THE EMERGING AGE OF INFORMATION TECHNOLOGY

SCOPE OF FEDERAL R&D IMPACTS

1940 1950 1960 1970 1980 1990 2000 2010






KEY FIGURES (PHOTOS SELECTED ON BASIS OF AVAILABILITY)

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COMPUTERS

1 - 1890 Automated punch-card machine (H Hollerith) used in U.S. census; Hollerith's firm merges with others, becoming IBM in 1924

2 - 1942 Machines to decrypt German, Japanese codes (U.S. Navy Computing Machine Lab, NCR)
3 - 1944 Harvard Mark I; weighs 5 tons
4 - 1945 Electronic Numerical Integrator and Computer (ENIAC), (J Eckert, J Mauchley, U Penn); computes ballistic firing tables; 19,000 vacuum tubes

5 - 1950 Standards Eastern/Western Automatic Computers (SEAC, SWAC), electronic stored-program machines, built for DoD (National Bureau of Standards)
6 - 1951 Electronic Discrete Variable Automatic Calculator (EDVAC), stored-program unit (ENIAC team, J von Neumann) for Army ballistics calculations
7 - 1951 Whirlwind computer (MIT) for flight simulation. Vectorscope graphics display; random-access, magnetic-drum core memory
8 - 1951 Univac I (ENIAC developers, Remington Rand) delivered to Census Bureau
9 - 1952 IBM 701 (Defense Calculator)
10 - 1952 MANIAC I built at LANL
11 - 1954 IBM 650, for business use
12 - 1956 TX-0, first transistor-based computer (MIT)
13 - 1956 LARC (Sperry-Rand) for atomic research

14 - 1960s -> Time-shared systems R&D: virtual memory, sharable software, "fuzzy logic," spreadsheet prototype, word-processing, MULTICS OS (JR Licklider, others)
15 - 1964 CDC 6600 (S Cray, Control Data) begins supercomputing era with its speed, architecture
16 - 1964 -> IBM 360 series business systems
17 - 1965 Idea for notebook computer (A Kay, MIT)

18 - 1973 Prototype with mouse, GUI desktop, Ethernet (Xerox PARC)
19 - 1976 Cray-1 vector machine (133 Mflops) to LLNL
20 - 1976 Apple I sells as a kit
21 - 1977 Apple Computer Co (S Jobs, S Wozniak). Apple II with color graphics in stores
22 - 1977 Microsoft Corp (P Allen, B Gates)
23 - late 70s -> Rise of personal computer: MITS Altair, Radio Shack TRS-80, Commodore PET and -64, Digital Research CP/M, others

24 - 1981 IBM PC, with Microsoft disk operating system
25 - 1981 Xerox 8010 Star. "Desktop" GUI, mouse
26 - 1982 Silicon Graphics Inc (SGI). Specializes in RISC technologies for high-end graphics machines
27 - 1982 SUN Microsystems (for Stanford University Network) (Scott McNealy, Bill Joy, others)
28 - 1982 Cray X-MP, with multiprocessor architecture
29 - 1984 Apple Macintosh.
30 - mid-80s -> PC clones: Compaq, HP, Dell, etc.
31 - 1985 NSF university supercomputing centers
32 - 1985 First distributed-memory parallel platform (Intel). Developed for ORNL
33 - 1988 Cray Y-MP installed at NASA, LANL

34 - 1992 Multiprocessor Cray C90 hits 1 trillion flops
35 - 1994 First "Beowulf" cluster (D Becker, T Sterling,)
36 - 1994 DNA computing demonstrated (Adelman, USC)
37 - 1997 ASCI Red (Intel) delivered to SNL
38 - 1997 Linux cluster supercomputer (Linux NetworX) to BNL

39 - 2000 ASCI White (IBM SP Power3) at LLNL achieves 7.22 teraflops
40 - 2001 NSF Lemieux (Compaq) at Pittsburgh Supercomputing Center, fastest system for U.S. academic research, attains 6 teraflops
41 - 2002 -> NSF Distributed Teroscale Facility initiative develops world's first multi-site terascale system

SOFTWARE

1 - 1940s First ENIAC instructions typed manually by 100 Navy women in war effort
2 - 1940s -> Physics, mathematics of signal processing - basis for advances in cryptography, telecommunications, image processing, spoken-language technologies
3 - 1946 Monte Carlo computational estimation method (S Ulam, J von Neumann)

4 - 1951 A-0 compiler translates machine language into higher-order code (Grace M. Hopper)
5 - 1958 Formula Translation (Fortran), first high-level programming language (John Backus, IBM)

6 - 1963 Complementory metal oxide semiconductor (CMOS) (Frank Wanless, Fairchild)
7 - 1964 Mouse, graphical user interface (GUI) (D Engelbart, Stanford)
8 - 1964 -> Moore's Law (G Moore, Fairchild)
9 - 1966 Dynamic Random Access Memory (DRAM)
10 - 1967 Floppy disk, read-write drive (A Shugart, IBM)
11 - 1967 Head-mounted display, precursor of virtual reality (VR) technologies (I Sutherland, Harvard)

11 - 1970 Relational database concept (E Codd, IBM)
12 - 1970s -> Computational complexity R&D (machine states, algorithms for structured programming, formal verification, cryptography)
13 - 1970s -> Spoken-language R&D
14 - 1970s Visualization innovations; WYSIWYG (C Simonyi)
15 - 1972 C language (D Ritchie, Bell Labs)
16 - mid-70s Prototype relational databases
17 - 1976-78 Public-key cryptography techniques

18 - 1983 GNU (for GNU's Not Unix) project (R Stallman, MIT) promotes "open-source," freely shared software
19 - 1985 Microsoft Windows 1.0
20 - mid-80s -> Software engineering metrics R&D
21 - late-80s -> Advanced discovery, data mining R&D

22 - 1991 Linux OS (Linus Torvalds, Finnish student)
23 - 1990s -> Software for embedded systems
24 - 1990s -> Digital library technologies
25 - 1990s -> Machine learning, intelligent systems R&D
26 - 1993 Mosaic Web browser (U Illinois students)
27 - 1994 Java language (Bill Joy, Sun)
28 - 1994 Netscape (Mosaic developers) free software
29 - 1995 -> Globus software for grid computing
30 - 1996 Google search engine (Page, Brin, Stanford)

COMPONENTS

1 - 1947 Transistor (J Bardeen, W Brattain, W Shockley, Bell Labs) - enables compact, solid-state computer circuitry to replace huge arrays of vacuum tubes
2 - late 40s Core memory (J Forrester, MIT)

1 - 1954 Microwave Amplification by Stimulated Emission of Radiation (MASER) (C Townes, Columbia)
4 - 1956 Magnetic hard disk technology (IBM)
5 - 1958 Integrated circuit (J Kilby, Texas Instruments, and R Noyce with G Moore, Fairchild Semiconductor)

2 - 1960 Packet-switching principle (P Baran, Rand)
3 - 1967 Concept of decentralized computer network
4 - 1969 DoD commissions ARPAnet for research

5 - 1972 Ethernet (R Metcalfe, Xerox PARC)
6 - 1973 Transmission Control Protocol (TCP) and Internet Protocol (IP) (V Cerf, Stanford, R Kahn)
7 - 1975 MFEnet, HEPnet (DOE) and NSFnet launched

8 - 1983 U.S. networks adopt TCP/IP standard
9 - 1986 NSF takes over ARPAnet; networks link in Internet
10 - 1986 Internet Domain Name System (DNS, such as .com, .org, .edu) developed (P Mockapetris, USC)
11 - 1989 World Wide Web (T Berners-Lee, [CERN]); concepts include URL, HTML, and HTTP

12 - early 90s -> Optical switches, routers, multiplexing
13 - early 90s Asynchronous transfer mode (ATM)
14 - 1992 First multicast backbone (Mbone) audio/video
15 - 1994 -> IPv6 design for billions of Net addresses
16 - mid-90's Grid computing concepts
17 - 1995 LDAP network directory protocol (U Michigan)
18 - 1999 First end-to-end all-optical network. Transmission speeds above 1 gigibit p/s (NGI)
19 - 1999 -> Hardware and software technologies for real-time, multimedia collaboration across networks

NETWORKS

1 - 1957 -> Semi-Automatic Ground Environment (SAGE). First large-scale IT communications network. Whirlwind platforms linked to remote radars in North American Air Defense System. Innovations: modems, digital phone-line transmission, system duplexing, software for real-time operations; cathode-ray tube (CRT) screen

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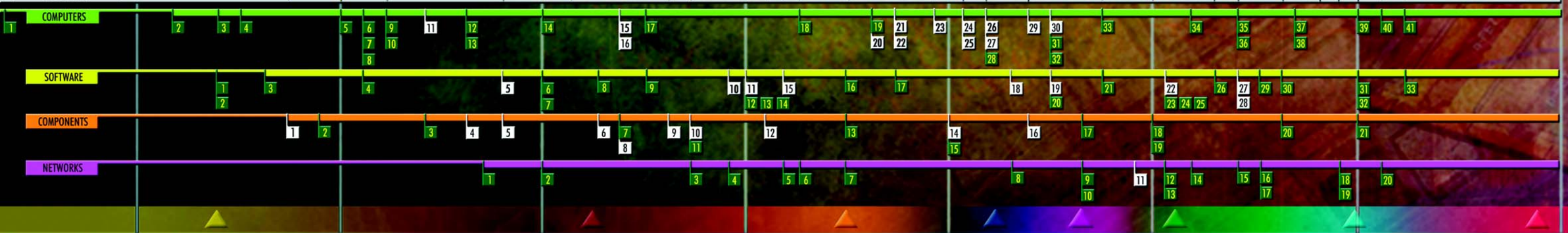
4 - 1982 Computer: TIME Man of the Year
5 - 1984 U.S. households with computer 8.2%; "cyberspace" used in novel Neuromancer
6 - late 80s 48-hr weather forecast run on Cray 1-MPP in 30 seconds
7 - 1990 Integrated avionics systems
8 - 1993 22.8% U.S. households with computer
9 - 1994 Toystory, first totally computer-generated movie
10 - 1996 Real-time NYSE stock quotes
11 - 1998 HDTV
12 - Late 90s Pervasive embedded processors
13 - 2000 51% U.S. households w/ computer
14 - 2001 DoD *smart cards* for ID
15 - 2002 NOAA issues <4000 U.S. forecasts per day
16 - 1 billion microprocessors sold worldwide

Color Code:
Text beneath upper color bars represents the timeline for that specific category.
The 'impact' arrows and the numbered boxes below the impact timeline are color coded to the column text, yellow text is Federally funded research and development, white boxes and arrows are funded by private sector.

IMPACT

Late 40s NMR spectroscopy
1950 First 24-hour forecast
1952 Univac I predicts election
1958 IT-based avionics
1958 First computer-controlled missile launch
1960 First satellite weather image
1962 Telstar I satellite
1966 First global climate model
1967 First real-time flight simulator
1967 Internet paper/maker
1970 Federated avionics software
1971 Magnetic stripe; NASDAQ
1971 digital market; barcode
1972 Pioneer 10 Spacecraft
Pong computer game; computed tomography
1973 MRI
Mid-70s Simulated crash testing
Mid-70s Automated air traffic control system
1979 Visicalc
1980s Integrated aircraft information systems



Rise of Information Technologies:

Computing Machines — WWII needs: ballistics, cryptography, flight simulation, nuclear physics

Operating Systems — Multiple operations with less human involvement

Connected Systems — Multiple users with terminals share time on system

Workstations — Powerful systems for single users Professional/ technical software applications

Personal Computers — Commodity computing systems Word processing

Networks of Computers — Local Area Networks (LAN) Wide Area Networks (WAN) Internet

Wireless Networking — Networking extended to wireless mobile, embedded devices and systems

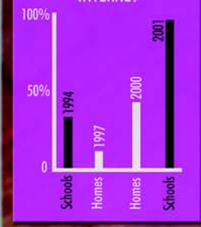
Convergence of Technologies — Systems of systems, digital society

LEGEND

- Federally funded
- Funded by private sector
- 33 - Federally funded
- 20 - Funded by private sector
- -> - Ongoing over time

NUMBER OF COMPUTERS IN USE (in millions)

PERCENTAGE OF HOMES/SCHOOLS WITH INTERNET



DIGITAL INFORMATION UNITS

Bit	A binary digit (0 or 1)
Byte	8 bits
Kilobyte	1000 bytes
Megabyte	1,000,000 bytes
Gigabyte	1,000,000,000 bytes
Terabyte	1,000,000,000,000 bytes
Petabyte	1,000,000,000,000,000 bytes
Exabyte	1,000,000,000,000,000,000 bytes
Zettabyte	1,000,000,000,000,000,000,000 bytes
Yottabyte	1,000,000,000,000,000,000,000,000 bytes

NITRD

THE EMERGING AGE OF INFORMATION TECHNOLOGY: SCOPE OF FEDERAL R&D IMPACTS

The graphic timeline at left (please fold out front cover) provides an overview of the role of Federally funded research in the history of information technologies in the United States. The timeline's aim is to show the developing outlines of the digital revolution and some societal indicators of technological transformation. It is not intended to be comprehensive.

Reading the timeline

Four information technology areas are highlighted by color (computers, software, components, and networks). Numbered descriptions of developments in each IT area, by decade, run across the top, with Federally funded activities in yellow. Below, corresponding timelines for each area show the sequence of these developments. Arrows indicate impact milestones.

Selected sources: Federal agencies and laboratories; IT industry Web sites; *Funding a Revolution,* National Research Council, National Academy Press, Washington, D.C., 1999; Computer History Museum; Greatest Engineering Feats of the 20th Century, National Academy of Engineering; History of Computing Project; IEEE History Center; History of Computing, J.A.N. Lee, former editor, IEEE Annals of the History of Computing; History in the Computing Curriculum, Association for Computing Machinery (ACM); Chronology of Personal Computers, Ken Polsson; Common Gateway Interface (CGI) Historical Timeline, Wayne E. Carlson.

Disclaimer: Dates given for key developments often vary among IT histories. The variations typically do not change the broad direction of advances. Nonetheless, the editors regret any inadvertent errors in this timeline.

Networking and Information Technology Research and Development

Advanced Foundations for American Innovation

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A Report by the Interagency Working Group on Information Technology Research and Development

Committee on Technology
National Science and Technology Council

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