained with diverse combinations of technologies, financial structures, market strategies, and customer feedback is essential for a new field to grow. The failure of specific firms and products can be dramatic and traumatic, but such failures are normal and healthy aspects of the emergence of new market-structures. Most entrepreneurial ventures fail. The reasons are endless: mismanagement, bad luck, poor decisions, bad timing, betting on the wrong technology, inability to adapt to market trends and customer demands. But entrepreneurs, venture capitalists, and larger firms can learn from failures—a process that works best when individuals and organizations learn to see failure as only one stage in a complex and unfolding process of market development.

These three themes—entrepreneurs, market–government boundaries, and learning—are conceptual touchstones for the vast amount of material we present in *Circuits, Packets, and Protocols*. Our emphasis, in a conscious departure from other existing histories of internetworking, is to devote particular attention to the forces that constrained and directed entrepreneurship in the products that enabled computer communication—as well as the consequences of entrepreneurial initiatives.

Sources and Methods

All histories are defined by their starting points and end points. Ours is not the first history of internetworking to start in the late 1960s, but we may be alone in

The Triumph of Ethernet: Technological Communities and the Battle for the LAN Standard. Stanford University Press; Paul Miranti. 2008. Chandler’s paths of learning. *The Business History Review* 82, 2, 293–300; Linda Argote. 2013. *Organizational Learning: Creating, Retaining and Transferring Knowledge*. Springer, New York; Mantzavinos, C., Douglass C. North, and Syed Shariq. 2004. Learning, institutions, and economic performance. *Perspectives on Politics* 2, 1, 75–84.

choosing to end our story in 1988—well before the dot-com boom, and even before the invention of the World Wide Web or the commercialization of the Internet.

As noted above, we chose 1988 purposefully. This decision was shaped by Pelkey's interviews of 85 industry and technical leaders during that year. His interviews are an invaluable resource, now available through the Computer History Museum, and this is the first book to use them extensively to understand computer communications. His interviewees include such leaders as Paul Baran, J.C.R. Licklider, Vint Cerf, Robert Kahn, Larry Roberts, Louis Pouzin, Robert Metcalfe, and dozens of others—many of whom are unfortunately unknown in existing histories of the Internet. These interviews, together over 1,887 transcript pages, are a singular resource for historians of computing and business. We encourage you to take a few minutes to read the Preface and Acknowledgments, which convey a sense of the richness of Pelkey's encounters with these dozens of industry leaders. Unless otherwise noted, all quotations in this book are drawn from these interviews. A full list of interviews appears in Appendix A.[6]

To complement these interviews, Pelkey collected data during the late 1980s about three distinct markets—data communication, networking, and internetworking. This data includes detailed firm-level sales and income statements, as well as data published by a variety of sources, including two leading market research firms, Dataquest and Datapro, and two leading investment banks, Alex. Brown & Sons and Montgomery Securities. A summary of these sources appears in Appendix B, Bibliography. These data, in combination with the original interviews, constitute an extraordinarily rich body of source material. They were the foundations of Pelkey's hypertext book, *Entrepreneurial Capitalism & Innovation*.

We co-authors have reflected at length on our interpretations of our source material, as well as our decision to end the narrative in 1988. We have tried, to the best of our abilities, to write these chapters to capture the points of view of our protagonists. That is, we're telling history moving forward. In doing so, we capture the contingency that typically is lacking, especially in histories that seek to explain how the heroes of the digital age came to occupy their places of glory. The messiness, complexity, and uncertainty that we present will feel familiar to all managers and engineers who have stumbled through the confusion of new markets and emerging technologies. Our goal is to show how individual struggles combined, over time, into collective actions of deep significance—Schumpeter's "gale of creative destruction."

In writing this book, we sought to avoid the myopia that results from oversimplified accounts where the "winners write history" and the "losers" are cast

6. In several cases, selections from interviews that appear in this book have been edited for clarity.

aside. These tendencies toward myopia and hagiography are especially prevalent in books about the pioneers of business and technology histories, which are often dominated by successful men such as Edison, Rockefeller, Watson, Gates, or Jobs. Unfortunately, such hero-worship obscures the real challenges that people faced, and the broader and more systemic factors that shaped the emergence of some technologies over rival alternatives.[7] To put the point another way, the biggest difference between our book and every other history of the Internet lies in this simple fact: in our book, standards for Ethernet local area networking and TCP/IP internetworking were not the preordained winners. In fact, when our account ends in 1988, tremendous uncertainty remained about which competing approach to networking and internetworking—Ethernet or Token Ring, TCP/IP or OSI—would emerge as global standards.

The fact that Pelkey's interviews were conducted during this phase of technological and commercial churn—and *before* the final outcome was known—gives them some special characteristics that are now impossible to replicate. In most cases, the people Pelkey interviewed were only dimly aware, if at all, that they might have any "legacy" to defend. Instead, the interviews contain candid reflections from leaders of business, government, and engineering who were, along with their interviewer, trying to piece together the various events that defined the growth of computer communications.

With our approach to historical writing—where the "winners" are not preordained—the technologies we describe can seem bizarre, and the cast of characters can be Tolstoy-esque. If we have been successful, our readers will perceive a viable balance between including enough detail to capture the complexity of the era while also keeping the narrative adequately paced and reasonably bounded. The scale of our analysis evolves; the earlier chapters are broad and engage some sweeping themes of political economy and technology. By the later chapters we're deep in the details of significant conferences, product demos, customer deals, and meetings of standards committees. Whenever possible, we rely primarily on the primary source material that Pelkey created and collected during the 1980s. We have sought to preserve the inherent complexity of the material, without making the narrative unduly complex. To help them get oriented, we encourage readers to consult both the list of acronyms at the beginning of the book and the Appendices and Index at the end.

This book is more a work of historical narrative than it is economic theory, but there is a body of scholarship that has informed and structured our understanding

7. Andrew L. Russell. 2017. Hagiography, revisionism & blasphemy in Internet histories, *Internet Histories: Digital Technology, Culture and Society* 1, 15–25.

of economic change. In particular, we have been guided by work in the fields of complexity theory, industrial change, and evolutionary economics. We have been inspired and influenced especially by scholars such as Brian Arthur, Giovanni Dosi, Louis Galambos, David Lane, David Mowery, Richard Nelson, Douglass North, John Padgett, Carlota Perez, Nathan Rosenberg, and Sidney Winter. It is pleasing to note that this influential literature, sometimes labeled "neo-Schumpeterian," was emerging at the same time as internetworking was evolving.

We believe readers will find it useful for us to describe how *Circuits, Packets, and Protocols* fits alongside existing historical accounts of the convergence of telecommunications and computing. A vast majority of this literature, published since the mid-1990s, documents and explains the sudden rise of the Internet—arguably one of the most consequential technological systems of the 20th century. Scholars writing in this vein track the invention of packet-switching, ARPA's investments in computing, the growth of the ARPANET, Vint Cerf and Robert Kahn's leadership in the creation of the TCP/IP standards, and some of the international collaboration and competition that set the stage for the Internet's global spread.[8] Many of these events took place during the time period that we examine in the pages that follow—and, indeed, we also describe these and related events, primarily through the lens of the interviews Pelkey conducted in the late 1980s. More recently, historians and scholars in related fields have explored the explosive growth of the commercial Internet in the 1990s, driven in large part by its "killer app," the World Wide Web.[9] By and large, the primary goal of historians of the Internet and Web

8. See, for example, Hans Dieter Hellige. 1994. From Sage via Arpanet to Ethernet: Stages in computer communications concepts between 1950 and 1980. *History and Technology* 11, 1, 49–76; Andrew S. Tanenbaum. 1996. *Computer Networks*. Prentice Hall; Arthur L. Norberg and Judy E. O'Neill. 1996. *Transforming Computer Technology: Information Processing for the Pentagon*, *1962–1986.* Johns Hopkins University Press, Baltimore; Roy Rosenzweig. 1998. Wizards, bureaucrats, warriors & hackers: Writing the history of the Internet. *American Historical Review* 103, 5 (December 1998); Janet Abbate. 1999. *Inventing the Internet*. MIT Press; Katie Hafner and Matthew Lyon. 1996. *Where Wizards Stay Up Late*; M. Mitchell Waldrop. 2002. *The Dream Machine: J.C.R. Licklider and the Revolution That Made Computing Personal*. Penguin; Urs von Burg. 2001. *The Triumph of Ethernet: Technological Communities and the Battle for the LAN Standard*. Stanford University Press; Andrew L. Russell. 2014. *Open Standards and the Digital Age: History, Ideology, and Networks*. Cambridge University Press; Bradley Fider and Morgan Currie. 2016. Infrastructure, representation, and historiography in BBN's Arpanet maps. *IEEE Annals of the History of Computing* 38, 3, 44–57.

9. See, for example, Tim Berners-Lee and Mark Fischetti. 1999. *Weaving the Web: The Original Design and Ultimate Destiny of the World Wide Web by its Inventor*. Harper, San Francisco; James Gillies and Robert Cailliau. 2000. *How the Web Was Born: The Story of the World Wide Web*. Oxford: Oxford University Press; Shane Greenstein. 2015. *How the Internet Became Commercial: Innovation, Privatization, and the Birth of a New Network*. Princeton University Press; David Kirsch and Brent Goldfarb. 2019. *Bubbles and Crashes*; Shane Greenstein. 2008. Innovation and the evolution of

has been to explain how the Internet came to be. We would draw your attention to the differences between their approach and chronology vis-à-vis ours—particularly since our account ends in 1988, before the commercial Internet traffic was permitted and before the public release of Tim Berners-Lee's World Wide Web browser in 1989.

Over the past decade, and in recognition of the Internet's global importance, the scholarship on Internet and computer networking developments and adoption outside the US has grown considerably.[10] Some of this work has demonstrated the importance of international contributions to the growth of the Internet itself, which is often perceived as a strictly US-based phenomenon. Other accounts have emphasized instead the fact that global adoption of Internet technologies took place against the backdrop of varied national and regional strategies to build networks for data and computer communication. Our story in *Circuits, Packets, and Protocols* complements these histories insofar as we identify and wrestle with the inescapable power of regulation and government power—including the shifting landscape of competition, antitrust, privatization, and intellectual property laws that set conditions for entrepreneurship and corporate change.[11]

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market structure for Internet access in the United States. In William Aspray and Paul E. Ceruzzi, eds., *The Internet and American Business*. MIT Press; Janet Abbate. 2010. Privatizing the Internet: Competing visions and chaotic events, 1987–1995. *IEEE Annals of the History of Computing* 32, 1 (January 2010), 10–22; Martin Campbell-Kelly. 2003. *From Airline Reservations to Sonic the Hedgehog*; Tom Nicholas. 2019. *VC An American History*; Niels Brugger and Ian Milligan (Eds.). 2018. *The SAGE Handbook of Web History*. SAGE Publishing.

10. See, for example, Martin Campbell-Kelly. 1987. Data communications at the National Physical Laboratory (1965–1975). *IEEE Annals of the History of Computing*, 9, 3–4 (July–Sept 1987), 221–247; Andrew L. Russell and Valérie Schafer. 2014. In the shadow of ARPANET and Internet: Louis Pouzin and the CYCLADES Network in the 1970s. *Technology and Culture* 55, 4, 880–907; Ben Peters. 2016. *How Not to Network a Nation*. MIT Press; Eden Medina. 2011. *Cybernetic Revolutionaries*. MIT Press; Ignacio Siles. 2020. *A Transnational History of the Internet in Central America (1985–2000): Networks, Integration and Development*. Palgrave Macmillan; Susanne K. Schmidt and Raymund Werle. 1998. *Coordinating Technology*. MIT Press; Thomas Haigh, Andrew L. Russell, and William Dutton. 2015. Histories of the Internet: Introducing a special issue of information & culture. *Information & Culture* 50, 2; Valerie Schafer. 2012. *La France en Reseaux*. Nuvis, Paris; Ignacio Siles. 2012. Establishing the Internet in Costa Rica: Co-optation and the closure of technological controversies. *The Information Society* 28, 13–23; and Martin Campbell-Kelly and Daniel D. Swartz-Garcia. 2013. The history of the Internet: The missing narratives. *Journal of Information Technology* 28, 18–33.

11. See, for example, Jasper L. Tran. 2019. The myth of Hush-A-Phone v. United States. *IEEE Annals of the History of Computing* 41, 4, 6–19; Steven W. Usselman. 2004. Public policies, private platforms: antitrust and American computing. In Richard Coopey, ed., *Information Technology Policy: An International History*. Oxford University Press, Oxford; Steven W. Usselman. 1996. Fostering a capacity for compromise: Business, government, and the stages of innovation in American computing.

Scholars writing about Internet history (and related topics) have been preoccupied with innovation and growth. Such a preoccupation is not unusual for histories of technology, which tend to skew toward novelty—and ours is no exception. With that said, there has been a noticeable uptick in scholarly interest in infrastructure, maintenance, and the underlying material conditions—from rare earth minerals to fiberoptic cables—that sustain access to the Internet.[12] And, general histories of computing have long documented the steady trend of miniaturization (mainframes to PCs to handheld), albeit with a focus mostly on consumer devices instead of middleboxes like modems, gateways, and routers. There are very few books or essays that attend to the individuals and companies who built the modems, multiplexers, and routers that fascinate us and that fill the pages of this book.[13]

As we combed through the substantial published literature, and reflected on the interviews and data that Pelkey collected, we found some structural aspects of computer communication that were not adequately recognized. We concluded that a new concept, a *market-structure*, could best capture some of the nuances that we wish to highlight.

Market-Structures

The basic terms of economic interactions are well known—firms, markets, industries—and thousands of books and articles by historians and economists document their workings.

Firms combine a number of business functions within a single organization. Firms can come into being through the actions of entrepreneurs, whose roles we

IEEE Annals of the History of Computing 18, 30–39; Steven W. Usselman. 2009. Unbundling IBM: Antitrust and incentives to innovation in American computing. In Sally H. Clarke, Naomi R. Lamoreaux, and Steven W. Usselman, eds., *The Challenge of Remaining Innovative: Insights from Twentieth-Century American Business*. Stanford University Press, Stanford, 249–280; Gerardo Con Diaz. 2019. *Software Rights*. Yale University Press.

12. See, for example, Andrew Blum. 2012. *Tubes: A Journey to the Center of the Internet*; Andrew L. Russell and Lee Vinsel. 2018. After innovation, turn to maintenance. *Technology & Culture* 29 (January 2018), 1–25; Brad Fidler and Andrew L. Russell. 2018. Financial and administrative infrastructure for the early Internet: Network maintenance at the Defense Information Systems Agency. *Technology & Culture* 59 (October 2018), 899–924; Brad Fidler and Amelia Acker. 2016. Metadata, infrastructure, and computer mediated communication in historical perspective. *Journal of the Association Information Science and Technology* 68, 2, 412–422; Nicole Starosielski. 2015. *The Undersea Network*. Duke University Press.

13. Ronald R. Kline. 2019. The modem that still connects us. In William Aspray, ed, *Historical Studies in Computing, Information, and Society*. Springer; Jeff Chase with Jon Zilber. 2019. *3Com: The unsung saga of the Silicon Valley startup that helped give birth to the Internet—and then fumbled the ball*. Pseudepigrapha; David Bunnell and Adam Brate. 2000. *Making the Cisco Connection: The Story Behind the Real Internet Superpower*. Wiley.

emphasized above and who are the major subjects of this book. Firms become successful if they can supply products through distribution channels that satisfy the buying demand of a sufficient number of customers. Such firms are vendors of these products. As time passes, firms develop organizational capabilities and often move through different phases, where they test their abilities to compete, persist, and adapt to change. Firms take diverse forms, such as proprietorships, corporations, and multinationals.

Markets are abstract and practical mechanisms that enable buyers and sellers to exchange artifacts, goods, or services. They include vendors in competition and cooperation with each other; they also include customers. Successful markets evolve over time, typically, from a few corporations to a population of many corporations. In many cases, markets can tend toward oligopoly or monopoly, where a single vendor presides over a dominant design for a technology (or service) and has eliminated practically all competitors.

Industries refer to a group of vendors that produce similar products or services. Industries typically are defined by principal product categories or activities, such as automobiles, computers, or mining. Industries can be understood as aggregates of firms that produce for the markets.

These three elements of an economic system—firms, markets, and industries—all fit together within the emergent process that we define as a *market-structure*. This concept points to the dynamic system in which firms, markets, and industries act upon each other and shape one another's trajectories. These dynamic interactions also are shaped by the factors we discussed above, namely, formal and informal institutions for education as well as a variety of government and legal institutions—regulation, investments in research, financial markets, and so on. By using the concept of a market-structure we demonstrate how markets act on an industry; how an industry, in turn, conditions the dynamics of markets; and how individual firms both shape and are shaped by the broader dynamics of markets and industries.

Market-structures are complex, adaptive systems. The economic historian W. Brian Arthur observed, "To look at the economy, or areas within the economy, from a complexity viewpoint then would mean asking how it evolves, and this means examining in detail how individual agents' behaviors together form some outcome and how this might in turn alter their behavior as a result."[14] Clearly, when a

14. W. Brian Arthur. 2013. Complexity economics: A different framework for economic thought. Santa Fe Institute Working Paper 2013-04-012. Retrieved February 7, 2021, from https://www.santafe.edu/research/results/working-papers/complexity-economics-a-different-framework-for-eco.

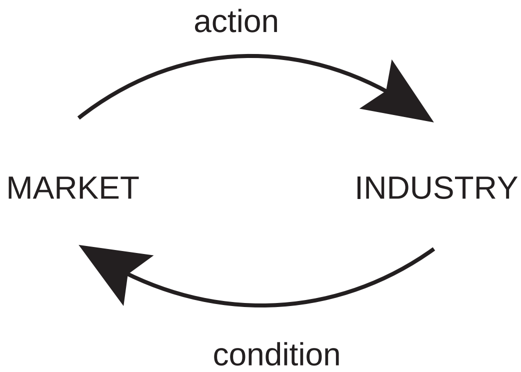

Figure 1 Market-structures. Illustration by James L. Pelkey and Loring G. Robbins.

complex system takes shape, it influences behaviors of the individual agents and actors. These elements are mutually constitutive and ever-changing (see Figure 1). At the same time, there are elements of stability present: the very existence of a market-structure—a firm, market, or industry—indicates that order has been achieved at one scale, even though there can be elements of chaos or disorder at other scales.

Market-structures embody both micro- and macro-economic features, such as: intra- and inter-firm decision-making, interactions between firms, prices, and interactions within markets (all the realm of microeconomics); and government actions such as antitrust enforcement and investments in research, monetary policy, the availability of investment capital, and the fluctuations of business cycles (all in the realm of macroeconomics). There are other institutions and other market-structures that form the environment of any given market-structure. It is this dynamism, complexity, and accounting for change over time that makes the concept useful for us. It is important to distinguish our term "market-structure" from the common term "market structure," as the latter refers to a static picture of actors in a given market. For us, the hyphen is essential because it indicates dynamic interaction. Since our book is a work of history, we ask how market-structures come into being, how they change over time, and how they decline.

One ready example of a market-structure is mainframe computing. IBM introduced the System/360 in 1964, which quickly became a commercial success and prompted other firms to change their behaviors in the market. System/360 became the "dominant design" because IBM was able to anticipate and learn how its customers—especially large manufacturers, government agencies, and universities—could adopt and use computers.[15]

15. Steven W. Usselman. 1993. IBM and its imitators: Organizational capabilities and the emergence of the international computer industry. *Business and Economic History* 22, 1–35; JoAnne

Some firms, such as GE and RCA, lacked the capabilities to keep up, and subsequently exited the market. Their decision allowed IBM to become more dominant. Over time, the cumulative actions of IBM, other firms, and legions of diverse customers changed the nature of the computer market-structure writ large. The same pattern recurred over the next several decades as computer and telecommunication technologies converged around packet-switching technologies. Technologies such as modems, LANs, and routers all emerged from a great variety of experiments and prototypes. Markets grew significantly once variation gave way to standardization, and dominant designs emerged.[16]

Clearly, the behavior of individual firms can have enormous consequences for markets, industries, and market-structures. Firms often struggle to adapt to change, and many firms fail. Firm-level behavior can be likened to the process of niche construction in evolutionary biology: the activities and choices of firms influence other firms, which modify their own behaviors in order to respond to competitors and customers and flourish in the environment (markets). These behaviors generate feedback that informs the overall direction of the process of change. As Schumpeter pointed out, competition takes place on at least two scales: between individual firms within an existing market and in the creation of an entirely new market. These acts of creation proceed from five forms of innovation: products, processes, business models, sources of supply, and mergers & divestments. In other words, it is a mistake to reduce innovation simply to changes in technology. Innovation can and does come from other sources—and, according to Schumpeter, innovation is the lifeline for firms that seek to maintain profitability over the long term.[17]

The developmental dynamics of firms occur within an ecology of social organizations and networks. There are competitive corporations, customers, vendors, law firms, accounting firms, venture capital partnerships, commercial banks, investment banks, governments, standards-making bodies, universities, and more. The

Yates. 2005. *Structuring the Information Age: Life Insurance and Technology in the Twentieth Century*. Johns Hopkins University Press.

16. Philip Anderson and Michael L. Tushman. 1990. Technological discontinuities and dominant designs: A cyclical model of technological change. *Administrative Science Quarterly* 35, 4 (Dec. 1990), 604–633. See, especially, page 613 ff, “A dominant design is a single architecture that establishes dominance in a product class. Once a dominant design emerges, future technological progress consists of incremental improvements elaborating the standard and the technological regime becomes more orderly as one design becomes its standard expression.” There is a substantial literature on dominant designs, organizational capabilities, and the evolution of technological systems such as electric power, bicycles, automobiles, and computers.

17. Schumpeter, *Theory of Economic Development*.

most important organizations or individuals to a firm are customers, customers which in this history are large corporations. Second in importance are competitors. There are direct competitors, those selling essentially the same product, and indirect competitors selling products that can be used for the same purpose but achieve the functionality through different means. If start-ups and existing firms seeking to capitalize on new technologies introduce similar products within a short period of time, the firm interactions may coalesce into the formation of a new market.

Market-structures proceed through three phases: *emergence*, *competition*, and *order*. (Note that these three phases map to the varying slopes on the S curve that all business students learn.) Emergence can last for many years and will consist of firms ranging from entrepreneurs attempting to form corporations to existing firms attempting to adapt into the new product category. What remains uncertain in the emergence phase is whether the products being commercialized hold enough economic potential to generate the sales to support successful firms. In the competitive phase of market formation, the product category has traction but it remains unclear how large the market will be or how long it will last. It is during this phase that weaker or less successful firms begin being acquired or merge or fail completely. The last phase of market formation, *order*, is when the often hundreds of firms that introduced products have shrunk to an oligopoly of as few as a half a dozen firms controlling two-thirds of the market.

These phases look different in different market-structures, as we'll observe through our study of three distinct market-structures that arose between computer and communications technologies, all in an astonishingly brief period of time, between 1968 and 1988: data communications, networking, and internetworking. Owing to Pelkey's extensive interviews and insider market data, we believe we have the most powerful and compelling set of data and analysis about computer communications available anywhere thus far.

To guide readers through the rich material collected here, we have provided a visual aid in the form of a "Roadmap" that appears in Appendix C. This Roadmap is a guide to the overall narrative and argument so that readers will know how any specific chapter fits into the book's overarching narrative. Finally, before we move on, we would like to highlight and reflect upon the three key terms in our title, *Circuits, Packets, and Protocols*. We purposefully chose these three words to correspond to the dominant technologies of the three market-structures we examine. *Circuits* refers to the circuit-switched telephone network, which was the established infrastructure for communications that became the backbone for modem technologies in the data communication market-structure. *Packets* refers to packet-switching, co-invented by Paul Baran, that created new possibilities for computer networking, manifest in the ARPANET and local area networking.

Protocols refers to the software code necessary to bring intelligence to packet switching, and build networks of networks—that is, internetworks—that blossomed in the 1980s and beyond.

Three Market-Structures at the Intersections of Communications and Computing, 1968–1988

In the late 1950s, corporate America began using computers in earnest. Executives began to take notice of the cost savings and productivity gains promised by Remington Rand, NCR, Burroughs, and the industry leader, IBM, and soon enough GE. Corporate computing began to spread widely in 1960 with IBM's introduction of the 1401, which sold an astounding 2,000 units. With IBM's introduction of the System/360 in 1965, corporate computing changed forever. Soon enough, two additional revolutions in computing reshaped American business: first minicomputers and then personal computers.

Mainframes suited centralized corporate cultures of the 1960s. One big computer, the Host computer, sat in a raised-floor, air-conditioned, often high-security room, with terminals and printers and other peripherals directly wired to it. Over time, however, corporate users wanted to locate terminals and printers at remote locations. To do so required sending the bits over the analog circuits of the telephone system. The devices that facilitated this arrangement were modems—products that converted the digital bits to analog sounds and then back to bits.

Data communications emerged between 1967 and 1971 in response to several factors. The environment for entrepreneurship became more favorable, thanks to regulatory changes in favor of competition and the availability of venture capital. There was also the increasing demand from mainframe users to connect to remote peripherals. As we describe in Chapters 1 and 2, over one hundred firms announced modem or multiplexer products. In 1968, Codex Corporation introduced the world's first 9,600 bit per second modem, and American Data Systems (soon Micom) the first time division multiplexer. Other competitors included Milgo, Infotron, General DataComm, Timeplex, Paradyne, Vadic, and Universal Data Systems. The data communication firms were shielded from new competition through most of the 1970s when market researchers predicted sales to peak at an uninteresting $150 million. In Chapter 4, we'll describe the market order that emerged in the late 1970s; by 1980, worldwide sales of data communication products exceeded $1 billion.

The second market-structure we examine, networking, emerged with the boom in minicomputing. The minicomputer revolution arrived in 1965 when Digital Equipment Corporation, a company financed by American Research and

Development, the first venture capital firm, announced its PDP-8. By 1968, entrepreneurs were flooding into the field of minicomputers; within four years, 92 competitors had announced products. Corporations, governments, and universities bought minicomputers because they were significantly less expensive than mainframes, and application software was readily available. With software readily available and the number of applications growing, corporate and government employees had newfound needs to access multiple computers and peripherals.[18] This need drove market demand for a new kind of product, the second wave in computer communications: networking. This market-structure was engulfed quickly in competitive chaos, with over a hundred firms offering competitive products.

In Chapter 3, we describe some of the origins of networking technologies—particularly packet-switching experiments funded by the US Department of Defense's Advanced Projects Research Agency. In Chapters 5, 6, and 7, we'll focus on the emergence of networking technologies as well as the strong currents of competition in the market-structure, which operated alongside cooperative movements to establish industry-wide standards. Our analysis features both established data communications companies and start-ups that entered markets for LANs.

During the 1970s, the proof that packet switching worked also inspired the creation of many kinds of networks. Three types of local networks evolved from packet switching and were designed for the offices and factories: Ethernet, token ring, and token bus. At first, these LANs did not use the telephone network but rather coaxial cable to interconnect the computers in a building or campus. This distinction would cause the data communication firms to ignore LANs until, often, it was too late.

As the 1970s came to a close, corporate managers purchased minicomputers, and looked for products to help them connect single terminals to multiple computers. In 1979, eager entrepreneurs launched three important LAN start-ups: 3Com, Ungermann-Bass, and Sytek. Along with two leading data communication firms, Codex and Micom, and a variety of other start-ups, companies experimented with different technologies to meet customer demands. Some firms offered products that were incremental improvements on circuit-switching equipment; others embraced the greater speed that packet-switching technologies enabled. The competitive phase of networking was particularly intense as over one hundred firms announced products. Other prominent firms include

18. Nathan Ensemenger. 2010. *The Computer Boys Take Over*. MIT Press; Campbell-Kelly, *From Airline Reservations to Sonic the Hedgehog*.

Interlan, Bridge Communications, Concord Data Systems, Proteon, Excelan, and Communication Machinery Corporation.

When personal computers were introduced in the early 1980s, they illustrated the impact of microprocessors, which were getting smaller and cheaper at the relentless rate described by Moore's Law.[19] Personal computers raised the stakes for networking. When networking first emerged, the need was to interconnect "dumb" computer terminals to multiple computers. The communication speeds were slow and the amount of data sent back and forth was modest. Personal computers would change those dynamics for they could transfer data at significantly higher interconnection speeds and the application software drove the needs for vast amounts of data. When IBM introduced its personal computer in August 1981, corporations went on a buying spree and within two years, more than twice as many personal computers were being bought as terminals. While it would take a few years for the profoundly different bandwidth requirements of personal computing to become evident in consumer demand, eventually packet-based LAN sales soared and circuit-switched data PBX sales collapsed. Not all LAN firms saw the changes being wrought by the personal computer, or reacted quickly enough. Corporations went on a tear installing networks, increasingly personal computer networks, and by 1985, networking sales totaled $1 billion, up from a mere $62 million in 1982. By 1988, it had become clear that the personal computer was giving rise to a new model of corporate computing, client server computing, with the mainframes and minicomputers functioning as data servers for the desktop personal computers. How the networking firms focused on terminal interconnection adapted, or not, to the needs of personal computers will be another focus of this history—and in Chapter 9 we'll see how market order for LANs was established.

The third market-structure of computer communications, internetworking, emerged from the conditions newly created by networking. Corporations soon discovered they had proliferating numbers of diverse networks that created isolated islands of computers. Interconnecting their network islands into larger enterprise-wide networks became the next focus. Fortuitously, many Fortune 500 companies were in the midst of building their own voice communication networks, appropriating the switching and circuits they historically had acquired from the telephone companies. Adding data to these wide area networks (WANs) was relatively easy because the technology was digital. But controlling WANs using circuit switching was still not optimal and again the advantages of packet switching prevailed when

19. Moore's Law refers to the 1965 observation from Gordon Moore, Intel founder, that the number of transistors on an integrated circuit doubles every 18–24 months. David C. Brock, ed. 2006. *Understanding Moore's Law: Four Decades of Innovation*. Chemical Heritage Foundation.

bridges, hubs, gateways, and routers were introduced to interconnect LANs over WANs. A new breed of internetworking firms emerged, including Retix, Cabeltron, Chipcom, StrataCom, Wellfleet, and Cisco Systems.[20] Their products introduced a new architecture and new operating systems designed for packet switching. Data communication firms, and most of the networking firms, were caught flat-footed or were so consumed with other opportunities, or problems, they lost out on what would in time be the largest computer communication market: internetworking.

The emergence of internetworking reflected the growing use of computers and, even more directly, the growing number of diverse networks. With ever-growing numbers of computers and networks, industry standards likewise became an ever-increasing bottleneck for suppliers and users. In Chapter 8 we'll see competition over standards for networking and internetworking. Standards committees, for decades, were widely perceived as the realm of backward-looking engineers who argued over the common denominator for established technologies. But the culture and practices of standards-setting changed with computer communications, where standards committees became forums for engineers to negotiate the parameters of industry for decades to come. In networking and internetworking alike, standards committees were meeting grounds where alliances of individuals and companies could seek to impose their will. In the late 1970s, a number of standards-making efforts were launched. The two that will be observed most closely are IEEE 802, to determine LAN standards, and ISO/OSI, to determine networking and internetworking protocols as well as LAN standards. IEEE 802 issued its Ethernet standard in 1983, and, in subsequent years, token bus and token ring standards. In Chapters 11, 12, and 13, we'll see how these alliances played out for internetworking—a fascinating case where market demand ran well ahead of supply. The OSI standards, especially those embracing LANs, took longer to negotiate. Vendors and customers gravitated to the only standard that was fully public, TCP/IP.

Our story concludes in Chapter 13, with descriptions of two public demonstrations in 1988. Both proved that internetworking could work—that is, computers from many vendors could function together seamlessly. At the Enterprise Networking Event, held in June in Baltimore, the OSI networking protocols were demonstrated in an installation connecting networks on site, in London and by satellite; plus, presentations from 50 vendors with OSI-compliant products and attended

20. In its early years, Cisco employees insisted that the company's name should start with a lowercase c, as homage to their hometown of San Francisco. Eventually, the company adopted the capitalized version of its name, although traces of the original spelling persisted in technical literature and software manuals for many years.

by an estimated 10,000 to 11,000 people. The focus was on large-scale connectivity across nations, government networks, and large industries like manufacturing. Interop was the third workshop organized by one individual entrepreneur, Dan Lynch, who had been instrumental in the transition of the ARPANET NCP to TCP/IP. The Interop Exhibition held in Santa Clara focused on the application of TCP/IP in internetworking products. In contrast to ENE, which was sponsored by government agencies and large corporations, Interop began with the continued leadership of Dan Lynch and a group of 54 vendors who were eager to present products and solutions to the specific challenges of interconnecting a wide variety of networks. Indicative of the interest in TCP/IP, Interop was attended by over 5,000 people.

In sum, the chapters in provide a new view of some deeply significant developments in computer history—and, arguably, world history. As we discuss in the next section, we're all still grappling with the consequences—good and bad—that follow from widespread adoption of internetworking. The fine-grained details of the entrepreneurs and researchers we present here shed light on the underlying and systemic relationships—the market-structures—that help us frame generalizations about technological and economic change. In the Conclusions, we'll apply some of our own lessons to analyze the internetworking market-structure in the decades after 1988. There, we will only gesture at some of the significant companies and issues since we do not have the same documentary basis of interviews and market data that inform our analysis of the earlier period. Accordingly, we end the book with an invitation to readers to apply the concepts and ideas that we use throughout the book, and let us know if you, too, find them helpful.

Why Do These Stories Matter?

The shift we document in this book—from centralized mainframe computers to internetworked personal computers—introduced changes in everyday life that were already obvious by 1988. Three decades later, and we now confront the ubiquity of smartphones, social media, and the "Internet of Things" that connects watches, cars, toilets, toasters, and so much more.

The economic value of internetworking is indisputable—just think about the stock market valuation of companies such as Google, Amazon, Facebook, and thousands of others around the world whose existence depends on internetworking technologies. The 20 years that we scrutinize in *Circuits, Packets, and Protocols* laid the foundations not only for the explosive business growth of the web and social media but for the economic and technological foundations of the global economy more generally. The products described in this book—modems, local area networks, and routers—should be considered as the essential "black boxes" of the global digital economy.

The changes that took place between the late 1960s and the late 1980s need to be understood in much finer detail. Through the Schumpeterian processes of innovation and creative destruction, a new global information infrastructure was established. There is a compelling analogy between digital data networks and the development of railroads in the mid-19th century. In both cases, technologies were at the heart of new, lucrative market-structures: the production of locomotives, steel rails, and freight and passenger operations; and the production of modems, LANs, and routers. These technologies also served as platforms or infrastructure for a vast range of social and economic activity, a function that economists and economic historians characterize as general-purpose technologies.[21] Scholars often pay attention to the linear aspects of infrastructure – railroad tracks, submarine cables, overhead telephone and telegraph wires, and today's globe-spanning optical fibers. But equally important are the connections between these lines: railroad switches and stations, telephone switchboards and central offices, and modems and routers. These points of connection are essential since they ensure that the entire infrastructure can be utilized efficiently.[22]

The two decades between 1968 and 1988 were remarkable times in American life, and we believe that some of the personalities and social dynamics we describe will contribute to the rich, textured understanding of American society. In the realm of political economy, the broader trends of deregulation and Reaganism are evident as the broader context behind rapid changes in technology and the growth of entrepreneurial capitalism that we document. These decades saw an alignment of regulation, technology, learning, and the availability of capital that was quite unlike other decades in the 20th century—and we see our story as a contribution to the effort to explain why change appears to happen with different intensities at different times. The self-evident international and global impact of digital, internetworked technologies also should be understood in large part as a product of distinctively American forms of political economy that prevailed between 1968 and 1988.

Pelkey started this project in the late 1980s because he wanted to make history meaningful and understandable to people who experienced it and lived through

21. Timothy Bresnahan and Manuel Trachtenberg. 1995. General purpose technologies: 'Engines of Growth'? *Journal of Econometrics*, Special Issue 65 (January 1995), 83–108.

22. Thomas Parke Hughes. 1993. *Networks of Power: Electrification in Western Society, 1880–1930.* Johns Hopkins University Press; Steven W. Usselman. 2002. *Regulating Railroad Innovation: Business, Technology, and Politics in America, 1840–1920.* Cambridge University Press.

that time, even though they might not have grasped the momentous technological changes happening around them. Like most people, Pelkey did not anticipate that the subject that captivated him would turn out to be such a crucial—and understudied—chapter in modern history. Rather, as an investor in computer communications, he felt that it was important to try to make sense of developments in the field for others who didn't have access to industry experts, and who might not have a passion for understanding the details of circuits, packets, and protocols. In a general sense, then, we hope readers appreciate that our book is simply an effort to explain the origins of the digital networks that surround, sustain, entertain, and bedevil us.

From our present vantage point, it's not at all clear how the long-term effects will shake out. We're currently in the midst of a "techlash"—a backlash against Silicon Valley companies and their products, which once promised to liberate users, but now appear equally likely to be tools of surveillance and oppression. Depending on who you ask, or how you're feeling, you may find different answers to some fundamental questions: Have these technologies led to widespread progress—or to inflated stock markets and deflated wages and sagging incomes? Has the unleashing of entrepreneurial energies been a good thing—and how widely shared have been the economic gains? As readers contemplate some hot-button issues of the day—net neutrality, the power of social media companies, the fates of privacy and security in a digital environment devoted to surveillance—they stand to benefit by learning more about how our digital, internetworked world came into existence. We hope that readers will gain a richer understanding of the dynamism, fragility, and complexity of socio-technical systems—as well as appreciation for the individuals who brought these systems to life.

1 Prelude to Change: Data Communications, 1949–1968

1.1 Overview

Some of the most iconic moments of the 1960s involved the blending of technology and ideas in new ways. Whether it was Neil Armstrong's walk on the surface of the moon or Jimi Hendrix's burning guitar in Monterey, the foundations of an astonishing era of technology-based change were being forged. And as with all iconic moments, hundreds of people and decades of effort went into the changes that crystallized in public perceptions as a history-altering spectacle. The 1960s were likewise a pivotal decade for the data communications industry, even if there was little public fanfare to accompany the key developments. Throughout this book we describe *market-structures*—dynamic relationships between markets and populations of firms that pursue similar product opportunities. During the 1960s, the market-structure for data communications slowly began to emerge, in spite of the dominance of two giant firms AT&T and IBM. The principal obstacle to the emergence of the data communications market-structure was AT&T's contesting the attachment of any devices not of its own, as well as the interconnection of other networks, to 'its' telephone network. But as we will see in this chapter, the FCC reversed its long-standing support of AT&T in 1968 and allowed independent companies to sell equipment that connected to the public telephone network. The FCC's decisions transformed telecommunications—clearing a path for a rush of new businesses forming around new technologies and the growing adoption of business computing. But before we get to the fateful events of 1968, and the extraordinary events of the next two decades that are the main subject of this book, we need to begin with a brief review of some of the important decisions and events that occurred between the end of World War II and 1968. We have organized this history into five sections: the federal government and its interactions with AT&T,

the emergence of the dominant computing firm IBM, technological innovation, new sources of capital, and entrepreneurial individuals who contributed to the emergence of the data communications market-structure.

1.2 AT&T, The Regulated Monopoly

Alexander Graham Bell invented telephony in 1876 and created the American Telephone & Telegraph Company in 1885. After a phase of competition with other telephone companies, AT&T became the most powerful telephone company in the United States. Its status as a regulated monopoly was established with the Kingsbury Commitment of 1913, a truce between AT&T and the Department of Justice. As a consequence, AT&T became the largest corporation in America by 1949, with revenue of $2.893 billion and net income of $233 million.[1] Enjoying the privileges of a monopoly, however, also invited the constant scrutiny of state and federal regulatory agencies.

When Harry S. Truman won the presidential election in 1948, he moved quickly to create an Administration with people who believed, as he did, in the aggressive use of antitrust to save the economy for competition. Monopolies were the enemy. And AT&T, the biggest of them all, had escaped the leveling cleaver of antitrust. Or so they believed. Holmes Baldridge, who became the new chief of the Antitrust Division's General Litigation Section, had for years harbored frustrations that AT&T had not been punished after an investigation during the 1930s—an investigation of which he had served as chief counsel.[2]

1.2.1 Hush-a-Phone

Baldridge had fresh justification handed to him on December 22, 1948, when the Hush-A-Phone Corporation filed a complaint with the FCC against AT&T. The complaint charged that AT&T's Foreign Attachment Tariff Restrictions prohibited telephone subscribers from using the Hush-A-Phone, a product that had been available since 1929. It was simply a plastic cup that fit over the telephone microphone to increase the privacy of telephone conversations and reduce extraneous noise. As innocent as it would seem, AT&T and the Bell operating companies interpreted the Foreign Attachment Tariff Restrictions as a very clear prohibition against any type of physical attachment to any AT&T equipment or facility, period—including a plastic cover on a telephone book in a public phone kiosk. AT&T's formidable legal

1. $2.893 billion in 1949 is equivalent to $31.6 billion in 2020.

2. "Baldridge later made it clear, at congressional hearings long after he left the government and after the case ended with a consent decree, that the complaint had been largely his personal project." Fred W. Henck and Bernard Strassburg. 1988. *A Slippery Slope: The Long Road to the Breakup of AT&T*. Greenwood Press, 57.

department argued, quite forcefully, that federal regulations were on their side. In place since 1911, the Tariff read:

> Equipment, apparatus and lines furnished by the Telephone Company shall be carefully used and no equipment, apparatus or lines not furnished by the Telephone Company shall be attached to, or used in connection therewith, unless specifically authorized in this tariff.[3]

Inspired by the growing number of complaints, on January 14, 1949, the Justice Department filed a civil antitrust suit against AT&T and its manufacturing subsidiary, Western Electric (WE). The Justice Department charged that the two companies had established a monopoly in the manufacture, distribution, and sale of telephone equipment. It asked the court to force WE to sell its 50% interest in Bell Labs to AT&T; divest AT&T of WE and split WE into three separate companies; require AT&T to bid all purchases competitively; and to license its patents to all applicants. Baldridge was not deterred by the conclusion from a recent investigation by California regulators that WE prices were 45% below an average of *independent* manufacturers' prices.[4] Under Baldridge, the Justice Department had clarity of purpose: AT&T was a monopoly. It needed to be broken up.

To defend itself, AT&T relied on a decades-old strategy: any chips in its technical foundation would undermine its exceptional technological service for the American public. Mike Slomin, who served as an FCC staff attorney in the 1970s, summarized AT&T's strategy in a 1988 interview: "Well, you know, the Hush-A-Phone distorts speech, and any one of 200 million people in this country might be called by, or might call, someone using a Hush-A-Phone. They're going to get a lousy telephone call. That's harm. They're not getting what they paid for."[5] The power in this defense was that it appealed both to the technological complexity of the telephone system as well as to AT&T's carefully crafted image as a civic-minded monopoly, one that had the unique and sacred responsibility of ensuring quality service for all Americans. The small office caught in the middle of this debate—AT&T on one side and antitrust regulators on the others—was the FCC's Common Carrier Bureau (CCB or bureau). The CCB eventually responded to its difficult position by acting creatively, and, ultimately, paving the ground for the emergence of a new market-structure.

3. Jordaphone Corp. of America and Mohawk Business Machines v AT&T, Decision, 18 FCC 644 (1954).

4. Alan Stone and William L. Stone. 1989. *Wrong Number—The Breakup of AT&T*. Basic Books.

5. Mike Slomin, oral history interview by James L. Pelkey, March 10, 1988, Allentown, NJ. Computer History Museum, Mountain View, CA. Available from https://archive.computerhistory.org/resources/access/text/2017/09/102740208-05-01-acc.pdf.

On February 16, 1951, the FCC released its initial decision and dismissed the Hush-a-Phone complaint in favor of AT&T. Hush-a-Phone petitioned for review, which sent the case into another phase of oral arguments and expert testimonies. As the months passed, AT&T successfully marshaled Department of Defense (DOD) support for their cause. DOD personnel began lobbying for case dismissal. AT&T had become indispensable to the DOD. It had recently taken on management of Sandia National Laboratories (responsible for the US nuclear stockpile). Moreover, in 1952 AT&T responded to the Defense Department's request for help in constructing a strategic air defense system. AT&T's role was to design an instrument capable of transmitting digital data over the analog telephone lines, and to design and build a telephone network connecting radar sites in Northern Canada to computers in the States and then onto aircraft and missile sites. This initiative would have lasting consequences for the Data Communication market-structure, as well as for the convergence between communication and computer technologies and market-structures.

The antitrust negotiations between the Justice Department and AT&T that began in the spring of 1953 had now dragged on for over two years. In the fall of 1955, the Justice Department once again solicited FCC advice on the issues of the antitrust suit. The chief of the CCB prepared the first response. The Commissioners thought it too weak in representing FCC powers and sent it back for redrafting. The job was assigned to CCB staff lawyer Bernard Strassburg—an individual who would go on to play a pivotal role over the next decades. Strassburg's response emphasized the Commission's powers to examine rate bases and to take appropriate actions, pointing out rate reductions that had been negotiated.

Independently, on December 21, 1955, Judge David Bazelon handed down the Court decision on the Hush-A-Phone case. Judge Bazelon reasoned that since the same effect of the Hush-A-Phone plastic cup could be created by cupping one's hands around the microphone, such a tariff was an:

> Unwarranted interference with the telephone subscriber's right reasonably to use his telephone in ways which are privately beneficial without being publicly detrimental. Prescribing what changes should be made in the tariffs to render them "just, fair, and reasonable" and determining what orders may be required to prohibit violation of subscribers' rights thereunder are functions entrusted to the Commission.[6]

Henceforth, independent equipment suppliers would be able to sell equipment that attached to the PSTN without requiring AT&T permission beforehand. What

6. Hush-A-Phone v. United States, 238 F.2d 266 (D.C. Cir. 1956).

mattered was that the conditions of being "privately beneficial without being publicly detrimental" were met. Hush-a-Phone's plastic cups, in the end, were proverbial stones in the hand of David that created the first chips in the foundations of AT&T's monopoly. AT&T responded by changing their tariff restrictions to allow foreign attachments, but only if they did not "endanger telephone employees, property or service." AT&T continued to restrict foreign attachments, thus ensuring that the debate over the boundaries of its monopoly power would continue.

Accordingly, the career staff in the Justice Department continued to keep a close watch on AT&T and other large firms, guided by prevailing economic theories that monopolies would inhibit innovation. Even so, the political winds above them had shifted. The election of Dwight D. Eisenhower as President in 1952 resulted in a more conservative, pro-business philosophy of antitrust enforcement. The Justice Department sought to resolve as many of the 144 active antitrust cases as quickly as possible.

This left a major impact on AT&T and the communications industry, namely when the Justice Department and AT&T announced on January 24, 1956, that an out-of-court settlement of US v. Western Electric had been reached. In some of the key terms of the agreement, AT&T:

1. Did not have to divest Western Electric, although Western Electric could not manufacture equipment other than that used by the Bell System, or the Government.
2. Was enjoined and restrained from engaging in any business other than the furnishing of common carrier communications services.
3. Was required to license Bell patents to any applicant that agreed to pay a reasonable royalty and agreed to make available their patents to Bell.

The significance of these latter two aspects of the Consent Decree—preventing AT&T from competing in the computer industry and licensing the Bell System's patents—can hardly be overstated. As we will see, the long-term dynamism of the data communications and internetworking market-structures flowed from these restraints on AT&T. But in the near and medium term, AT&T's continued ownership of Western Electric and continued monopolistic control over telephone service generated tremendous profits: from 1949 to 1968 the revenues of AT&T grew from $2.893 billion to $14.0 billion, or by 380%.

Again, AT&T had foiled the Federal Government's efforts to introduce competition into telecommunications. In essence, no one was willing to risk the uncertainty of what might happen if AT&T were forced to do what it steadfastly resisted; and not without reason, for not only had AT&T created the world's finest telephone system but as the world's largest corporation any negative impact on its hundreds of thousands of employees and shareholders would certainly have political consequences. So, the Justice Department did what it could to prevent the monopolist from interfering with other competitive markets, and constrained AT&T, and WE, to common carrier communications.

AT&T had equally fought off the efforts of other companies to connect non-AT&T devices to their network. Granted, their tariffs had to be "just, fair, and reasonable," but who was to say what those words meant other than AT&T; and challenging AT&T's interpretations had proven lengthy, and expensive, with little hope the FCC would rule against AT&T. The tradition of fighting any changes at the periphery of the network, a tradition dating to the 19th century, had again proven successful: AT&T's monopoly remained intact.

So, the world of telecommunications, as in AT&T, had walled itself away, steeling itself against change, seemingly harmonious with the pace of the 1950s, but soon to be at odds with the great changes to be introduced by computers. They were already facing the massive investment and challenging task of managing the conversion of their network from analog to digital. One of the reasons Bell Labs was innovating computers was to use them as digital switches. As a result, it made sense for AT&T to get into the computer business, both because they were one of the largest customers of IBM and Digital Equipment Corporation (DEC), and because Bell Labs was already designing and building computers. But the 1956 Consent Decree they had just signed prohibited their entering competitive markets.

1.2.2 Challenges to AT&T: MCI and Carterfone

Another set of business and legal challenges to AT&T came from aspiring competitors who petitioned the FCC to allow access to wireless frequencies for private communications. In 1956, a number of trade associations and manufacturers of microwave equipment lobbied the FCC for more relaxed regulation of the use of radio frequencies for private installations. This prompted the FCC to review its policies for allocating radio frequencies. A few years later, in 1959, the FCC ruled, in what would be known as the "Above 890" decision, that private companies could use radio frequencies above 890 megacycles (microwave frequencies) for use to meet private transmission needs.

In 1963, a company was launched that few at the time had any idea would become a serious competitor to AT&T. The original idea for the business came from a motivated entrepreneur who saw the opportunity in microwave technology to increase the sales of his short-wave radio equipment and service business. John D. "Jack" Goeken along with Donald and Nicholas Phillips, Leonard Barrett, and Kenneth Garthe founded Microwave Communications Inc. (MCI) on

October 3, 1963. Goeken's vision was to offer shipping companies in the Midwest affordable microwave communication lines, between truckers along Route 66 between Chicago and St. Louis, and between barges on the Illinois Waterway. Customers would share the same line so that their rates would be far less than was offered by the telephone company. Goeken planned to connect two-way radios with microwave relay stations—in short, a service for mobile business communications. Goeken filed an application for a license to the FCC in December 1963. In addition to the always pressing need to raise money, Goeken and the other founders knew they needed legal help. In January they hired Haley, Bader and Potts. Attorney Michael Bader, having recently fought a successful case against AT&T over a television microwave relay system in Texas, thought that if MCI were successful, this new area of communications law would be a promising source of business for his firm. Goeken and Bader began the lengthy process of making presentations to FCC commissioners and staff. Eventually, a hearing before Herbert Sharfman, the examiner appointed by the FCC, was scheduled for February 1966.[7]

As Bernard Strassburg, who had become chairman of the CCB in November of 1963, prepared to make the bureau's recommendations on the MCI application, he wasn't convinced Goeken and his company could deliver on their goal of a private microwave communication service. However, after consulting with two economists, Manley Irwin and William Melody, Strassburg decided that approving the MCI application would be a good way to test the waters of competition in the communications market. Convinced that the growing demands for new communications technologies would add to the market and stimulate additional communication services, he urged the FCC to grant the application. On July 1967, the CCB sent Sharfman their "Proposed Findings of Fact and Proposed Conclusions" recommending approval of the MCI application. Sharfman released the preliminary response in favor of MCI in October of 1967.

In the meantime, another wireless entrepreneur had made himself a thorn in AT&T's side and asked the federal government to stop the monopolist from crushing him. Thomas Carter was an easy-going entrepreneur from Texas—a practical man who invented a clever device named the Carterfone. His invention was motivated by the simple desire to solve the communication problem of oil field workers, far from phones, maybe aboard an offshore oil rig, trying to reach home.

It's important to note that Carter, like MCI's Goeken, was seeking to meet the communication needs of business users. Neither was looking to create a mass-market gadget; and neither was using output from a research lab to create new

7. Philip Louis Cantelon. 1993. *The History of MCI 1968–1988: The Early Years*. Heritage Press, 31–47.

technologies. Rather, these were practical men who saw opportunities for devices that could solve practical problems that arose in the course of ordinary business.

The Carterfone was a device that connected a two-way radio to the telephone network (see Figures 1.1 and 1.2). It would allow calls between users on a two-way radio and users on the telephone network. Once an operator made the connection between the two callers by placing the phone handset on the acoustic cradle, the Carterfone automatically transmitted the signal from the telephone handset to the radio and then stood by to receive the voice signal from the radio. The operator of the Carterfone could then monitor the call and adjust levels manually if needed.

When Carter first introduced the Carterfone in 1959, he had been surprised to learn the reasons why the telephone company objected to its use: it interfered with their end-to-end service responsibility and could be harmful to telephone service. As a result, it violated the tariffs banning foreign attachments to the telephone network. Carter was not so easily discouraged and sold Carterfones anyway—

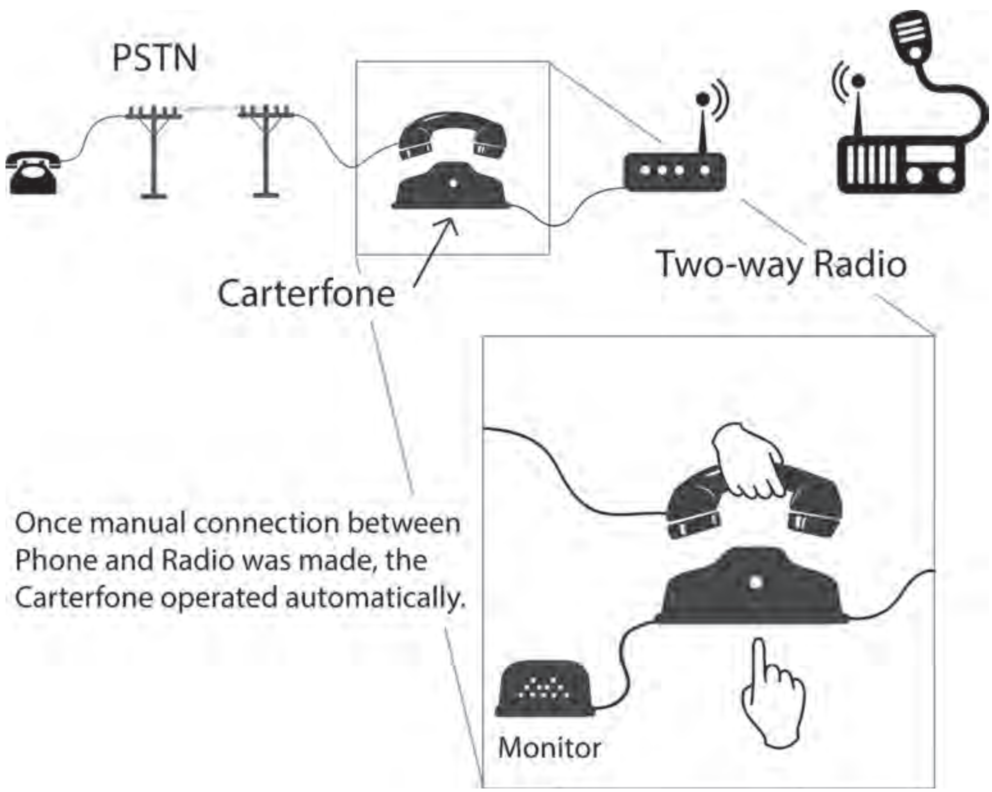

Figure 1.1 Carterfone connections with telephone and radio networks. Source: Illustration by Loring G. Robbins.

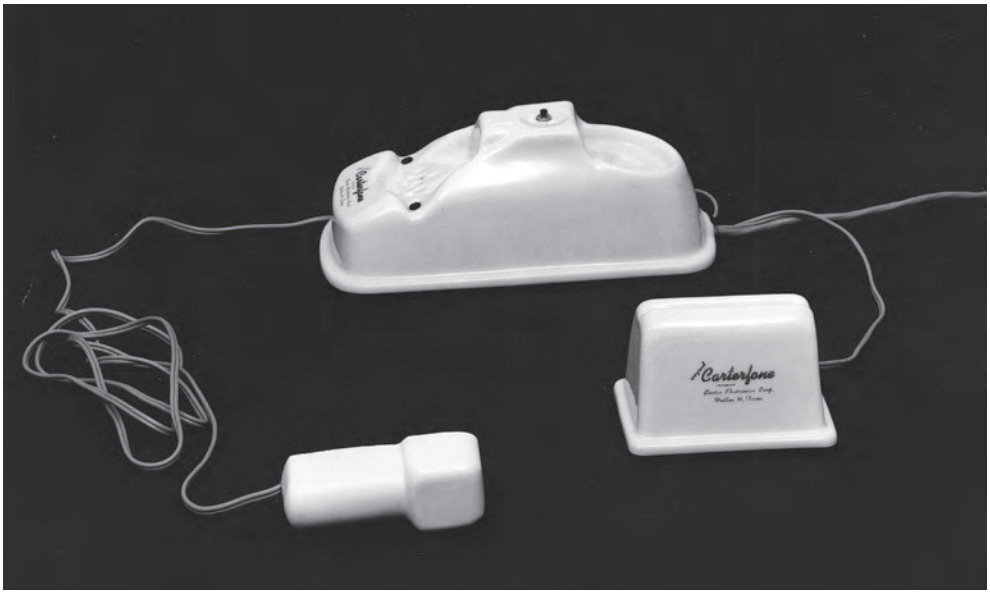

Figure 1.2 The Carterfone. Source: Image courtesy AT&T Archives and History Center.

approximately 3,500 units in the United States and overseas by 1966. But threats that the telephone company would terminate customers' telephone service posed a real obstacle to sales, so in 1966 Carter brought an antitrust suit against the Bell System and the General Telephone Company of the Southwest. The United States District Court, Northern District of Texas, referred Carter's case to the FCC under the doctrine of primary jurisdiction to resolve questions of whether the tariff permitting telephone companies to suspend, or terminate, service if non-AT&T devices were connected to telephone company facilities was valid. The key issue was one of "foreign attachments."

Once at the FCC, the Carterfone case was referred to the CCB, the same office that had dealt with the Hush-A-Phone controversy in the 1950s. The CCB scheduled hearings to collect information for both cases—MCI and Carterfone—for 1967. At the same time, bureau staff members were mobilizing to have an unprecedented public discussion about the future of communication services in the United States, with an eye toward anticipating technological changes that could alter long-established regulations and market-structures.

Strassburg, who had written the Bureau's opinion for the Hush-a-Phone matter, was beginning to speak publicly about the profound technological, political, and economic challenges that he saw on the horizon. In 1965, Strassburg assembled a task force to examine data communications, and spoke regularly—and publicly—

with industry professionals on subjects such as market entry, information privacy, and the coming convergence of computers and common carrier communications. He remarked in a 1966 speech: "Few products of modern technology have as much potential for social, economic and cultural benefit as does the multiple access computer."[8]

The far-reaching consequences that he discerned prompted him to view the FCC's role, and his bureau's role, in a broader way than one might expect from a career government lawyer steeped in the philosophy of supporting the monopolistic AT&T. On October 20, 1966, he gave a speech to an audience of computer and data processing professionals in which he articulated his understanding of the responsibilities and roles of the FCC:

> The Commission is obliged by the policies and the objectives of the Communications Act to ensure that the nation's communication network is responsive to the requirements of an advancing technology. The Commission has the obligation, the authority, and the means to reappraise and refashion any established policies in order to promote the public interest through an effective realization of the social and economic benefits of current technology.[9]

In early 1967, Haakon Ingolf (H.I.) Romnes, who had previously been President of Western Electric, became AT&T's new Chairman and Chief Executive Officer. Romnes did not fully subscribe to AT&T's long-standing policy of opposing foreign attachments. Shortly after taking office, he expressed the opinion that Bell's responsibility for the network could be maintained if there were "suitable interfaces or buffer devices to keep the attached equipment from affecting other users of the network."[10]

The MCI hearings began in February and lasted nine weeks. The Carterfone hearings were scheduled next, for April. Fred Henck, Editor of the respected trade publication *Telecommunications Reports*, would comment later that it was hard to find someone to report on these two insignificant cases, referred to around the office as the "cats and dogs."[11] Strassburg, on the other hand, began to see the

8. Bernard Strassburg. 1968. The marriage of computers and communications—Some regulatory implications. *Jurimetrics Journal* 9, 1, 12–18.

9. Strassburg, "The marriage of computers and communications."

10. Peter Temin and Louis Galambos. 1987. *The Fall of the Bell System: A Study in Prices and Politics*. Cambridge University Press, 44.

11. "At *Telecommunications Reports*, we reflected the view of our news sources that neither case was very important. Our main problem was finding someone on our small staff with enough time to cover what we considered rather insignificant hearings. Along with a few other minor cases going

Carterfone hearings as a way to revisit the foreign attachments tariff, which, as he was increasingly learning, was a real impediment to the use of the telephone system for data processing and to innovation of communication devices. He reflected on this period in a 1988 interview:

> We used the Carterfone issue and the Carterfone proceeding as a vehicle for revisiting the policy, which was basically a Bell System policy, which had been embraced by the FCC and the regulatory commissions for many generations, against customers, willy-nilly, interconnecting anything they chose to the telephone network, no matter how innocuous it might be unless the item was specifically authorized by the telephone company's tariffs. Well, the telephone company wasn't likely to tariff anything of consequence, so as a result, anytime anybody wanted to promote a piece of equipment and to have it work with the telephone network, they either had to sell it to the Bell System, if they could convince Western Electric and Bell that they had something sellable, or if they couldn't succeed in that channel, then attacking the tariff insofar as the claim was unlawful – and that the Commission should order it amended in order to accommodate their device. But that was a very cumbersome process to go through; the administrative hearing and the time and the cost involved that, to a small entrepreneur with a piece of equipment – it discouraged people. It discouraged the market from developing, and that's why, I think, the United States was so far behind other countries, because, in terms of customer-premise equipment, simply because there was no entrepreneurship, the entrepreneurship was blunted and discouraged by this institutionalized practice of saying: "You can't connect with us." In other words, everything that went on had to go on within the Bell System, Bell Laboratories. That was where innovation began and ended.[12]

When it came time to argue the Carterfone case before the Hearing Examiner, Chester F. Naumowicz, Jr., the CCB took the position that the tariff provisions limiting use of customer-provided equipment be canceled. It should be replaced, instead, by a clear and affirmative statement that "customer-provided equipment, apparatus, circuits, or devices may be attached or connected to the telephones furnished by the telephone company… for any purpose that is privately beneficial to

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on at the time, the Carterfone and MCI hearings were referred to generically in the office as 'cats and dogs.'" Henck and Strassburg, *A Slippery Slope*, 102.

12. Bernard Strassburg, oral history interview by James L. Pelkey, May 3, 1988, Washington, DC. Computer History Museum, Mountain View, CA. Available from https://archive.computerhistory.org/resources/access/text/2015/11/102738016-05-01-acc.pdf.

the customer and not publicly detrimental."[13] In other words, the CCB was not arguing that users could substitute customer-provided equipment for that provided by the telephone company—only that it should be permissible to connect or attach devices to telephones furnished by the telephone company.[14]

The Carterfone hearings took but seven days. Maybe sensing a fundamental change in progress, Romnes assembled a high-level Tariff Review Committee to conceive alternative interconnection tariffs that would protect the network. The facts that AT&T permitted connection of foreign attachments by the military and government, as well as equipment of TV networks, all suggested there had to be a solution other than total prohibition.

In August 1967, Examiner Naumowicz issued his initial decision. Ignoring the argument for a broad policy change, he ruled narrowly that harm from use of the Carterfone had not been proven. Left unsettled were the overarching questions about how AT&T could defend the boundaries of its monopoly, and how the FCC and courts would define that monopoly in the face of technological change and entrepreneurial incursions.

1.3 IBM

Now to the story of the emergence of the computer industry, the features that made it so attractive to AT&T, and the potential that made it so concerning to Bernard Strassburg in his new role as chief of the bureau.

At the end of World War II, when AT&T dominated telecommunications as a regulated monopoly, IBM was a large corporation that dominated the office equipment market. It did not even enter the computer market until 1952. Yet within a few decades, IBM was ascendant—the largest computer firm within an oligopoly of a few firms. How that happened is critical to our history.[15]

13. Henck and Strassburg, *A Slippery Slope*, 104–105.

14. "We were also being very cautious in how far we thought the tariffs ought to be amended and how far we ought to go. We didn't view the issues in Carterfone as having to do with any replacements or substitutions for the equipment provided by the telephone company. It was how the telephone service provided by the telephone company, including the instrument, the terminal, should interface with other equipment and under what circumstances it should permit connection to other equipment which it didn't provide. We were not talking about eliminating or abandoning this whole concept of end to end responsibility by the telephone company. We were talking about what can be done at each end by the customer with the service that he buys from the telephone company." Strassburg interview, Computer History Museum.

15. See, generally, James W. Cortada. 2019. *IBM: The Rise and Fall and Reinvention of a Global Icon*. MIT Press.

IBM was already a substantial and successful company before the idea of selling computers ever crossed the minds of any IBM executive, in particular, Thomas Watson, Jr., the son of the president and CEO. In 1949, the revenues of IBM were $183 million, every dollar of which came from the office equipment market, which had been their primary source of revenue ever since their inception. None came from computers.

The initial genius and entrepreneur of IBM was Herman Hollerith who was the inventor of punch card tabulation machines in the mid-1880s. In 1911, he sold his company, Tabulating Machine Company, to Charles Flint, who merged it with two other firms he had recently acquired to form the Computing-Tabulating-Recording Corporation (C-T-R), the recognized starting point of IBM, although it was not until 1924 that they changed the name to International Business Machines. Thomas J. Watson, Sr., was hired as the general manager in 1914 after a successful career with the National Cash Register Company (NCR) and became president of IBM in 1915. By the 1950s, IBM's major competitors were Remington Rand, NCR, and Burroughs. When IBM chose to invest in expansion during the Depression, whereas the other three elected to retrench, IBM became the leading firm. In 1950, IBM controlled 90% of the punch card market.

When the Korean War broke out in 1950, Watson Sr. offered IBM's help. IBM undertook a study to determine how it could best aid in the war effort. James Birkenstock, manager of the IBM Future Demands department, and mathematician Cuthbert Hurd recommended IBM build a "general-purpose scientific" computer. Code-named the Defense Calculator, it became the most expensive investment in the company's history to that point.[16] Watson Jr. remembers the subsequent confusion: "Our engineers and production mangers weren't sure how to proceed."[17]

The year 1952 proved to be very busy for IBM. On January 21, the Justice Department filed an antitrust lawsuit against IBM alleging they had acted illegally to preserve their 90% share of the highly visible punch card business. (As with AT&T in the communications industry, the government wanted to restructure the leading firm in the office equipment industry. These would not be the last antitrust suits the Justice Department would file against AT&T and IBM.) Watson Sr. added fighting the lawsuit to running the company, while Watson Jr. focused on his passion—getting IBM into the computer business. On April 29, Watson Jr. announced at the annual meeting that IBM was building "the most advanced, most flexible

16. Thomas J. Watson and Peter Petre. 1991. *Father, Son & Co: My Life at IBM and Beyond*. Bantam Books, 216–217.

17. Watson and Petre, *Father, Son & Co*, 259.

high-speed computer in the world."[18] The new machine was introduced a year later on April 21, 1953, as the IBM 701 Electronic Data Processing Machine.

IBM was not the first company to sell an electronic digital computer; that distinction belongs to the Eckert–Mauchly Computer Corporation and Engineering Research Associates. It took little time for IBM to assert market dominance in the computer market behind the skillful leadership of Thomas Watson, Jr., who became president in 1952. Watson Jr. remembers his father believing: "the electronic computer would have no impact on the way IBM did business, because to him punch-card machines and giant computers belonged in totally separate realms."[19] Once IBM entered the commercial computer business with its IBM 701 in 1953 and their scientific computer the IBM 650 two years later, they lost no time in making sizeable capital and research investments to accompany their extensive organizational capabilities. Despite his father's cautionary advice, his son had seen a very different future for the company.

Understanding IBM's deficiencies in computing, Watson Jr. made it a priority to win the contract being let by MIT and the Air Force to develop a computer for the Semi-Automatic Ground Environment (SAGE) air defense system. Jay Forrester, the MIT engineer responsible for procurement, held serious discussions with Remington Rand, RCA, Raytheon, Sylvania, and IBM. In October 1952, he selected IBM to be the subcontractor assisting MIT's Lincoln Laboratories to finalize the SAGE computer design. For IBM, SAGE represented the opportunity to learn state-of-the-art computer technologies from the most advanced computer development laboratory in the world. But while IBM learned, staff at Lincoln Labs felt burdened. Norman Taylor, one of Forrester's most trusted managers, remembered: "IBM seemed awful stupid to us. They were still designing circuits like radio and TV circuits."[20]

The SAGE project was a prime example of a massive government-sponsored project with an explicit goal of innovating existing and new technologies. The scale of the project itself required a level of organizational complexity that few if any firms had ever considered. SAGE impacted the fortunes of IBM and other firms involved almost immediately. The technology trajectory of computers had accelerated significantly. SAGE innovations such as core memory, real-time response to multiple users, keyboard terminals, computer-to-computer communications, printed circuit board construction, and diagnostic and maintenance systems became standard features in all future computers. At the time, it catapulted IBM from a "stodgy company" (as Watson Jr. characterized it) to a technological leader.

18. "A Notable First: IBM 701," https://www.ibm.com/ibm/history/exhibits/701/701_intro.html.

19. Watson and Petre, *Father, Son & Co*, 200.

20. Glenn Rifkin and George Harrar. 1988. *The Ultimate Entrepreneur*. Contemporary Books, 22–23.

Watson Jr.'s first significant act after taking over the reins from his father was to sign a consent decree ending the 1952 antitrust lawsuit. In the 1956 decree, IBM agreed, among other restrictions, to separate itself from its Service Bureau Corporation. The restrictions placed on the punch card business were not severe and with each passing year would prove insignificant, for punch cards were becoming less and less important to the company as a whole.

By the mid-1950s, IBM management fully understood the benefits of designing and building advanced computers for the government—the company could generate invaluable goodwill while maintaining access to cutting-edge knowledge it could apply in its next generation of computer designs. After IBM lost a bid in 1955 to build a super-fast computer for the University of California Radiation Laboratory, they sold a more aggressive design, to become known as STRETCH, to the Los Alamos National Laboratory as well as to the Atomic Energy Commission and the National Security Agency (NSA).

The STRETCH computer was sold commercially as the IBM 7030, announced in April 1961, and like the earlier 7070 introduced in 1959, used transistors instead of vacuum tubes. Early transistor computers also included the IBM 7090, a mainframe designed for large-scale scientific and data calculations. An early application of the 7090 was for the massive airline reservation system for American Airlines (AA). The name of the project—as well as much of the underlying technology—was drawn from the SAGE project, and titled Sabre for "Semi-Automatic Business Research Environment."

The inspiration for Sabre came from a fortuitous airplane conversation in 1953 between senior IBM sales representative R. Blaire Smith and C.R. Smith, then president of AA. The two connected the concept of the SAGE network with the need for an automated flight reservation system in which flight reservations could be created and recorded and the data made available to agents in any location. Before the two organizations began discussions on how to implement the project, president C.R. Smith of AA was quoted as saying: "You'd better make those black boxes do the job, because I could buy five or six Boeing 707s for the same capital expenditure."[21] In 1959, IBM and AA signed a development agreement that eventually led to a $30 million project.

IBM failed to foresee the massive amount of software development involved in implementing the Sabre system and consequently the project experienced many cost and schedule overruns. Initially, IBM terminals were located in travel agencies

21. James L. McKenney. 1994. *Waves of Change: Business Evolution Through Information Technology*. Harvard Business School Press, 111.

and connected by telephone lines using modems to IBM computers in AA's headquarters. When it was finally operational in 1964, Sabre revolutionized the airline reservation industry and was quickly duplicated by other airlines.

In October 1959, IBM announced the 1401, targeted for small business customers. After deliveries began in 1960, more 1401s would be installed than any other computer at that time—by the mid-1960s more than 10,000 had been installed.[22] Business customers were clearly embracing the use of computers, and IBM was successfully positioned to benefit the most from this trend.

At the same time, IBM faced a major challenge in maintaining order across its two computer divisions: the General Products Division, which sold lower priced computers, and the Data Systems Division, which sold general-purpose scientific and business computers. These divisions were making and selling a variety of different computer models, effectively competing against each other. But the main issue was the massive cost in software development for each project. Of the main transistorized models in production in 1960, none ran compatible operating systems. In the early 1960s, senior executives sought a drastic simplification of IBM's products, reducing its several product lines to one computer architecture that could meet the full spectrum of customer requirements, all using the same peripherals and software.

In January 1961, Frederick P. Brooks, Jr., lead designer for a recently cancelled 8000 series of business computers, was assigned to head development of a new line of compatible products that could serve all the requirements of IBM customers. As product manager, Brooks oversaw the massive hardware and software development effort involved in developing this revolutionary new "computer architecture," a term he first coined. The new system would be called the System/360. Gene Amdahl, who had previously worked on the 704, 709, and STRETCH computers, was engineering manager and chief architect.

The production of the System/360 was a massive gamble, but based on the difficulties in developing software to operate the new family of processors, as well as previous experiences with Sabre, it is worth noting that the efforts IBM undertook to develop advanced understanding in software development foreshadowed the future importance of software in computer history. The challenges, delays, and huge time and cost demands on IBM resources were especially evident to Brooks. In his chronicles of the project, *The Mythical Man-Month*, he coined what became known as "Brooks' Law," which states that "adding manpower to a late software project makes it later."[23]

22. Pugh, *Building IBM*, 266.

23. Pugh, *Building IBM*, 295.

On April 7, 1964, Thomas Watson, Jr., and the management of IBM made the most important product announcement in their company's history. IBM would begin shipping six models of the revolutionary new System/360 in April 1965. In the first 30 days IBM sold an unbelievable 1,000 System/360s. At a cost to IBM of an estimated $5 billion, the System/360, the innovative new series of mainframe computers, sent IBM's competitors scrambling for survival.

By investing in large-scale production, distribution channels, and management structures, IBM had secured first-mover advantages and created a dominant design for the mainframe computer industry. The scale and scope of attention IBM was able to bring to an average sale would dwarf whatever any competitor could do. As evidence of IBM's dominant market-structure position, IBM was shipping "over 1,000 model 360 systems a month" by 1969.[24]

The competition could do little at first other than wage a war of words. They argued that IBM could never deliver, it was too expensive, and it was not even state-of-the-art—it didn't use integrated circuits, for example. But all were forced to develop new product lines to stay competitive. One way competitors tried to differentiate their products from System/360 was time-sharing—largely because IBM did not support time-sharing in the announced System/360s.

The explosion in growth of computer service bureaus seemed to validate the notion that computers were analogous to utility service in electricity or water.[25] Service bureaus sold computer time and services to other companies as independent organizations or operations of computer manufacturers.[26] Existing since the earliest days of commercial computing, it was not until time-sharing that service bureaus could support real-time access to many users at the same time. By 1966, an estimated 800 service bureaus generated $650 million in revenues—thought to be

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24. "Since it entered the computer business 15 years ago, IBM's volume has increased 17 times (to $5.3 billion last year [1967]) and its net income has gone up 20 times (to $651.5-million). Last year, IBM zoomed past Texaco and U.S. Steel to become the nation's eighth largest industrial company when it added $1.1-billion in revenues. That is like creating another Coca-Cola or another Celanese in just one year. In Wall Street's assessment, IBM is now the most valuable corporation around. Early this week, IBM's common shares were worth $41.5-billion. The common shares of AT&T, with assets eight times larger, were worth $26.3-billion. The stock market appraises IBM stock as worth at least as much as the combined shares of 21 of the 30 companies that go to make up the Dow-Jones industrial average." "Where IBM looks for new growth," *Business Week*, June 15, 1968, 88.

25. Manley R. Irwin. 1967. The computer utility: Competition or regulation? *The Yale Law Journal* 76, 7, 1299–320; Robert M. Fano. 1967. The computer utility and the community. *IEEE, Int'l Conv Record* Part 12, 30–34; Paul Baran. 1967. The future computer utility. *The Public Interest*, Summer 1967, 75–87.

26. John L. Roy. 1970. The changing role of the service bureau. *Datamation*, March 1970, 52.

growing at 40% per year.[27] IBM, even though restricted as to how they could compete in the service bureau business by their 1956 Consent Decree with the Justice Department, ran two nationwide service bureaus.[28]

By the end of the 1960s, IBM dominated the mainframe industry, thanks to Watson Jr's entrepreneurialism, technologies fueled by defense funding, the flexible and modular architecture of the 360 line of computers, and an expert sales and marketing operation. But the increasing demand for time-sharing soon would create opportunities for competitors.

1.4 New Technologies for Computing

The shifting fortunes of the two dominant firms in the converging fields of communications and computing, AT&T and IBM, depended upon several factors, including the changing regulatory environment and the decisions of key executives to risk pursuing new opportunities. At the same time, the story of data communications in the decades between World War II and the late 1960s is in large part the story of technological innovation. During this period, new developments in computer technology, and the resulting decrease in the cost of computing, changed the landscape of possibilities for a growing number of institutional and commercial customers and the existing companies and many entrepreneurial start-ups that served them.

1.4.1 Transistors

The transistor was the first of three technological discontinuities to radically alter the computer market-structure, the other two being the integrated circuit and the microprocessor. Transistors became an alternative to vacuum tubes, which were large, costly, unreliable, and consumed large amounts of energy. Although functionally equivalent to vacuum tubes, transistors had profound technological differences from vacuum tubes: where tubes worked by electrons flowing through voltage gradient, transistors channeled electrons through semiconductor materials.

27. Gilbert Burck. 1968. The computer industry 's great expectations. *Fortune*, August 1968, 142

28. Irwin noted: "These new developments in technology and services raise the question, once again, of the status of IBM's consent decree. Does time sharing merely permit IBM to sell computer time over telephone lines, or is IBM processing customer data for a fee? What is legitimate activity for IBM as a manufacturer and IBM as a service bureau? The answers to these questions are not clear, but as if to hedge its short term anti-trust bet, both the Service Bureau Corporation and IBM, the parent corporation, have recently introduced nationwide systems of time-shared computer centers. In the long run, however, IBM many find it necessary to convince the Justice Department that new technology has invalidated major premises of its 1956 judgment." Irwin. The computer utility: Competition or regulation. *Yale Law Journal*, 1299.

Table 1.1 **Government purchases of semiconductor devices 1955–1960**

	Total Semiconductor Shipments ($ millions)	Shipments to Federal Government ($ millions)	Government Share of Total Shipments (percent)
1955	40	15	38
1956	90	32	36
1957	151	54	36
1958	210	81	39
1959	396	180	45
1960	542	258	48

Source: Richard R. Nelson, Government and Technical Progress: A Cross-Industry Analysis (Pergamon Press, 1982), 60. Used with Permission.

During World War II, the US government significantly increased funding of semiconductor research at Bell Laboratories, universities, and industrial companies, and created the MIT Radiation Laboratory to coordinate the research. These investments bore fruit on December 23, 1947, when the first transistor was demonstrated at Bell Labs. Walter H. Brattain and John Bardeen demonstrated a crude, but working, amplifying transistor made from germanium and wires. Their demonstration motivated William B. Shockley to work out the seminal principle of a solid-state transistor over the following five weeks, which was announced publicly in early 1948. AT&T subsequently sought to disseminate knowledge of transistors widely through seminars and licensing agreements. Managers at AT&T and Bell Labs understood that they would not be able to keep the technology to themselves. Had they kept the transistor proprietary, then the subsequent growth in the semiconductor, and all related industries, would certainly have been very different.[29]

By 1952, Western Electric (and a few other firms) manufactured approximately 90,000 point-contact transistors, which were sold primarily to the military. Data from 1955 to 1960 clearly shows the importance of government purchases (see Table 1.1). Two important sources of demand were the early commitment of the Air Force to use semiconductors in the Minuteman Missile in 1958 and the growth of IBM. IBM was the largest customer of every semiconductor company due to their transition to transistorized computers such as STRETCH in the mid-1950s.

29. On Bell Labs, see, generally, John Gertner. 2013. *The Idea Factory: Bell Labs and the Great Age of American Innovation*. Penguin.

One of the first transistor computers, the Burroughs Atlas Mod 1-J1 Guidance Computer built for the Air Force, was operational in September 1957. IBM announced its 7070 transistorized computer in September 1958; RCA, the 501, in December 1958. The first available commercial transistor computer was the General Electric 210, delivered in June 1959.

The transistor, as a technological discontinuity, as the economist Joseph Schumpeter might describe it, would strike "not at the margins of the profits and the outputs of the existing firms, but at their foundations and their very lives."[30] Transistors made computers more reliable, faster, smaller, and consume less power and generate less heat. Once firms started making computers with transistors, they never again used vacuum tubes.

1.4.2 Integrated Circuits

Transistors represented a major improvement over vacuum tubes but were not without problems of their own. Transistors came packaged as one transistor per each small "pot." The pots were much smaller than vacuum tubes, hence more devices could be squeezed into the same space. But as the desired complexity of device interconnections kept growing, wiring all these small devices became an interconnection nightmare, and very costly. From the years 1952–1959, firms and governments around the world searched for an answer to the problem of interconnections. Two companies—Texas Instruments (TI) and Fairchild Semiconductor—played the most significant roles in solving this problem.

In 1958, TI made the propitious decision to hire Jack Kilby. Within two months, he conceived of the solution to the problem of interconnecting large numbers of transistors and other components. Kilby's idea would come to be known as the "Monolithic Idea," where a single *monolithic* block of semiconductor material would contain all components and interconnections. Kilby hand-fabricated a monolithic, *integrated* circuit in September 1958, and TI filed for a patent in February 1959. But Kilby was not alone: another team of scientists, also with roots at Bell Labs, was likewise achieving impressive results with silicon.

In early 1956, William Shockley left Bell Labs to start Shockley Transistor Laboratories in Palo Alto, CA—located in the future Silicon Valley. Shockley recruited people who would become legends in the history of semiconductors, including Robert Noyce, Gordon Moore, and Jean Hoerni, to join his firm. But Shockley was no executive. Eight of his recruits were terribly dissatisfied, and made it known they would

30. Joseph A. Schumpeter. 1942. *Capitalism, Socialism and Democracy*. Harper & Brothers, 84.

prefer a new home. Instead of moving to an established firm, the "traitorous eight" raised venture capital and founded Fairchild Semiconductor Corporation in early 1957. Noyce is considered the father of the integrated circuit because he not only conceived of the Monolithic Idea, as had Kilby, but also its means of manufacture—the planar process. Fairchild's patent was filed in July 1959. The problem of interconnecting transistors had been solved. Ever since, the path of innovation has been to make device and interconnection features smaller, and the resultant integrated circuit, or chip, bigger.

The integrated circuit was not an overnight success for one simple reason: they cost too much to make. Development of the integrated circuit soon received a boost in May 1961, when President John F. Kennedy challenged the imagination of the American public to put a man on the moon. To do so would require the use of integrated circuits. Through 1964, purchases of integrated circuits for the Apollo Guidance Computer, used in the Apollo spacecraft modules, and the Air Force Minuteman guidance computer drove the market for integrated circuits (see Table 1.2). Once again, government support proved essential to market lift-off.

Even though the government had committed two critical programs to integrated circuits, into 1963 there remained sharp debate as to whether integrated circuits were the ultimate solution. But by then the costs of manufacturing integrated circuits were in steep decline due to the volume purchases by the government, and any doubt as to their reliability was dispelled.

A new computer start-up, Scientific Data Systems, founded in 1961 by Max Palevsky, was the first to introduce a computer using integrated circuits. The SDS

Table 1.2 **Government purchase of integrated circuits, 1962–1968**

	Total Integrated Circuit Shipments ($ millions)	Shipments to Federal Government ($ millions)	Government Share of Total Shipments (percent)
1962	4	4	100
1963	16	15	94
1964	41	35	85
1965	79	57	72
1966	148	78	53
1967	228	98	43
1968	312	115	37

Source: Richard R. Nelson. *Government and Technical Progress: A Cross-Industry Analysis*, 63. Used with permission.

92 shipped in 1964; IBM did not ship a computer using integrated circuits until 1969.

1.4.3 Modems

The SAGE system described above was the source of several landmark innovations in the history of computing, including advancements in memory; novel input/output devices such as cathode ray terminals and light pens; and a systems approach to the coordination of thousands of engineers, programmers, and managers. But for the purposes of our focus on data communications, the innovations that supported its data communication capabilities stand out above the rest—specifically, the invention of the modem.

By 1955, SAGE consisted of two Q7 computers residing at each of 23 direction centers across the United States. These direction centers were in turn connected to radar sites across northern Canada and to the airfields and missile sites in the US. AT&T was contracted to design and build the telephone line network as well as the instrument to convert the digital signals to analog for transmission and then back to digital for the computers. AT&T Bell Labs worked with the Cambridge Research Laboratory of the Air Force to create the radar data processing and transmission equipment for the SAGE system. The first modems emerged from this collaboration. These modems transmitted data from remote radar sites in Canada to IBM 790 computers in the United States. A paper, "Transmission of digital information over telephone circuits," describing this first modem implementation was published in the *Bell System Technical Journal* in 1955. The name modem comes from its function: *mod*ulating, or suppressing, information onto a telephone line, and then *dem*odulating, or recovering, the modulated information from the line. The design objective is to accurately transmit as many 0's and 1's as possible in a fixed period of time. Since each 0 or 1 is a bit, the convention is to rate modems by how many bits per second (bps) they transmit. The faster the modem, the more challenging it is to engineer.

By the time the SAGE system was completed, AT&T built and installed well over two hundred SAGE modems. In addition, AT&T then redesigned the modem and began selling commercial modems in 1958, beginning with the Bell Data Set 101 that transmitted at the "blazing" speed of 110bps. This formally marked the beginning of the Data Communication market-structure (see Figure 1.3).

1.4.4 Mainframes and Modems

The mainframe era of computing refers to the 1950s, when IBM and its competitors produced systems like the IBM 700/7000 series that suited the highly centralized

Figure 1.3 Bell 101 modem, 1958. Source: Image courtesy AT&T Archives and History Center.

corporations of the day.[31] The mainframe era has clear roots in the technologies and architecture of SAGE. The mainframe architecture featured one big computer, the Host computer that sat in a raised-floor, air-conditioned, often high-security room. Terminals, printers, and other peripherals were directly wired to the Host computer in essentially a star configuration. The host, or Big Blue, was thought the "boss" and all other devices were "slaves."[32] This centralized architecture was perpetuated by IBM and gave a great deal of power to their corporate clients, the Data Processing or Management Information System departments.

At first, all the slave devices were local, but following the success of the IBM System/360 corporations wanted to locate terminals and printers at remote locations. To do so required sending the bits over the analog circuits of the telephone network. That drove the need for modems of higher speeds (bps). Modems and multiplexers—products that enable more than one computer device to share a telephone circuit—were the products of the first wave of computer communications: data communications. Modems and multiplexers were highly co-evolving technologies, yet only a handful of firms mastered both.

1.4.4.1 Time-sharing

Time-sharing as an idea first surfaced in the late 1950s. Frustrated with the time-consuming method of batch processing, where jobs were created on punch cards and delivered to a computer operator who would run the job later, scientists and computer programmers sought ways to interact directly with the computer. In 1959, Christopher Strachey, a British mathematician, gave the first public paper on time-sharing at a UNESCO congress; and, working independently, Professor John McCarthy distributed an internal memo about time-sharing at MIT. Under the leadership of Professor F.J. Corbato, time-sharing was first demonstrated at the MIT Computational Center in November 1961.

Time-sharing might have lingered there were it not for the visionary leadership of Dr. J.C.R. Licklider and his license to invest government funds. In October 1962, Dr. Licklider became the first director of the newly created Information Processing Techniques Office (IPTO) of the Advanced Research Projects Agency. His charge

31. The market-structure of first-generation mainframe computers (1950–1959) consisted of only seven companies and 31 computer models. Other companies developed computers but they did not sell them commercially. Research and development funding came almost entirely from the U.S. Government. Although a commercial computer market existed, it was far from clear what its economic potential might be.

32. For recent discussions around eliminating the once-conventional "master/slave" terminology, see Elizabeth Landau. 2020. Tech confronts its use of the labels 'master' and 'slave.' *Wired* July 6, 2020, https://www.wired.com/story/tech-confronts-use-labels-master-slave/.

was to invest in advancing information technologies. Based on his experiences at MIT Lincoln Labs and Bolt, Beranek & Newman, and his vision of man–machine interactions, too briefly summarized as interactivity, he prioritized funding to time-sharing projects. And if projects didn't exist, he created them. For example, at MIT he helped create Project MAC (for machine-aided cognition or multiple-access computer) under the leadership of Professor Robert M. Fano, and approved $3 million a year in funding for the project. It would become the most influential effort in time-sharing. In 1967, IPTO funding to over a dozen time-sharing projects, at both universities and research organizations, exceeded an estimated $12 million.

Time-sharing required new software and hardware, as well as the most challenging innovation—an operating system that could support many simultaneous users and create the illusion that each user had exclusive control of the computer. The speed of the computer made this sleight of hand possible: if the computer could switch back and forth between programs fast enough, users perceived that they had both real-time and on-line performance. This experience was simply impossible in operating systems designed to process programs in batch fashion.

The first computer company to embrace time-sharing was General Electric (GE). In May 1964, a GE computer was used in a time-sharing demonstration at Dartmouth College. That summer, GE announced its 600 series computers would all support time-sharing, using software developed at Dartmouth. And that fall, MIT surprised everyone when it announced it would buy a GE computer for use as the main computer for Project MAC. IBM, which had abandoned internal efforts to develop a time-sharing system and did not support time-sharing in its initial releases of System/360, had jeopardized its valuable connection to MIT. Support for time-sharing was added when IBM released the TSS/360 time-sharing operating system for the 360 model 67 released in 1967 and later the System/370 announced in 1970.

As time-sharing spread, so did the demand for the required communications hardware, such as modems, multiplexers, and communications processors to transmit data between terminals and mainframes.

1.4.4.2 Minicomputers

The roots of minicomputers can also be found in the SAGE Project. In 1953, Kenneth Olsen, a recent graduate of MIT and one of 400 engineers hired to staff the SAGE Project, was reassigned to work as a liaison to IBM, the firm contracted to manufacture the SAGE computers. When it was time for a new assignment, Olsen went to work for an advanced engineering group at MIT Lincoln Labs led by Wes Clark. Clark had approval to build a transistorized computer, the TX-2. The contrast between the working environments of IBM, where development was slow and subject to heavy bureaucracy, and the lively pace of research and collaboration at Lincoln Labs, made a lasting impression on the young Olsen, who was inspired to recreate the research lab culture in his own business. In early 1957, Olsen left MIT to test his entrepreneurial skills and, together with Harlan Anderson, and supported by venture capital from American Research & Development, they founded Digital Equipment Corporation (DEC) in August 1957. Their first product, the PDP-1, released in 1959, borrowed significantly from the TX-2. In the fall of 1965, DEC introduced the first commercially successful minicomputer: the PDP-8. In 1966, DEC went public with a valuation of $77 million, 770 times its founding valuation. In the few years that followed, venture capital investors eager to discover the next DEC funded an explosion in the number of minicomputers.

It was not until DEC introduced their PDP-8 that businesses began to use the minicomputer as a smaller version of a mainframe computer. For smaller companies, minicomputers would soon occupy the central role that mainframes occupied. They were the repository of all the accounting and operational data and enabled printing of timely reports. Eventually, they performed the same role with manufacturing data, such as inventory levels and purchasing information on vendors and orders outstanding. The next stage was integrating all the manufacturing data and information into what became known as MRP systems (initially Material Requirements Planning and later, as the software became more inclusive and sophisticated, Manufacturing Resource Planning). It took roughly a decade for third-party software vendors to emerge and create, sell, and support software that even the minicomputer companies had a hard time creating. In the interlude, minicomputer companies found a welcome home focusing on the fast-growing data communication market, providing statistical and time division multiplexing functions, acting as communication processors, or becoming a building block of private networks.

Minicomputers were also used as time-sharing computers. DEC's first computer to support time-sharing was the PDP-6, released in 1964. The DEC time-sharing operating system TSS/8, which ran on the PDP-8, was released in 1968. Later in the mid-1970s, Hewlett-Packard introduced their HP 3000, another popular minicomputer that supported time-sharing.

1.5 Venture Capital and Public Capital Markets

The success of an entrepreneurial endeavor often hinges on the availability of capital needed to fund the proposed business idea. Traditional sources of start-up funding came from institutional loans and wealthy families, but in the late 1960s venture capital partnerships were beginning to emerge as an alternative source of risk capital for early-stage start-ups.

The modern venture capital industry is generally considered to have begun with the founding of American Research and Development Corporation (ARD) in 1946 by Georges Doriot, a former dean of the Harvard Business School who many consider the "father of venture capitalism," with Ralph Flanders and Karl Compton (a former president MIT) and other distinguished leaders from the Boston area. ARD is considered the first major venture capital success story with its initial investment of $70,000 into the founding of DEC for 70% of the ownership in 1957. DEC's initial public offering in August 1966 was considered a "wild" success story, valuing DEC at $8.25 million.[33] The success of ARD's "long-tail" investment strategy, in which one or a few high performing outliers in the "long-tail" of the distribution curve increased fund returns significantly, proved the viability of a well-managed portfolio of early-stage equity investments.

Another important influence in the development of the modern venture capital industry came in the form of government policy, when in July 1958 President Dwight D. Eisenhower signed into law the Small Business Investment Act. The act licensed private, Small Business Investment Companies (SBICs), and made available Small Business Administration loans to leverage a company's pool of capital by up to 4 dollars for every 1 dollar of private investment. More than 500 SBIC licenses were issued by the end of 1961.[34] The majority of SBICs invested in debt financing or real estate, but many invested in private companies, including the growing number of semiconductor manufacturers and other technology start-ups that were founded in the 1960s. Prominent SBICs that made investments in early technology start-ups included Continental Capital Corporation, founded in 1959 by Frank Chambers, and Boston Capital Corporation, founded in 1960, the largest SBIC at the time, with an investment pool (including government loans) of about $100 million ($810 million in current dollars).[35] Some notable companies that received SBIC funding included American Microsystems Inc., Intel, and ROLM. The growth in private investment companies as a result of the SBIC Act helped many young investment professionals gain experience and capital, inspiring several to form new venture partnerships. William Draper, III, and "Pitch" Johnson formed their SBIC, Draper & Johnson, and went on to build successful venture partnerships Sutter Hill and Asset Management Company.

The 1960s saw the formation of influential venture partnerships such as Greylock Partners, founded in 1965 by former ARD vice president William Elfers, and

33. "Digital equipment markets its shares," *New York Times*, August 19, 1966, 42.

34. John W. Wilson. 1985. *The New Venturers—Inside the High-Stakes World of Venture Capital*. Addison-Wesley, 21.

35. Tom Nicholas. 2019. *VC: An American History*. Harvard University Press, 136–140.

Venrock Associates, by Laurance Rockefeller in 1969, both prominent East Coast examples, while on the West Coast Draper, Gaither & Anderson was the first limited partnership, started in 1959. One of the most successful venture capitalists in the early tech industry was Arthur Rock. Rock and Tommy Davis started their limited partnership Davis & Rock in 1961. Rock's investments in Scientific Data Systems, Fairchild Semiconductor, and later Intel were among the legendary investments of early Silicon Valley history.

The sustained growth economy of the United States that began in the early 1950s had neither the breadth nor legs to support the policies and actions of the Federal Government during the 1960s. The simultaneous spending on both "guns and butter"—the Vietnam War and the "Great Society"—forced the government to issue excess money. Perceived by a growing number of professional fund managers as a certain prescription for inflation, they sought new ways to increase their investment returns to offset the erosive potential of inflation.[36] Seeking higher returns than could be earned by investing in bonds, the fund managers began investing in stocks, and were amply rewarded on January 10, 1967. On that day, following President Lyndon B. Johnson's State of the Union address, buying stocks for their growth potential turned into a stampede when the third largest volume of shares at that time were traded on the NYSE. A two-year bull market ensued. The most desired stocks were the "glamour" stocks or "Houdini issues": IBM, Xerox, Polaroid, and Kodak.[37] Stock prices traded as high as fifty times next year's projected earnings.

Investor appetite and willingness to pay high prices for technology companies induced private technology companies to go public in order to raise always-needed cash and create desired liquidity for shareholders. Computer leasing companies proved an immediate favorite. By June/July 1967, investor actions resembled a "speculative orgy" according to *Business Week* with the AMEX up 50%. By August it would be up 70%. It seemed as if all a company had to do was embed "tronics" in its name, and it became a "high-flyer." The markets peaked in September 1967, then regained momentum in the spring of 1968, opening another market window for technology companies, especially those that were computer related.[38]

The "hot" market for technology stocks induced the transformation of venture capital from largely an activity of wealthy families to one of professionally managed fund partnerships like ARD. Investors, having made money on their private investments that went public, wanted to reinvest their capital gains in other new, private technology companies. The goal was to achieve 10 to 20 times their investment

36. "The market warms up," *Business Week*, January 21, 1967, 25.

37. "Pension advisors play it cool," *Business Week*, April 1, 1967, 116.

38. "Speculative spree alarms AMEX," *Business Week*, July 15, 1967, 36.

in three to five years. A new breed of venture fund managers emerged in response. Unprecedented sums of money began flowing into venture capital. By 1970, the first year for which records were kept, $83 million was invested, up from $10 million (by estimate of the authors) in 1966.

1.6 The Early Entrepreneurs of Data Communications

Entrepreneurs have always played valued roles in human societies. Why? Because societies have always confronted problems, and curious individuals enjoy the challenge of solving them. But to be successful, entrepreneurs must have more than curiosity; they must possess the unique combination of vision and leadership. They must envision a new way of doing things and be capable of attracting others to help them achieve that vision. Very few entrepreneurs have all of the resources at their disposal to solve their problems of choice—so the help of others is essential. Beyond the initial idea for a business, the entrepreneur or co-founders need to build a team, raise the necessary capital to develop the technical product, and build a successful model for generating business revenue.

As important as the vision and leadership of individual entrepreneurs is the environment in which they act. The massive government investment in technology following World War II resulted in an unprecedented scale of technological innovation and created the building blocks for many of the entrepreneurial innovations of the emerging information economy. When combined with changes in regulatory policy favoring competition and the growth in the availability of venture capital, the time was ripe for those with entrepreneurial aspirations. The pioneers in the early evolution of computer communications paved the way for the flourishing entrepreneurial culture of the late 1960s, 1970s, and 1980s. The work of Thomas Carter, William Shockley, Kenneth Olsen, and many others of this time marked the first wave in the explosion of new products, new methods of production, and the formation of new industries.

1.6.1 Codex

Entrepreneurship does not always begin with a grand vision of the future. Sometimes the motivation can simply be a desire to do what one enjoys most, to escape an unpleasant work environment, or being forced to try something different. Such was the case for Jim Cryer and Arthur Kohlenberg in 1962 when their employer, Melpar Electronics, informed them that they were closing the advanced research laboratory they had been running as director and chief scientist, respectively. Even though offered the option to move to Virginia, both men had little desire to leave the Boston area. They believed that on their own they could win technology development contracts being let by government agencies. So they incorporated a new company, Codex, and joined thousands of other companies swept up in the federal government's funding of technological innovation that included large defense projects following SAGE, and newer ones like NASA's Apollo project.

Cryer and Kohlenberg knew just such an opportunity: the Air Force wanted better error-correcting codes for digital transmission over telephone lines. They also knew that Robert Gallager, then a young professor at MIT, and his graduate student, Jim Massey, had developed new error-correcting techniques, thought a sure bet to secure a development contract. Their instincts were right. Soon they had a contract to develop exotic error-correcting codes for the Air Force's Ballistic Missile Early Warning System, the successor to SAGE. Error-correcting codes were needed to restore the lost data. Better codes required more of the total capacity of the communication lines, or bandwidth, leaving less bandwidth for radar data. More powerful codes also required faster modems.

Even before taking possession of their first AT&T modems in the 1950s, the Air Force wanted faster ones. The need for speed came from wanting to create and maintain a worldwide command and control system for air defense. Brigadier General H.R. Johnson, Director of Point-to-Point Planning for Headquarters Airways and Air Force Communications Systems (AFCS), USAF, from 1950 to 1955, remembers a senior member of his technical staff, Bill Pugh, calculating: "a suitable goal would be 10,000bps in a voice band" for modems. That goal was then set forth in 1956 in: "the proposed General Operational Requirement that AFCS sent to the Air Force, which subsequently became the research document for the Air Force Communications System."[39] Yet a decade later, reliable modems operating at that speed remained an elusive goal.

Such was the background in 1966 when Cryer and Kohlenberg began taking seriously the idea of Codex developing a leased-line modem to sell to the Air Force. That they knew the Air Force yearned for higher speed modems for their air defense system made the opportunity seem a sure bet. But there was a problem: up to that point Cryer and Kohlenberg had little experience, or for that matter any real interest, in selling products. Their competence lay in solving difficult technical problems, not in managing what they imagined as the boring business of stamping out the same products, day-in, day-out. The very prospect demeaned Codex's proud corporate ethos of: "if not technically challenging, it was not worth doing."[40]

39. Harold Richard Johnson, oral history interview by James L. Pelkey, May 3, 1988, Cupertino, CA. Computer History Museum, Mountain View, CA. Available from https://archive.computerhistory.org/resources/access/text/2016/04/102738128-05-01-acc.pdf.

40. Art Carr, interview by James L. Pelkey, April 6, 1988, Newton, MA. Computer History Museum, Mountain View, CA. Available from https://archive.computerhistory.org/resources/access/text/2015/10/102737982-05-01-acc.pdf.

Even so, Cryer and Kohlenberg worried about Codex's dependence on the feast-or-famine nature of government contracts, when sales could be $1 million one year and nothing the next. Selling a product, such as modems, did have prospective advantages.

In discussing the subject with MIT's Gallagher, Cryer and Kohlenberg learned that a high-speed 9,600bps modem—four times faster than the fastest commercial modem then available from AT&T—was possible. Wanting to know how, they pressed him further. Gallagher then told them about Jerry Holsinger, a 1965 MIT Ph.D. graduate whose thesis had been on high-speed data transmission over telephone lines. He last heard Holsinger had left MIT Lincoln Labs and was employed by a small R&D shop on the West Coast named Defense Research Company. Intrigued, Cryer and Kohlenberg convinced themselves that a 9,600bps modem would give Codex the competitive edge and hopefully the financial security they needed to be successful while upholding their proud tradition of solving hard problems.

On meeting Holsinger in early 1967, Cryer and Kohlenberg discovered he had already formed a company, Teldata, and was soliciting investment from venture capitalists or anyone else who had money. Holsinger claimed he had a working prototype of a 9,600bps modem, one developed at Defense Research Corporation with funding from the NSA. He confided his original design had not worked on normal telephone lines, but he had perfected the design and had a working breadboard prototype. All he needed to do was convert his modem to printed circuit boards to have the world's first 9,600bps modem.

Holsinger thought of himself as an entrepreneur, not an employee working for a salary or as a research scientist, but he was having trouble convincing others that they should invest their money with him—not surprising given he lacked business experience and was only two years out of graduate school. Holsinger remembers how green he was: "If somebody like me were coming to me now, I would probably tell them the same thing. Go belly up to somebody." It didn't take long for him to realize: "it wasn't really what I wanted to do. I thought that I wanted to run a business, but it wasn't in the cards at that point, so I ultimately got together with Codex and they bought out the rights of the people on the West Coast, and they effectively got me and a production-prototype modem design in that process."[41]

Cryer and Kohlenberg persuaded Holsinger they were serious about building a modem business and, lacking an alternative, Holsinger agreed to sell Teldata to

41. Jerry L. Holsinger, oral history interview by James L. Pelkey, April 6, 1988, Westborough, MA. Computer History Museum, Mountain View, CA. Available from https://archive.computerhistory.org/resources/access/text/2016/04/102738129-05-01-acc.pdf.

Codex in May 1967. Codex acquired 82.36% of Teldata's shares for $94,000. Securing the technology for its first product accomplished, Codex engineers turned to the task of developing the actual product. As often is the case with cutting edge technologies, the process was fraught with challenges and setbacks.

1.6.2 Milgo

Codex embarked on its journey into modems by way of acquisition. Many other defense contractors and electronics companies, like Rixon Electronics, Collins Radio, and Stelma, began selling modems, like AT&T had, by using technology they developed for the government. The first independent company to really challenge AT&T, Milgo Electronics Corporation (Milgo), hired a talented individual, Sang Whang, and funded the project internally.

Monroe Miller and Lloyd Gordon, the "Mil" and "Go" of the name "Milgo," had served the defense agencies and NASA ever since founding their company in 1956. They, like Cryer and Kohlenberg, learned that NASA and military agencies wanted faster modems. In 1965, they hired Sang Whang out of Brooklyn Polytechnic Institute to develop a line of modems to sell to the Kennedy Space Center for downrange instrumentation. In 1967, Milgo introduced its commercial 2,400bps modem, the 4400/24PB. Edward Bleckner, head of Milgo's efforts to enter the modem business, hired an executive search firm to find a seasoned sales/marketing executive with modem experience. They luckily caught up with Matt Kinney on the telephone as he was stranded by a snowstorm at LaGuardia airport. He remembers: "They asked me if I'd like to come and talk to them about a job, and I said, 'Where are you?' They said, 'Miami, FL.' The answer: 'You bet your sweet life!'"[42]

In joining Milgo in January 1968, Kinney brought to Milgo needed experience in selling commercial data communication products and an understanding that significant changes might soon propel the demand for data communications; that is, if Tom Carter won his case against AT&T. Kinney remembers: "Tom Carter is one of my oldest and dearest friends. Hell, I knew in '66 that if Carter prevailed, which seemed highly unlikely at the time, that the industry would take off."[43]

Carter's chances depended entirely on the willingness of federal regulators to reexamine the fundamental assumptions upholding AT&T's monopoly.

42. Matt Kinney, oral history interview by James L. Pelkey, March 9, 198, Sunrise, FL. Computer History Museum, Mountain View, CA. Available from https://archive.computerhistory.org/resources/access/text/2017/10/102738573-05-01-acc.pdf.

43. Kinney interview, Computer History Museum.

1.6.3 Bernard Strassburg

In entrepreneurship, it is not only the case that the motivation needs be economic or defined by the starting of a company. Accordingly, our usage of the term comes from our recognition that entrepreneurs exist in all elements of society. To restate what we said in the Introduction, we follow Joseph Schumpeter's definition of entrepreneurship: "The typical entrepreneur is more self-centered than other types, because he relies less than they do on tradition and connection and because his characteristic task—theoretically as well as historically—consists precisely in breaking up old, and creating new, tradition." The last entrepreneur we will mention here is not an entrepreneur from the business sector, but one from the government regulatory sector who, nevertheless, acted with similar foresight and vision in relation to the emerging technologies of computer communications. The emergence of the new market-structure of data communications was fueled by technological innovation as well as acts of entrepreneurship from multiple individuals across multiple sectors. In an area that was heavily regulated, *policy* entrepreneurship was complementary to the efforts of entrepreneurs in companies such as Codex and Milgo—and, arguably, every bit as creative and significant.

Before 1965, Bernard Strassburg, Chairman of the CCB of the FCC, viewed the relationship between AT&T and the FCC as collaborative: "It was truly a symbiotic relationship. The regulated monopoly operated in what was considered to be the public interest and, in turn, was shielded against incursions by rivals and competitors, including the possibility of government ownership."[44]

By late 1966, however, Strassburg had radically rethought his view as he began to understand the importance of computers. Upon learning about developments in data communications in 1965, he recalled that he "assembled a task force, a small group of staff members to sort of take an overview of the various dimensions of data communications; what the problems seemed to be, if any, and what we should do about them."[45] Knowing he had to educate the Commissioners to the needs of computers, he also contacted the Institute of Electrical Engineers (IEEE) to give a series of lectures to the Commissioners. One of the lecturers was Paul Baran, who Strassburg knew, and as future chapters will make clear, was a dominant figure in the history of computer communications.

Strassburg's revised understanding of emerging computer technology was due in large measure to the research of economist Manley Irwin, who consulted with the FCC in 1966 and who was assigned to draft a speech Strassburg was scheduled

44. Henck and Strassburg, *A Slippery Slope*, xi.

45. Strassburg interview, Computer History Museum.

to make at American University on the subject of computers. Irwin's paper outlined the developing trend: computer technology required a method of sharing data over large distances, and the method in use at the time was via telephone lines and modems. In addition, AT&T employed an increasing amount of computer technology in their own operations, both for processing internal data and for switching in their telephone networks.

What Irwin saw was the coming convergence of the computer and communications industries. Strassburg realized the importance of Irwin's ideas and recognized that he would do well to get out in front of the potential for conflict between the two evolving industries.

Strassburg realized computer users would want to interconnect terminals and computers over the telephone network in ways certain to be resisted by AT&T. In a speech to an audience of computer professionals on October 20, 1966, he declared, "Few products of modern technology have as much potential for social, economic, and cultural benefit as does the multiple access computer."[46] One obstacle to this potential was economic—the problem of market entry: Who would be allowed to sell what products and services? Did AT&T have the right to monopolize products and services others wanted to sell? Strassburg was about to test the waters to see how serious the problem of convergence was. He remembers: "I decided that we ought to formalize this thing. We sensed enough ferment out there to say: 'Well, look we're going to encounter some problems here, and let's get on top of them sooner, rather than later, and for once let a regulatory agency be out in front, rather than trying to shovel up the mess that's left behind."[47]

Consequently, Strassburg and Irwin led the FCC in initiating a formal proceeding on November 9, 1966, when the FCC announced that CCB would hold a public inquiry titled: "Notice of Inquiry, In the Matter of Regulatory and Policy Problems Presented by the Interdependence of Computer and Communications Services and Facilities (Docket F.C.C. No. 16979)."[48] The Notice of Inquiry, also written by Irwin, read: "We are confronted with determining under what circumstances data processing, computer information, and message switching services, or any particular combination thereof—whether engaged in by established common carriers or

46. Strassburg, "The marriage of computers and communications."

47. Strassburg interview, Computer History Museum.

48. Strassburg remembered: "I decided that we ought to formalize this thing. We sensed enough ferment out there, or enough concern, to say: 'Well, look we're going to encounter some problems here, and let's get on top of them sooner, rather than later, and for once let a regulatory agency be out in front, rather than trying to shovel up the mess that's left behind." Strassburg interview, Computer History Museum.

other entities—are or should be subject to the provisions of the Communications Act."[49]

In anticipating the challenges brought on by the emerging field of data communications, Strassburg had acted, in fact, as an early entrepreneur of the same industry. His vision of the coming demand for new technologies and innovative ways of using existing technologies helped open areas of opportunity for many others.

1.7 Emergence of the Data Communications Market-Structure

The technologies and early products of data communications were well developed by the late 1960s and had formed the beginnings of a viable market, mainly to government agencies and institutions that leased private access to AT&T's telecommunications network. The entrepreneurs of the leading companies in the field, Codex and Milgo, both made the important decision to expand beyond their reliance on government contracts and to focus on developing and selling new products to commercial customers. The timing was important, for having the foresight to see the coming of deregulation their early moves in developing commercial products and establishing sales and distribution put them ahead of the pack when the rush to start companies began at the close of the decade.

1.8 In Perspective

There were multiple forces of dynamism in American communications and computing in the decades after World War II. Massive federal investments drove advancements in the technological underpinnings of electronics and computing. Individuals working in a number of different settings—established corporations like IBM and new companies like Codex and Milgo, and researchers at MIT and other universities—seized the moment to create new opportunities. Even in an industry that appeared to be stable, the telephone industry monopoly, the incumbent monopolist was under increased attack, forced to defend itself from antitrust officials, FCC regulators, and entrepreneurs who aspired to be AT&T's competitors.

The year 1968 was shaping up to be a very busy and potentially transforming year for the FCC and CCB. While FCC Examiner Naumowicz had issued his initial decision in August 1967 that the Carterfone did not pose a threat in connecting to the telephone system, the debate continued over the wider implications of allowing users permission to interface with AT&T's network. On the matter of MCI, after Scharfman's initial response in favor of approving MCI's license, the FCC, at the time operating with six commissioners after the retirement of commissioner

49. Computer I, Docket No. 16979, NOI 7 FCC 2d 19 (1967).

Loevinger, was split along party lines with the three Democrats in favor and the three Republicans against. Their final decision would not be made until after the politically auspicious appointment of commissioner Rex Lee by President Johnson, which was made in late 1968, before the election of Richard Nixon. By the end of 1967, Strassburg and the CCB had received responses to the Notice of Inquiry and, as we shall see in the following chapter, it was to be the tip of an iceberg heralding an unforeseen demand for communications technology.

In addition to the key events at the regulatory level, private firms like Codex and Milgo were poised to take advantage of a rush of new interest and investment in technology, giving rise to many garage tinkering start-ups as well as well-funded ones like Intel.