38 IDEAS AND INVENTIONS THAT SHAPED INFORMATION TECHNOLOGY AS WE KNOW IT TODAY

Note: This table does not show *enabling* or *supporting* discoveries, inventions, and developments – such as electricity, magnetism, electromagnetism, electrons, x-rays, machine tools, vacuum tubes, cathode ray tubes, semiconductors, transistors, integrated circuits, lasers, and so on – which underlie other technologies besides information technology. Also, it does not show interesting developments that dead-ended (such as the Dimond Ring programmable read-only memory, which is spelled without an 'a', and was invented by Thomas Dimond who probably spent his entire career at Bell Labs trying to design something round with a hole it in, so that his name would be remembered and misspelled for years to come).

Idea/Invention					First Practical Implementation	
	Name	**Originator/Inventor**	**Date**	**Description of Core Concept**	**Date**	**Details**
1	**Digital computer**	Charles Babbage	1822	The idea that a range of complex computations could be performed by a machine (the "Difference Engine").	[1943]	Not completed in Babbage's lifetime. See (8) below.
2	**Programmable computer** (using a program fed into the computer while it operates)	Charles Babbage	1834	The idea that a general-purpose computer could be built that would perform any one of wide range of computations based on a program of instructions fed into the machine while it operates (the "Analytical Engine").	[1943]	Not completed in Babbage's lifetime. See (8) below.
3	**Electrical digital communication**	Samuel Morse	1832	The idea that the written word could be communicated in digital form over long distances by *electrical* means. (The idea of non-electrical digital communication, using smoke signals or semaphore, pre-dated the telegraph by many centuries.)	1837	Wheatstone and Cooke's pilot "Electric Telegraph" link with the associated "Morse Code", developed by Vail (see below). Note that digital communication pre-dated analog electrical communication, such as the telephone (1876), by almost four decades.
4	**Data compression**	Alfred Vail	1837	The idea that the different frequencies of use of different letters and symbols in written language could be exploited in the digital encoding process to minimize the total number of symbols needed to encode a passage of text – in effect, exploiting redundancy in the original data. (The final version of "Morse Code" used character signals whose length was inversely related to frequency of use.)	1837	On Wheatstone and Cooke's pilot telegraph link. Morse's original code (1832) did not employ this principle. Alfred Vail developed the improved code, although it continued to be known as the "Morse Code". Later implementations of data compression used a wider range of mathematical techniques to perform compression, but the core concept – of compression by exploiting redundancy in the raw data – was Vail's.

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5	**Printing telegraph** (or "teleprinter") and its **fixed-length character-encoding scheme** (the "Baudot Code")	Émile Baudot	1870	The idea that the formerly manual task of digitally encoding and decoding text (in Morse Code) could be performed automatically by a typewriter-like device. Mechanization of the decoding process required a change from Morse Code (with variable character length) to an accurately-timed fixed-length character code (the 5-bit Baudot code, forerunner of ASCII and Unicode).	1875	The Baudot printing telegraph. Note: Baudot's 5-bit Code was later extended to 7, 8, and 16 bit codes to support lowercase letters, symbols, and non-English alphabets and ideographs: 7-bit ASCII in 1963, 8-bit EBCDIC in 1964, and 16-bit Unicode in 1992.
6	**Telephone** (analog electrical communication)	Philipp Reis, a science teacher in Friedrichsdorf, Germany Reis never pursued his invention, so credit for the invention of the telephone has been given to: Elisha Gray *and* Alexander Graham Bell (who independently and concurrently invented the telephone sixteen years later)	1860 1876	The idea that sounds (particularly the spoken word) could be converted into electrical signals of an analog nature, carried over long distances, and then converted back into sound.	1877	The first telephone exchange in Hartford, Connecticut.
7	**Radio**	Nikola Tesla Note: <u>not</u> Marconi, whose patent, filed in 1897, was overturned by the Supreme Count in 1943, recognizing Tesla as the true inventor of radio.	Circa 1885	The idea that electromagnetic waves with frequencies within what is now known as the radio spectrum could be used to carry information (initially digital information, in the form of telegraph signals) through the air (or through space) over long distances.	1899	Marconi's early radio systems, used for ship-to-shore communication and for a link across the English Channel (followed, in 1901, by the first transatlantic link).

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8	**Electronic digital computer**	Alan Turing and Tommy Flowers, at Bletchley Park	1937	The idea that Babbage's Analytical Engine could be implemented using electrical and electronic components (relays, vacuum tubes, etc) using an architecture based on a CPU, memory, and I/O circuitry.	1943	The Colossus (a secret code-breaking computer used in World War II). During implementation, the idea also emerged that a teleprinter (designed for telegraphic communication) could act as a computer input/output device.
9	**Digital encoding of analog signals** (pulse code modulation or PCM)	Alec H. Reeves at ITT, France	1937	The idea that an analog signal such as an audio signal could be represented in digital form by a process of sampling at regular, short intervals and encoding the voltage of the analog signal as a string of bits.	1964	The first PCM links, carrying 24 voice channels on twisted-pair cables, in the UK. PCM was later use to encode music-quality audio signals and, later, video signals (leading to the present-day digital video standards DV, MPEG-1, MPEG-2, and MPEG-4). See also (35) below – compression of digitized images and video.
10	**Spread-spectrum radio**	Hedy Lammar (the film actress) and George Anthiel	1941	The idea that digital information could be transmitted over a range of radio frequencies by the transmitting device "hopping" between different frequencies in a pre-determined way that the receiving device could follow, sending short bursts of information on each frequency.	1942	The original application for which the technique was developed was secure radio communication during World War II. Spread spectrum technology continued to be used in this manner after the war and was considerably refined. In 1985 the technique was updated for the commercial market by Jim Omura who proposed it as an approach to shared utilization of a band of frequencies by using orthogonal pseudo-random bit streams to control the frequency-hopping process. The technique makes the communication immune to interference, even from relatively strong fixed-spectrum sources radiating within the same band (e.g. microwave ovens). Spread-spectrum became the foundation of code-division multiple access (CDMA) radio communication for some cellular telephone networks and wireless LANs.
11	**Stored-program digital computer** (programs stored in memory before execution starts)	John Louis von Neumann, at Princeton	1945	The idea that a program could be placed in the memory of a computer *before* being executed (rather than fed into the computer using a paper-tape reader or other device *while* being executed).	1949	EDSAC, built by Maurice Wilkes and his team at Cambridge University, and first demonstrated on May 6, 1949.

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12	**Programming languages and compilers**	Maurice Wilkes, Cambridge University	1948	The idea that a symbolically represented program could be translated into machine code by a second program (a compiler) that treats the first program as input data.	1957	Various pilot languages and compilers developed by Wilkes and his team at Cambridge University, leading to FORTRAN, developed by John Backus at IBM, released in April 1957.
13	**Storage of data on a magnetic tape**	Remington Rand Inc.	Circa 1949	The idea that a tape recorder, as previously used for analog audio recording, could be used to record digital data.	1951	Tape drive of the Remington Rand Univac I computer. This was not very reliable and was superseded in 1952 by IBM's "vacuum column" tape drive, shipped with the IBM 701 system.
14	**Subroutine libraries**	Maurice Wilkes, Cambridge University	1950	The idea that small programs that perform frequently-required tasks could be re-used from program to program by being attached to each new program and "called" by the main program as needed. Note: a program was originally called a "routine", hence "subroutine", which kept its name even after the new term "program" was adopted.	1950	Started to be used immediately in 1950.
15	**Storage of data magnetically on a rotating rigid disc or drum**	IBM	Circa 1951	The idea that the main memory of a computer could be complemented by a slower, non-volatile storage device based on magnetic storage of information on a rotating disk (or drum) in order to hold intermediate results in complex operations, as well as frequently used programs (thus making the latter accessible without mounting a tape on a tape drive).	1953	The magnetic drum of the IBM 650 system. This was superseded in 1956 by the first disc drive, the IBM RAMAC (Random Access Method of Accounting and Control), shipped with both the IBM 305 and the IBM 650.
16	**Operating systems**	The RAND corporation	1955	The idea that a program that manages the resources of a computer (an "operating system" or "control program") could be written and run continuously on the computer, so that the user interacts with the operating system rather than directly with the machine.	1964	The Dartmouth Time-Sharing System (DTSS), Dartmouth College, developed by John Kemeny and team.

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17	**Time-sharing and multi-tasking**	Christopher Strachey, Oxford University	1959	The idea that an operating system could be written that shares the resources of a computer between several users and/or tasks, using the CPU in a series of time-slices.	1964	The Dartmouth Time-Sharing System (DTSS), Dartmouth College, developed by John Kemeny and team.
18	**Display of computer output on a cathode ray tube** (rather than printing it on a teleprinter)	DEC	1961	The idea that the printing section of a teleprinter could be replaced with a television-style cathode ray tube (CRT) in order to display information, particularly (a) commands and user data typed by the user on the keyboard, and (b) responses from the computer.	1961	The Type 30 display terminal, which was part of DEC's PDP-1 computer system. This CRT, which had a round screen, pre-dated the more user-friendly IBM 2260, launched in 1965.
19	**Computer databases**	Charles Bachmann	1961	The idea that information that will need to be referred to from time to time could be permanently stored in files on a computer (rather than input to the computer at the time of processing) and that such information could be arranged in a logical structure that allows for efficient information retrieval.	1961	General Electric IDS.
20	**Hypertext**	Ted Nelson, while a student at Harvard	1965	The idea that an untrained person could navigate through a universe of information held on computers by means of direct cross-indexing between different pieces of information.	1993	Incorporated in the Mosaic browser, after further refinement of the hypertext concept by Tim Berners-Lee and its specific definition in HTML. Demonstrations of the hypertext concept were performed at Bell Labs as early as 1985 using an example database of information about movies, strikingly similar to the present-day Internet Movie Database (IMDB).

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21	**Graphical user interface** (GUI) and **computer mouse**	Doug Engelbart and his team at the Stanford Research Institute	1965	The idea that man/machine interaction using a CRT terminal, instead of being based solely on typed commands and responses, could be achieved in part using a device that allows the user to point to, and act on, graphical images (icons, tabs, and buttons) that represent choices, commands, actions, programs, and files, displayed on the CRT screen. The mouse proved to be the most popular of several pointing devices tested. (The less-popular touch-screen stylus was resurrected for hand-held "palm" devices; and this was later superseded by direct finger contact.)	1984	Apple Macintosh, 24 Jan 1984. Pointing devices were used with *non-iconic* screen displays as early as 1961, for example with the DEC Type 30 CRT display.
22	**Packet switching** of data and the communication protocols necessary to accomplish this (IP, TCP, UDP).	Paul Baran at the RAND Corporation *and* Donald Davies at the National Physical Laboratory, UK (independently and concurrently)	1965	The idea that a highly resilient data network could be built based on moving data from point to point in independent "packets", rather than as a continuous flow of communication, and that the path taken by each packet could be determined individually by the network switches based on point-in-time conditions in the network.	1969	The original three-node Arpanet, which demonstrated packet switching in operation. The definition of IP and other related protocols evolved over the next six years and became stable by 1975.
23	**Electronic mail**	The idea of personal electronic mail had been touched on in science fiction stories in the 1950s. The first small-scale demonstration of a service resembling the current form of electronic mail was conducted at MIT, under Project MAC, in 1965.	n/a	The idea that messages in text form can be sent directly from one person to another via a global data network (like the Internet) by using store-and-forward message switching programs (not a new idea) in combination with a suitable addressing scheme and a suitable directory administration process.	1971	An email service available to Arpanet users, based on a program written by two programmers at BBN (Ray Tomlinson and a colleague). The many scale-related problems of email were solved piecemeal as email communities grew. The last major development, which allowed email to become universal, was the 1986 Domain Naming Standard (see (36) below). This broadened the use of the email address format "name@domainname", used from the early days of Arpanet and chosen by Ray Tomlinson in 1971 to denote the address of someone whose mailbox was on another system. (The "@" standard forced out of the market the "X.400" email standards that had been championed by some vendors and service providers in the early 1980s.)

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	Name	**Originator/Inventor**	**Date**	**Description of Core Concept**	**Date**	**Details**
24	**Personal computer**	Small computers used by a single person had been touched on in science fiction in the 1960s, but credit for making the personal computer a reality goes to: Stephen Wozniak & Steve Jobs (Apple) and Ed Roberts (MITS).	n/a	The idea that a computer could be made cheap enough and small enough to be *widely* bought and used by individuals at home and in business. (The word "widely" is important. In the 1960s it would have been possible for rich people with large houses, such as Howard Hughes, to own a personal mainframe, had they so wished.) The term "personal", as adopted in the late 1970s, was really more about price and size than about exclusive use or ownership; but "small, cheap computer" does not have the same marketing appeal as "personal computer".	1975	The MITS Altair 8800 (1975), although this was really for hobbyists. The first personal computer fit for general use was the Apple II (1977) followed by the IBM PC (12 Aug 1981).
25	**Word processing**	Text-editing experiments were done in GE and Bell Labs as early as 1966, but nobody has claimed to have originated the concept. The term "word processing" was not used until around 1973.	1966	The idea that a written document could be typed into, and temporarily stored on, a computer, then reviewed and edited on a CRT display, and printed out only when the author has made all desired corrections and changes to it.	1977	The DEC WS78, which comprised word-processing software and a purpose-built computer with 8-inch floppy disc drives.
26	**Relational databases**	Edgar Frank Codd, at IBM	1970	The idea of storing of data in a database in the form of a set of two-dimensional tables, without any table being "senior" to any other table.	1976	Honeywell's Multics Relational Data Store (MRDS). This came after the early versions of Ingres, developed at Berkeley in 1975, but Ingres was not turned into a commercial product until after the launch of MRDS.
27	**Data storage on a removable flexible disc** (the floppy disc)	Al Shugart, at IBM	1970	The idea that the technique of magnetic data storage, as already used in disc drives containing fixed, rigid discs, could be applied to a flexible, removable plastic disc that could be easily carried or stored.	1971	IBM's first 8-inch "memory disc".

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28	**Collision-based data communication protocols** (e.g., ethernet) and **Local Area Networks** (LANs)	Norman Abramson (Aloha protocol for radio data networks, 1970) Robert Metcalfe & David Boggs (the concept, as applied to wire-based communication, 1973)	1970	The idea that a data communication protocol could be operated over a shared medium (such as a cable or a chunk of radio spectrum) by allowing many end-points to attempt to send data in packets at any time, each then "listening" to find out if its packet has collided with another end-point's packet, in which case the end point would try again a random interval later.	1970	The Aloha radio data network, funded by DARPA and developed by Abramson at the University of Hawaii. The Ethernet standard, jointly promoted as an industry standard by Xerox, DEC, and Intel, was outlined in 1973 by Metcalfe and developed into a formal standard in 1976 by Metcalfe and Boggs. Although the Aloha technology was replaced by forms of radio transmission of data that did not use collision-based techniques, the use of collision-based protocols over radio networks was revived in 1997 in the form of ethernet over wireless LANs.
29	**Optical storage disc**	Klaas Compaan & Piet Kramer, at Philips in the Netherlands	1972	The idea that read-only data, including digitally encoded music, could be stored on a rigid plastic disc as a series of pits, pressed into the disc when it is made; and that the data could be read by a focused laser beam in the playing device that scans the pits as the disc rotates. Another feature introduced with the CD was a constant linear density of pits. In the player/reader, the speed of rotation of the disc is varied depending on the location of the head, so as to maintain a constant linear velocity (CLV) between the surface of the disc and the read head.	1982	The read-only audio CD, used initially for music, but designed with data in mind. The CD started to be widely used for data in 1985 (the "CD-ROM"). Out of the same line of development came the write-once 12-inch disc, used for data archiving. Further evolutions of optical disc technology have included the DVD and recordable (write-once and write-many) versions of the CD and the DVD.

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30	**Public Key Cryptography**	Whitfield Diffie	1974	The idea that information could be encrypted by one person (Alice) and decrypted by another (Bob), without Bob having to securely convey a secret key to the Alice beforehand. This can be done by using an asymmetric encryption algorithm that has a pair of complementary keys: a secret key and a public key. In this example, Bob sends his public key openly to Alice (and to anyone else who wants to use it). Alice encrypts the message using Bob's public key and sends the result to Bob. Bob, who is the only one in possession of his secret key, uses it to decrypt the message.	1976	When Diffie proposed the idea of an asymmetric encryption algorithm in 1974 he was not certain that such a thing existed. However, two algorithms were developed as a solution to the problem posed by Diffie: in June 1976, the Diffie-Hellman-Merkle algorithm, and in April 1977, the Rivest-Shamir-Adleman algorithm (known as "RSA"). RSA came to dominate the market and is now used in almost all commercial cryptography, both on the Internet and on private networks.
31	**Alphanumeric network addresses** (ANAs)	Unknown	1978	The concept that a physical end point on a large data network could be addressed by an *alphanumeric* string (rather than a by a numeric string like an IP address or an ISDN telephone number). This fairly simple idea was not a big step in itself, but it paved the way for DNS (see (36) below) – which was a cornerstone of both the World Wide Web and universal email.	1978	ANAs were offered as an optional mode of addressing on several private data network switches (e.g. Telenet, Tymnet, CASE DCX).
32	**Electronic spreadsheet**	Dan Bricklin & Bob Frankston	1978	The idea that a paper spreadsheet, as widely used in accounting, could be represented in a computer (and displayed on the screen) as a dynamically updateable image of a paper spreadsheet, holding both the fixed numerical values and the formulae that generate the row and column sub-totals and totals in the sheet.	1978	VisiCalc.
33	**Creation of presentation slides using a program**	Unknown	1983	The idea that a word-processor-like computer program could be used to create presentation slides containing large-font text and simple graphics, easily viewable when projected on a screen.	1983	The PC program "Overhead Express". In 1985 a system specifically designed to connect to a video projector was launched – the Videoshow system. This was later replaced by PC programs that did the same thing using a standard PC.

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34	**Compression of digital audio signals**	Unknown (military developments) Richard Cox & others at Bell Labs (low-quality voice algorithms), 1982 R. Veldhuis, M. Breeuwer & R. van der Wall (music-quality algorithm), 1989	Circa 1970	The idea that the bit-rate of a digitized audio signal could be greatly reduced, without significant loss of quality, to permit economic transmission and storage of digitized audio signals. Compressed digital audio signals were first used in military applications where the resulting digital signals needed to be of sufficiently low bit-rate that they could be encrypted in real-time using then-available processors (which were very slow by modern standards).	1984 1992	*For telephony over expensive bandwidth:* Various products for use in private voice networks, based on the CELP algorithm and other similar algorithms. *Music-quality:* Sony's ATRAC algorithm, used in the Sony MiniDisc. The original ATRAC algorithm achieved a 4:1 compression ratio versus uncompressed audio CD. It was superseded by MPEG-1 Audio Layer 3 ("MP3") and Dolby AC-3 ("Dolby Digital"), which achieve ratios of 9:1.
35	**Compression of digitized photographic images and video signals**	CompuServe (static images) Apple (extension of the concept to moving images), circa 1989	1986	The idea that visual analog information, contained in a photograph or a series of images like a television signal or film, could be compressed after digitization (using PCM as applied to the analog signal derived from an analog scanner or video camera), so that the resulting data file or datastream would contain far fewer bits of data than with an uncompressed PCM signal, by taking advantage of redundancy in the image and the way that the human eye and brain process visual images.	1987 1991	*Still images:* GIF (Graphics Interchange Format) introduced by CompuServe for images. *Video:* Apple's first version of QuickTime, demonstrated in May 1991 and released on December 2, 1991. (Microsoft's product, Video for Windows, did not appear until November 1992.)
36	**Domain Naming Standard** (DNS)	Jon Postel, Paul Mockapetris, & Craig Partridge	1986	The idea that an alphanumeric addressing scheme could be operated on a very large data network (like the Internet), without a single administrative authority, through a set of rules for a hierarchical naming scheme, progressive delegation of name assignment, and a distributed address translation database.	1986	Used right away for email, telnet, and ftp communication. Became a critical component of browsers and the World Wide Web in 1993.
37	**Hypertext Markup Language** (HTML) and **Hypertext Transfer Protocol** (HTTP)	Tim Berners-Lee while at CERN	1989	The idea of building screen displays piecemeal from text and graphics stored in different locations, and navigating these distributed data sources via hypertext references.	1993	The Mosaic browser, which provided the means by which the World Wide Web came into existence, supporting an HTTP/TCP layer on top the existing IP Internet.

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38	**Monopolization of the supply of software**	Bill Gates, Microsoft	Circa 1988	The idea that the existence of a de facto PC architecture standard, combined with possession of intellectual property rights to the operating system for that architecture, plus revenue streams from these rights, could be used to monopolize the supply of PC operating systems, common office application software, and any future application that proves to be popular, by obtaining ideas and know-how from other companies by means of acquisition, intimation, or theft; and by trampling to death any emerging competition that threatens this monopoly position.*	1990	The start of Microsoft's transformation of the PC software market was marked by the launch of Windows 3.0 (1990) and IBM's subsequent acknowledgement that Microsoft was not serious about continued joint work on OS/2. (DOS and earlier versions of Windows paved the way for the monopolization of the market for PC operating systems and, later, standard "Office" application software, but Microsoft's ability to control the market was not established until the late 1980s.)

* Obviously, monopolization of markets is a very old idea. However, monopolization of a market for an intangible good (like software) is a lot harder to achieve than monopolization of a market for a tangible good – although it could be argued that many religions were early examples of "intangible goods" that had become monopolies in various "markets". IBM had almost monopolized the market for software *for IBM mainframes* in the 1960s and 1970s; but this was really an indirect result of the monopolization of the mainframe hardware market. IBM's software could not run on other types of computer (such as hardware from Honeywell or DEC), so IBM had not actually monopolized the market for software in any particular class of software (e.g., operating systems or payroll applications). When the first personal computers emerged in the late 1970s, few would have foreseen that monopolization was feasible for software *in its own right*, in a non-monopolized hardware market.