Douglas Carl Engelbart: Developing the Underlying Concepts for Contemporary Computing

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Currently, the World Wide Web is the hottest topic in contemporary computing and popular culture. The Web's meteoric rise is difficult to escape notice. Web stories are plastered in the popular press, and advertisements now include cryptic strings of letters starting with http://. But what is missing from the current commercial descriptions of the Web is a discussion about the 30-year history of research and development that created the underlying technologies on which the Web is based. Much of this foundation was laid in the 1960s by Douglas Carl Engelbart. In 1968, at the ACM/IEEE-CS Fall Joint Computer Conference, Engelbart demonstrated his concept of "interactive computing" to a group of computer scientists, and this is now considered a seminal event in the history of computing. The technologies Engelbart originally presented included: windowed screen design, the user interface, hypertextual linking of documents, the mouse, collaborative computing, and multimedia. His pioneering work in the 1960s influenced future generations of computer designers and developers. Almost 30 years after Engelbart's initial demonstration, many of his pioneering visions are now commonly found in personal computers and the developing World Wide Web.

Introduction

Today, people do not need to know the name Thomas Alva Edison to turn on an electric light and read a book. Similarly, they do not need to know the name Douglas Carl Engelbart to turn on a personal computer, click on an icon with a mouse, and access the digital libraries of the world. However, unlike Edison, Engelbart remains a little-known figure in the history of technology. Engelbart remains unfamiliar despite the fact that he invented the mouse, window-style computer screen displays, and other key concepts that are used everyday when people operate their computers.

For over 30 years, Engelbart has pursued a vision of interacting with computers that has remained mostly ignored by the computer industry. However, without realizing it, the computer industry has spent the last 20 years implementing ideas Engelbart first demonstrated in the 1960s. Engelbart's goal was to develop interactive computer systems that would match computational capabilities with human capabilities. He was interested in designing a new category of computer applications for augmentation not automation. Utilizing computer technology, Engelbart envisioned a future in which individuals and small groups would be able to augment the strengths of their most important natural tools for dealing with the world—the abilities to perceive, think, reason, analyze, and communicate. First, he wrote a paper to explain his framework for developing interactive computing. Afterward, he built a working model to demonstrate his vision. In the process of creating the model, Engelbart designed a series of interactive computer tools that became the foundation for the future development of hypertext, computer-supported cooperative work, the graphical user interface, electronic mail, on-screen editing, video conferencing, and the World Wide Web.

Early Influences

Engelbart began his engineering career at Oregon State College in 1942. He enrolled in an electrical engineering program because he was interested in learning about radar (then known as radio detecting and ranging, hence, RADAR) technology. World War II was in progress, and Engelbart recalls:

> By the end of my sophomore year, if you were in college in engineering, you were getting deferred. But, they dropped all that, and so I got drafted at the end of my sophomore year. And when you get drafted, you can opt for different choices. So, I took a test that the Navy was giving for the RADAR, trying to screen people to go into this new technology. So, as an enlisted man, I got to get drafted into the Navy and go into its yearlong training program.[1]

Engelbart was drafted into the U.S. Navy, where he was introduced to a number of new technologies, including wave propaga-

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tion, antennas, and amplifiers. Following this training, Engelbart was sent to the Philippines. As his ship backed out of its berth in San Francisco, whistles and firecrackers started going off, and people began cheering. Japan had just surrendered. Instead of going into active combat, Engelbart was sent to the Philippines to help with the demobilization efforts. As a Navy electronics technician, he took care of radios, sonar (then known as sound navigation ranging), teletype transmission, and radar. This experience was an introduction to all types of new communication technologies.

Engelbart's vision of using the computer as an interactive communication tool began to take shape after the end of World War II. Toward the end of his naval career, he read Vannevar Bush's article "As We May Think" that was published in the July 1945 issue of *Atlantic Monthly*. The article inspired Engelbart to pursue a career developing better communication and "knowledge" tools. Bush published the article as a reflection on how technology could help solve problems in a postwar society. During the war, Bush realized that the amount of scientific data being written and collected was growing at an accelerated pace. As a result, he believed that people would need new types of knowledge tools to locate, organize, coordinate, analyze, and navigate through the increasing volumes of research information.

In "As We May Think," Bush described a hypothetical device called a memex (memory extender) as an example of the type of knowledge tools that should be developed. The memex was a workstation conceived to use a variety of analog technologies such as microfilm readers and storage. Bush described it as follows:

> A memex is a device in which an individual stores all his books, records, and communications, and which is mechanized so that it may be consulted with exceeding speed and flexibility. It is an enlarged intimate supplement to his memory.
>
> It consists of a desk, and while it can presumably be operated from a distance, it is primarily the piece of furniture at which he works. On the top are slanting translucent screens, on which material can be projected for convenient reading. There is a keyboard, and set of buttons and levers. Otherwise it looks like an ordinary desk.[2]

Bush's memex was envisioned to aid the process of thinking through a mechanized indexing system. Different pieces of information in the system could be connected by creating individualized associative trails. A trail was similar to the trail of mental association in a person's mind. Used as an augmentation tool, the memex would supplement and extend human memory capabilities and reflect the associative nature of the human mind. In the following passage, Bush describes the process of linking trails of information:

> When the user is building a trail, he names it, inserts the name in his code book, and taps it out on his keyboard. Before him are the two items to be joined, projected onto adjacent viewing positions. At the bottom of each there are a number of blank code spaces, and a pointer is set to indicate one of these on each item. The user taps a single key, and the items are permanently joined.[3]

"As We May Think" was not predicting the future, but creating it.[4] Bush's compelling vision of information technology influenced future generations of computer pioneers. After reading Bush's article, Engelbart went back to school to finish his BS in electrical engineering and graduated in 1948. Afterward, he took an engineering job at the Ames Research Laboratory in Mountain View, California, with the National Advisory Committee for Aeronautics (the forerunner of the National Aeronautics and Space Administration, NASA). After working at Ames for several years, he got engaged to be married. But the Monday after he became engaged, Engelbart realized that he had achieved all of his life goals—get an education, get a steady job, and get married. Now, at the age of 25, he began to think about a new goal for his life. He later described his decision-making process as follows:

> I dismissed money as a goal fairly early in the decision process. The way I grew up, if you had enough money to get by, that was okay; I never knew anybody who was rich. But by 1950, it looked to me like the world was changing so fast, and our problems were getting so much bigger, that I decided to look for a goal in life that would have the most payoff to mankind.[5]

It looked to me like the world was changing so fast, and our problems were getting so much bigger, that I decided to look for a goal in life that would have the most payoff to mankind.

For several months while driving to work, Engelbart contemplated his skills and the various kinds of goals he could pursue. He was also looking for a cause that could utilize his engineering education and his interest in computers. While searching for his new goal, Engelbart realized that he ran into the same issue time and time again. Like Bush, he understood that humankind was moving into an era in which the complexity and urgency of global difficulties were surpassing the traditional tools for dealing with problems. Engelbart recalled:

> I had this kooky thing happen to me in 1951 where I decided to commit my career to trying to help mankind be able to cope better with complexity and urgency and the problems of the world. I had an image of sitting in front of a display and working with a computer interactively. I had been a radio and radar technician during World War II, so I knew that any signals that came out of a machine could drive any kind of hardware—they could drive whatever you wanted on a display. But I really didn't know how a computer worked. Still, I though, "Boy! That's just great!" The images of the different symbologies that you could employ, and other people sitting at workstations connected to the same complex, and working in a close, collaborative way. And I just said, "Well, that's something I can pursue as an electrical engineer, and maybe try to follow as a goal."[6]

Based on his experiences as a radar technician, Engelbart envisioned using computers as a technology to interact with information displayed on screens. At the time, Engelbart had never worked with a computer. But, he had read about them in books. From his radar experience, Engelbart understood that if computers could show information on punch cards and paper printouts, they could write or draw information on a display screen. He saw the

connection among a cathode-ray screen, an information processor, and a medium for representing symbols to a person. Engelbart began sketching out a system that would enable people to steer through different information domains using knobs, levers, and transducers.

It was not until eight years later that Engelbart was able to begin his goal of developing interactive computing systems. First, he quit his job and went to the Graduate School of Electrical Engineering at the University of California at Berkeley. Professor Paul Morton had started to explore computer science and was developing the California Digital Computer. While in graduate school, Engelbart's ideas about interactive computing were not understood or well-received by his colleagues, who were punching cards to interact with the computer. In contrast to a traditional batch-processing method, Engelbart wanted to connect a keyboard to the computer and have a person interact directly with the machine. Because his ideas were not acceptable to the university community, Engelbart settled on a different research topic to complete his degree. In 1955, he earned his PhD along with half a dozen patents for bistable gaseous plasma digital devices. After leaving academia, Engelbart began to look to the commercial world as a way to pursue his vision for developing interactive computer systems.

Initial Concepts of Augmentation

In October 1957, Engelbart accepted a job at an organization called the Stanford Research Institute (SRI). SRI was interested in conducting research in military, scientific, and commercial applications for computers. During his first two years at SRI, Engelbart earned a dozen patents, working on magnetic computer components, fundamental digital-device phenomena, and miniaturization scaling potential. By 1959, Engelbart had enough recognition at SRI to begin to pursue his own research interests. With support from SRI and a grant from the U.S. Air Force Office of Scientific Research (from Harold Wooster and Rowena Swanson), he worked for a couple of years to produce a paper describing his interactive computing concepts.

At first, he tried to find an established discipline as a basis for the framework of his design. But people in other disciplines, such as documentation and artificial intelligence, were not interested in his ideas. Finally, he discovered a Rand Corp. report written by J.L. Kennedy and G.H. Putt titled "Administration of Research in a Research Corporation." The thesis of the report argued that when a researcher starts an inter- or new-discipline project, the researcher would encounter difficulties when approaching individuals in established disciplines. Each discipline has its own unique conceptual framework that new members of the profession begin to learn during the first year of professional school. If a conceptual framework did not exist for a new-discipline research project, then an appropriate framework must be created. After reading this report, Engelbart started developing his own unique conceptual framework for designing interactive systems.

In 1962, Engelbart finished his paper titled "A Conceptual Framework for the Augmentation of Man's Intellect," and a condensed version was published the following year in P.W. Howerton and D.C. Week's book *Vistas in Information Handling*. In his paper, Engelbart defined *augmenting man's intellect* as the capability of a man or woman to approach a complex problem situation, gain understanding about his or her particular needs, and derive solutions to the problems. Engelbart's system was conceptualized to augment or support people working in a variety of disciplines, including diplomacy, management, social science, programming, law, and design. He wanted to develop a set of core tools that all these various intellectual workers could use. Additionally, he wanted to develop specialized tools to meet particular requirements to help augment the way different types of intellectual workers solve problems.

In his 1963 paper, Engelbart explained his theoretical approach for developing computer-based augmentation systems. Engelbart's conceptual framework attempted to orient people toward the possibilities and problems associated with using modern technology. In developing his design theory, he started with the human perceptual system. An individual communicates to and receives information from the world through his or her motor channels. According to Engelbart, this processing is of two kinds. The first category of processes includes those processes of which a person is generally conscious, such as recognizing patterns, remembering, visualizing, abstracting, deducing, and inducing. The second category of processes involves self-generated information, such as unconscious processing, mediating received information, and mediating conscious processing itself. These methods of processing information are acquired as individuals grow up and live within a given culture. People are specifically taught conceptual and symbolic ways to process information, including spoken and written language. Moreover, people are taught to use tools and methods for organizing structures. All of these symbolic and organizational methods constitute one big system that augments human capability. See Figs. 1 and 2.

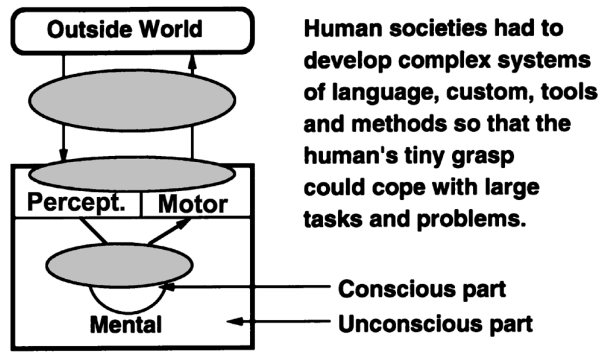


Fig. 1. In the development of his chapter "A Conceptual Framework for the Augmentation of Man's Intellect," Engelbart argued that our basic mental–motor–perceptual machinery cannot do much by itself.

Furthermore, Engelbart argued that culture shapes the processing of information by developing techniques for us to organize and utilize our basic human intellectual capabilities so that we can understand very complex situations and attain methods for devising and implementing solutions to problems. In examining the methods and tools people use in the problem-solving process, Engelbart developed the concept of augmentation means. Augmentation means are the tools and methods used to supplement human problem-solving capabilities. Engelbart categorized augmentation means into four classes:

1) *Artifacts*—physical objects designed to provide for human comfort, the manipulation of things or materials, and the manipulation of symbols;
2) *Language*—the way in which the individual classifies the picture of his world into the concepts that his mind uses to model that world, and the symbols that he attaches to those concepts and uses in consciously manipulating the concepts ("thinking");
3) *Methodology*—the methods, procedures, and strategies with which an individual organizes his goal-centered (problem-solving) activity; and
4) *Training*—the conditioning needed for the individual to bring his skills using the three augmentation means listed above to the point where they are operationally effective.[7]

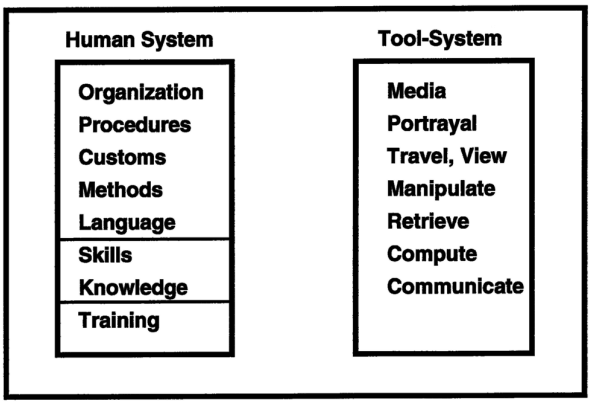


Fig. 2. In the design of the augmentation system, Engelbart treated it as a two-part system. One part was technology, and the other part was human factors.

Engelbart created a diagram (see Fig. 3) of a general system to illustrate how human processes interact with artifact processes. He referred to this type of general system as an H-LAM/T system (Human using Language, Artifacts, and Methodology, in which he is Trained). In his paper, Engelbart proposed to design a new computer-based system that would bring together a trained human being with his or her artifacts, language, and methods. In contrast to traditional artifacts, such as paper and pencil, the artifacts in the new system would include computers with computer-controlled information-storage, information-handling, and information-display devices.

Engelbart realized that a shift from artifacts, such as paper and pencils, to digital computer-based tools would alter organizational structures, because changes in the augmentation means would alter the way people work. A change in physical artifacts would consequently change the language and the methods used in problem-solving activities within an organization. Simultaneously, while he was designing his augmentation system, Engelbart was aware that this new technology would alter the way people work. Realizing that computer-based systems would change work practices, Engelbart argued that people would require training.

Training is necessary to bridge the gap between old and new technological systems. Engelbart used the example of an untrained aborigine to illustrate this point. An untrained aborigine would not be able to drive a car in urban traffic, because the aborigine would not be able to bridge the gap between his cultural background and contemporary society. However, it would be possible for the aborigine to learn step by step how to drive safely. According to Engelbart, human minds learn by a series of small steps rather than by large leaps, and the small steps depend on the previous steps. The structure or organization of these small actions or steps can be called process hierarchies.

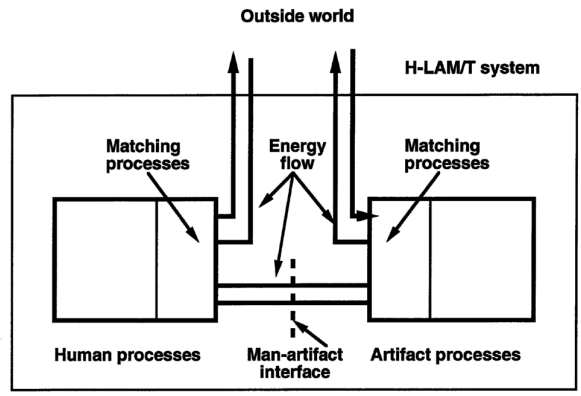


Fig. 3. A diagram representing the two active domains within the H-LAM/T system.

Process hierarchies are broken down into individual small steps or subprocesses. People develop a repertoire of subprocess capabilities or tools that they select and adapt to execute higher order activities. For example, a mechanic must know what functions his or her tools can perform and how to use them. Similarly, the intellectual worker must know the capabilities of his or her tools and understand the suitable methods, strategies, and rules for making them work. When an intellectual worker writes a document, the process of writing is used as a subprocess or tool for higher order activities, such as organizing a committee, creating a report, or preparing a legal brief. The shift from pencils and paper to digital tools, such as word processing, changes information handling and the skills required to use new technological artifacts. Thus, people would need to learn how to work with these new tools.

Symbolic Manipulation

In Engelbart's terminology, working with a complex machine involves a cooperative interaction between the domains of human processes and artifact processes. The term *man–machine interface*, now called the discipline of human–computer interaction, has been used for some years to represent the boundary across which energy is exchanged between people and machines. Engelbart stated that the exchange across this "interface" occurs when an explicit human process is coupled with an explicit artifact or computer process. For example, the finger and hand motions used to type on a keyboard (explicit human processes) activate key-linkage motions on the keyboard (explicit artifact processes). Thus, the computer interface is the point of interaction between the artifact processes of the computer and human-processes.

According to Engelbart, developing computer artifact processes to match human processes would result in a new fourth stage in the development of human intellectual capabilities. In his framework, he devised a hypothesis to describe each of the four stages of human symbolic manipulation. The first stage is concept manipulation. Humans have the biological capability of generating concepts and abstractions. They can mentally manipulate these concepts and "think" about abstract situations. The second stage is symbol manipulation. In this stage, humans take a great step forward when they learn to represent specific concepts in their minds with particular symbols.

In the third stage of development, manual external symbol manipulation, symbol manipulation activity now supplements the individual's memory and ability to visualize concepts. Manual external symbol manipulation includes graphic representation and the "means" or devices used to make graphic representations of symbols such as a stick and sand, pencil and paper, and straightedge or compass. He argued, that the "means" or methods used to externally manipulate symbols have principally been associated with the evolution of the individual's present way of manipulating concepts or thinking. Simply stated, the media we use to symbolically record ideas will influence the way we think. Engelbart asserted that current patterns of thinking have been shaped by the way we manually manipulate symbolic representations. For instance, the written alphabet influences our ability to conceptualize the world, because it is an abstract method for symbolizing people, objects, and ideas. The literate mind creates a worldview that is not possible by experiencing the world through our senses, because written concepts can be constructed through logic, deduction, and critical reasoning.

In stage four, Engelbart combines symbol manipulation with the use of language. He asserts that in addition to the methods we use to manipulate symbols, language also affects the way we think. Building on the Whorfian hypothesis[8] that argues language plays a prominent role in shaping the perceptual world of the people who use it, Engelbart further argued that a second factor in language's influence on culture is external symbol manipulation. Using this second factor, Engelbart proposed a neo-Whorfian hypothesis that stated, "both the language used by a culture, and the capability for effective intellectual activity, are directly affected during their evolution by the means by which individuals control the external manipulation of symbols."[9] In other words, the tools or media we use to externally manipulate symbols influence language and ultimately the way we think.

Interactive Computing

Engelbart's framework (see Fig. 4) suggested a fourth stage in the evolution of human intellectual capability. Engelbart called this new stage "automated external symbol manipulation." Computers add the ability to automate the external manipulation of symbols. A shift from manual to automated external symbol manipulation would result in a fourth stage in the development of human intellectual capabilities. This fourth stage would occur because, according to the neo-Whorfian hypothesis, these new tools would alter the human thinking process.

In this fourth stage of evolution, Engelbart described his vision for interactive computing:

> The symbols with which the human represents the concepts he is manipulating can be arranged before his eyes, moved, stored, recalled, operated upon . . . this could be a computer, with which individuals could communicate rapidly and easily, coupled to a three-dimensional color display within which extremely sophisticated images could be constructed, the computer being able to execute a wide variety of processes on parts or all of these images in automatic response to human direction.[10]

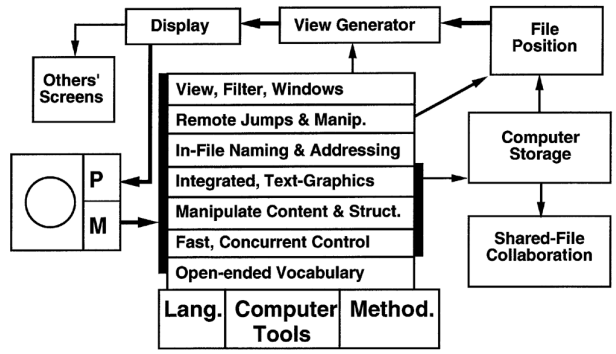


Fig. 4. A diagram from Engelbart's framework showing how the motor capability of the abstracted human module drives the computer tools and employs the associated methodological and conceptual-linguistic parts of his augmentation system in different modes. (P = perceptual, M = Motor; see Fig. 1.)

Engelbart was aware that moving from manual to automated symbol manipulation would create changes in the human system. In 1988, Engelbart stated:

> It takes a long time (generations) to discover and implement all of the fruitful changes in the human system made possible by a given, radical improvement in technology. Where, as is the situation now, technology improves by rapid, large steps, it is predictable that the human system will become critically stressed in trying to adapt rapidly in ways that formerly took hundreds of years. There has to be a much-enhanced consciousness about concurrent evolution in the human system.
>
> The technology side, the tool system, has inappropriately been driving the whole. What has to be established is a balanced coevolution between both parts. How do we establish an environment that yields this coevolution? Well, that's where the bootstrapping in a laboratory comes in. I said I wanted to do what I knew it was going to be like in our future. So we had to be more conscious of the candidates for change—in both the tool and the human systems.[11]

Engelbart came up with the concept of bootstrapping as a method of analyzing the coevolution of human and tool systems. Bootstrapping is building the tools to build better tools and simultaneously testing them on yourself during the inventive process. Engelbart and his team served as both the developers of the technologies and the subjects for the analysis and evaluation of the new augmentation system. To implement the

bootstrapping strategy, a team of people from diverse disciplines, including psychology, computer programming, and computer engineering, were assembled. People working on the project were expected to change to this newly evolving design and its emerging terminology.

Support From ARPA

Once Engelbart's theoretical framework was completed, the next step was to get funding to build and test a working model. Engelbart first gained support from Licklider through the Advanced Research Projects Agency (ARPA) and later from Bob Taylor at NASA. Licklider, a psychology professor and researcher at the Massachusetts Institute of Technology, shared Engelbart's vision of interactive computing. In 1960, he wrote a paper titled "Man–Computer Symbiosis."[12] In this paper, Licklider asserted that a new relationship between humans and computers was necessary. Martin Campbell-Kelly and William Aspray have described his paper as follows:

> The single most important idea in Licklider's paper was to advocate the use of computers to augment the human intellect. This was a radical viewpoint at the time and, to a degree, at odds with the prevailing view of the computer establishment, particularly artificial intelligence (AI) researchers. Many computer scientists were caught up by the dream that AI would soon rival the human intellect in areas such as problem solving, pattern recognition, and chess playing. Soon, they believed, a researcher would be able to assign high-level tasks to a computer. Licklider believed that such views were utopian.
>
> He argued that computer scientists should develop systems that enabled people to use computers to enhance their everyday work. He believed that a researcher typically spent only 15 percent of his or her time "thinking"—the rest of the time was spent looking up facts in reference books, plotting graphs, doing calculations, and so on. It was these low-level tasks that he wanted computers to automate instead of pursuing a high-flown version of AI.[13]

In 1962, Licklider became the first head of ARPA's newly established Information Processing Techniques Office (IPTO). IPTO's objective was to invest in research projects that would provide more capable, flexible, intelligent, and interactive computer systems. Licklider's interests in the human factors aspects in complex human–human and human–machine systems made him an ideal director of IPTO.

> Licklider had come to IPTO in 1962 with a vision of how to increase human–computer interaction and established a program of breadth and depth to realize this vision. His successors ... all subscribed to this vision and continued to promote it.[14]

Licklider moved quickly to get funding for Engelbart's project. By early 1963, funding was approved, and Licklider requested that the project be connected to the System Development Corporation's (SDC) AN/FSQ32 computer in Santa Monica, California. SDC was developing a time-sharing system for the Q32. Later that year, an online data link was established between Menlo Park, California, and Santa Monica with a CDC 160A minicomputer at the SRI location. Engelbart describes the computer as follows:

> Mind you, the CDC 160A, which was the only commercially suitable minicomputer that we knew of, even though having only 8K of 12-bit words, and running at about 6 microseconds per instruction, cost well over $100,000 (1963 dollars). It had paper tape in and out; if the system crashed, you had to load the application program from paper tape, and the most recent dump of your working file (paper tape), before you could continue. A crude, industry-standard Flexowriter (online typewriter) could be driven; otherwise it was paper tape in and out.[15]

Although the funding Licklider provided was a start, the project needed more money to develop interactive systems. Suddenly, an offer for support came from Bob Taylor, who was working at NASA headquarters. Months earlier, Engelbart had visited Taylor and left behind a copy of his framework report and proposal. After reading the report, Taylor had actively gone out seeking funds. The combined ARPA and NASA backing was enough to begin developing a working model.

The Augmentation Research Center

Engelbart set up the Augmentation Research Center (ARC) at SRI. The goal of this research was directly oriented toward augmenting the capability of humans to deal with tough knowledge work. Engelbart's team wanted to invent new methods to process effectively the large volumes of information that knowledge workers use. Peter Drucker had coined the term *knowledge workers*. Drucker defined knowledge as the systematic organization of information. Knowledge workers were people who create and apply knowledge to productive goals. In the late 1960s, Drucker's *The Age of Discontinuity* predicted that a social transformation would occur in the last quarter of the 20th century. The U.S. economy would shift from an economy that manufactured products to one that was based primarily on the exchange of knowledge.

Engelbart's primary research goal was to invent technologies that would support the knowledge worker. A secondary goal of the augmentation research was to develop computer systems that support active collaboration among groups of knowledge workers. This aspect of Engelbart's research has become the discipline of computer-supported cooperative work. His augmentation system was the first major research work done in office automation and text processing. In fact, the entire augmentation project was much more ambitious and broad in scope than the current office productivity tools we use in the professional work environment of the 1990s. Today, we are still trying to implement many of the concepts Engelbart introduced in the 1960s.

The system ARC developed was called NLS (for oNLine System). It included such advanced features as electronic mail, computer conferencing, multiple windows on a screen, and a mouse. NLS was designed to enable any team member to read material written by anyone else working on the project and make comments on the documents. Electronic documents could be accessed from any terminal connected to the augmentation system. Documents were "shared" and distributed among members of the group during the development process. This project was the first prototype of a paperless office. No paper changed hands during the communication exchange, and access to information was perceptually immediate. The ability to create, share, and store documents

was achieved by connecting the text-editing system with a special kind of electronic filing organization system that would serve as a combined memory, record, and medium for unifying individual research efforts.

A software journal was established for individuals and groups to have access to a shared electronic space for thinking and communicating. The journal enabled individuals to insert comments into the group record of the augmentation experiments or browse through them. Moreover, the augmentation system allowed programmers to trace the way system features had developed and evolved. The journal was part of the overall dialogue support system designed to make more effective the decision-making process in small group interactions. Additionally, the journal organized the dialogues, notes, and publications created during the process of developing the augmentation system and testing how the NLS software worked. NLS was the central software application, and it focused on the composition, modification, and study of structured textual material. Computer interfaces were developed to enable users to interact with the textual information displayed on screens and terminals.

Engelbart and his team designed unique methods for interacting with the system. In addition to a traditional keyboard, the user could input commands with a five-key, one-hand chord keyset. Simple one-character commands were input through the chord: for example, I (insert), D (delete), and M (move or rearrange). After the command is typed, the user points with the "mouse" to tell the system where on the screen the command should be executed. Engelbart's mouse was a box with hidden wheels underneath. Ted Nelson described working with the mouse as follows:

> The Engelbart Mouse is a little box with hidden wheels underneath and a cable to the terminal. As you roll it, the wheels' turns are signalled to the computer and the computer moves the cursor on the screen. It's fast and accurate, and in fact beats a lightpen hands down in working speed.[16]

In tests, the mouse outperformed the lightpen and joystick in placing a cursor in random screen positions. Engelbart states: "The actual invention of the mouse was the result of analyzing the various characteristics of other pointing/input devices."[17] In addition to hand-held devices, they experimented with knee and head cursor controls. But, muscles would cramp. As a result, they stayed with the mouse. Engelbart's mouse was an analog device covering large steel wheels and exposing a series of three buttons. By rolling the mouse over a flat surface, the operator could move rapidly through a document, pointing the cursor at target areas and clicking the mouse buttons to enter commands. With a few hours of practice, a person could learn to operate the mouse and chord keyset. Engelbart describes interacting with the NLS system as follows:

> Besides using a standard keyboard for character entry, an [NLS] user may optionally use a five-key, one-hand, chord keyset. Remarkably little practice is required in order to enter alphabetic characters, one hand-stroke per character. With less than five hours practice, a person can begin profitably working in a two-handed, concurrent mode—operating the mouse with one hand and simultaneously entering command characters and short literal strings with the other.
>
> Here is an example of a low-level action which reveals some basic characteristics of high-performance execution. It is a very simple situation, but representative of what is met over and over and over again in doing hard knowledge work. The worker is composing or modifying something in one area of the screen, when his eye catches a one-character typo in another area. For a skilled [NLS] worker, the typo could be corrected in less time than it would take someone to point it out to him—with three quick strokes of the keyset hand during a casual flick of the mouse hand, and an absolute minimum of visual and mental attention taken from the other ongoing task.[18]

The display consoles were equipped with typewriter-style keyboards, the five-finger chord keyset for one-character input, and a mouse for cursor control (see Fig. 5). Screens were generated on small CRTs in a machine room and transmitted through a closed-circuit television system to individual workstations. When character-based displays became available, Engelbart's team developed external boxes for attaching mice and keysets.

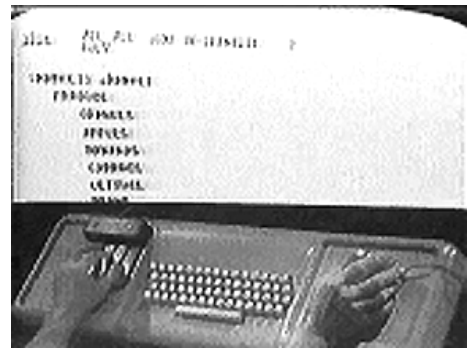


Fig. 5. Captured frame from the 1968 demonstration. Split screen with Engelbart demonstrating how to use the chord keyset in his left hand and the mouse in his right hand.

The Demonstration

Engelbart's project received its first time-sharing system in 1968, an SDS940 (see Fig. 6). They designed their own responsive display system to work with the computer. Engelbart described it as follows:

> The computer and display drivers time-shared their attention among multiple, 5-inch CRTs, which happened to be the most economical size for a given percentage of screen resolution. In front of each CRT we added a commercial, high-quality video camera, mounted with a light shroud over the camera lens and CRT screen. The resulting video signal, amplified and piped out to our laboratory, drove the video monitors that were our workstation displays. Two display generators, each driving up to eight CRTs, implemented with vacuum-tube technology, were both bulky and very costly. It took one and a half people to keep those things running all of the time. The stroke-generated characters and vector graphics allowed us to have flexible, mixed text and graphic document presentations. The display generators were driven from a direct-memory-access channel that provided very fast (i.e., one refresh-cycle time) creation of a new display image.[19]

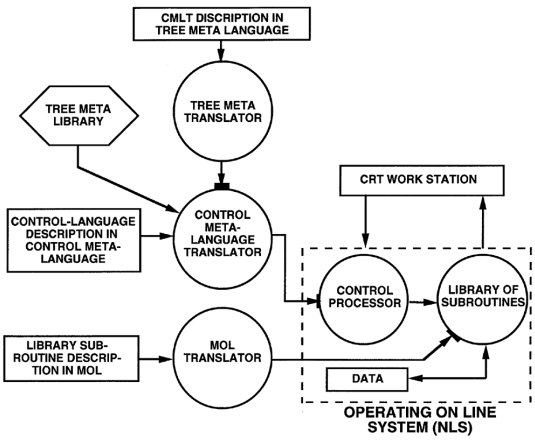


Fig. 6. The basic organization of the SDS940 system used in 1968. Subroutines that did the application work were written with the MOL940 language developed by Engelbart's team. The control processes were specified in a control metalanguage, then compiled with a control-metalanguage translator into the control processor, which interacted with the user. A tree-meta-translator enabled the team to do compiler compiling. They described a new compiler in a meta-compiler language, then compiled it with the tree-meta-translator into the new running compiler.[27]

Now, Engelbart and the 16 members of his team were ready to demonstrate the system they had invented and introduce their concept of interactive computing (see Fig. 7). They decided to risk everything by demonstrating their innovative new way of operating computers to a major gathering of the computer industry known as the ACM/IEEE-CS Fall Joint Computer Conference in San Francisco in December 1968. Engelbart had to use the majority of his grant money to obtain special video projectors and microwave antennas to transmit between the lab and the conference center. Additionally, the team built modems for the demonstration. Engelbart described how the demonstration was presented as follows:

> We set up to give an online presentation using a video projector pointing at a 20-foot screen. Brooks Hall is a large auditorium, and that video projector could put up our display images so you could read them easily from up in the balcony. The video projector we rented (built by a Swiss company, Eidophor) used a high-intensity projection lamp whose light was modulated by a thin film of oil, which in turn was modulated by the video signal. On the right side of the stage, I sat at our Herman Miller [an office furniture company's custom-designed] console. We set up a folding screen as a backdrop behind me. I saw the same image on my workstation screen there as was projected for the audience to see.
>
> We built special electronics that picked up the control inputs from my mouse, keyset, and keyboard and piped them down to SRI over a telephone hookup. We leased two microwave lines up from our laboratory in SRI, roughly 30 miles. It took two additional antennas on the roof at SRI, four more on a truck up on Skyline Boulevard, and two on the roof of the conference center. . . . Back in our lab, we dismantled a number of the display units in our display system, so that we could use the cameras in San Francisco and SRI. We borrowed a few tripods and got some extra people to be camera people. . . .
>
> On my console on the stage, there was a camera mounted that caught my face. Another camera, mounted overhead, looked down on the workstation controls. In the back of the room, Bill English controlled use of these two video signals as well as the two video signals coming up from SRI that could bring either camera or computer video. Bill could select any of these four video images with optional mixing and frame splitting. We had an intercom that allowed him to direct the action of the people in our lab at SRI who were generating computer images or handling the cameras sending the video up from SRI.[20]



Fig. 7. Engelbart demonstrating his system at the 1968 ACM/IEEE-CS Fall Joint Computer Conference.

After spending most of his grant money on the presentation, Engelbart's project would have been in financial trouble if the demonstration did not work. Fortunately, it did work, and the people in the audience got very excited about developing interactive computer systems. Engelbart's demonstration showed the type of information space Bush had described in his 1945 article and the method of interactive computing that Licklider wrote about in 1960.

In the demonstration, he accessed files from the computer's memory and displayed them on a large screen in the auditorium. Then Engelbart collapsed the written textual descriptions into a series of one-line headings (a basic outline). A click on the mouse button would then expand the headings into the larger text. Another command displayed a graphic representation of how the various documents were linked in the system (see Fig. 8). Finally, through another set of commands, Engelbart connected with a colleague located at his lab and displayed on the screen a video image of his coworker. They could see the document, see each other, and discuss the project through audio contact. In this demonstration, Engelbart showed hypertext links (invented with Jeff Rulifson, see Fig. 9), computer-supported cooperative work, video conferencing, computer graphics, and sophisticated word processing.

To further explain his ideas to the computer establishment, Engelbart coauthored a conference paper with English. The paper was written to be an example of the rules of hierarchy and text structuring used in the augmentation system.

> Every paragraph . . . started with an alphanumeric label in the manner of the classic outlining system learned by most high school students. Engelbart and English reported that, when made dynamic by a computer processor, their design facilitated a number of varied and well ordered perspectives on information. For example, users could check logic and completeness by requesting the screen to display "statements" having the same outline level of importance; they could quickly locate specific supporting material by selecting the appropriate alphanumeric heading; they could expand and tie together topics by creating a subheading at the most appropriate point in a given body of thought.[21]

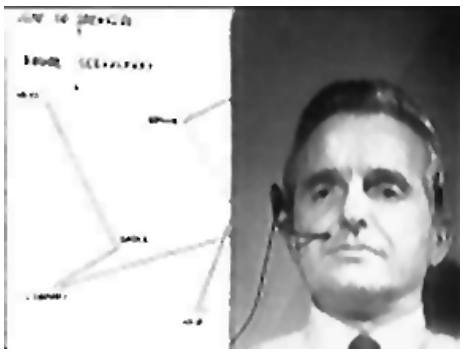


Fig. 8. During the 1968 demonstration, Engelbart explained how his interactive system could link information. Engelbart coinvented hypertext links with the system's chief architect, Rulifson.



Fig. 9. Teleconferencing during the 1968 demonstration between the SRI lab in Menlo Park and Brooks Hall in San Francisco. A view of text retrieval with the image of Paxton in the corner of the screen.

Impressive as Engelbart's demonstration was, the commercial computer establishment did not think his vision of interactive computing was practical. They did not think it was realistic, because the demonstration represented a paradigm shift from batch processing punched cards to direct interaction. Despite the lack of support from the computer establishment, the NLS project continued to develop at ARC with funding from ARPA.

On the Arpanet

In 1969, ARC became the second site connected to the Arpanet system, the beginning of today's Internet. Joining the Arpanet achieved a subgoal of Engelbart's NLS project: to support active collaboration among groups of workers. In the spirit of collaboration, Engelbart and his team volunteered to develop and operate the Network Information Center for the original Arpanet research community. Sharing information among many computers in different locations was not a new idea to the ARC team. They had been working on a smaller, localized network for years. With the creation of the Arpanet, Engelbart's NLS system now became accessible to ARC researchers working across geographical distances and became accessible to other researchers outside of the ARC project. In 1970, the NLS software was reprogrammed for the PDP-10 TENEX. Engelbart and Lehtman describe NLS programming tools as follows:

> Programmers had access to a number of languages we created: Tree Meta, a compiler-compiler, was used to bootstrap us onto different machines ([S]DS 940, PDP-10, PDP-11, and DEC 20) and to create the other compilers and assemblers we used. L10 was a block-structured language with pattern-matching and string-construction facilities. The same pattern-matching syntax was used by less sophisticated users to generate filters in the core workshop. The Command Meta Language (CML) was used to create user interfaces that were independent of terminal type (display or typewriter) and individual user preferences. CML grammars were interpreted. Contextual entries into syntactic and semantic help systems were generated from the CML grammars. The Output Processor interpreted a comprehensive document-formatting language.[22]

In addition to software tools, the architecture and general character of the NLS system was oriented toward supporting collaborative dialogue among distributed participants. Key features of the system included the online Journal, electronic mail, and a Shared-Screen Telephone conference system. The journal system, originally conceived about 1966, was developed to chronicle events by means of a series of unchangeable entries. These entries would be preserved for later integration into more organized treatments. Additionally, Engelbart wanted the entries to serve the same purpose as a professional journal. Engelbart compared his online journal to a professional print-based journal:

> The NLS Journal serves its users in a manner similar to professional journals, with these significant quantitative differences: fast, flexible computer aids serve an author in creating a dialog item, and help multiple authors to collaborate toward that end; publication time is very much shorter; significant "articles" may be as short as one sentence; cross reference citations may easily be much more specific (i.e., pointing directly to a specific passage); catalogs and indexes can be accessed and searched online as well as in hard copy; and full-text retrieval with short delays is the basic operating mode. The end effect of these changes is a form of recorded dialogue whose impact and value [have] a dramatic qualitative difference over the traditional, hard-copy journal system.[23]

Five years after joining the Arpanet, the NLS Journal system had 30,000 accession numbers. Approximately 20,000 were used for Journal items and 10,000 for catalogued hard-copy items. Both whole documents and think pieces appeared as items in the Journal. In addition to sequencing items as a record of a

"conference session," any item could become a part of another "session" or be used as a citation link. Moreover, authors had the option of restricting access of an item to a specified distribution list, and the item would not appear on public indexes.

In addition to the Journal, the NLS system was equipped with a Shared-Screen Telephone option. This option developed from a special "connection" feature in the NLS system that allowed mutually agreeing users of Display NLS to connect through the computer system by sharing the same NLS control and display portrayal.

> In this mode of teleconferencing, two or more people, positioned at separated display consoles, can link their displays so that all see the same image, and at option any can exercise control. When simultaneously talking on the telephone the resulting dialogue can be uniquely effective—corresponding to an in-person conference around a collective assemblage of their scratch pads, working records, and individual support facilities. To add extra power to such sessions, special conferencing-aid tools and conventions can certainly be developed to advantage.[24]

Both the Journal System and the Shared-Screen Telephone option demonstrated how computers could be used to support "collaborative dialogue." From Engelbart's perspective, the most important feature of networking was bringing together human resources—knowledge, skill, creativity, intelligence, and drive. In the early 1970s, he envisioned a future in which collaborative human communication was built on a foundation of computer networks.

Aftermath

The Arpanet technology made it possible for outside research groups to connect to a computer network and use the NLS system with the bootstrapping methodology. In the early 1970s, the wider ARPA-funded community of computer researchers was beginning to join the bootstrapping process. Ironically, just when Engelbart decided that team augmentation or workgroup computing would be their goal, his own team began to experience growing pressures from the bootstrapping process. These pressures were technological, psychological, and social.

The technological pressures Engelbart's team experienced came from the building of a computer system that tried to keep pace with the latest hardware and software advances. Consequently, the system changed every six to eight months and had to be constantly upgraded or redesigned. The social pressures were the result of people on a regular basis having to learn new roles, change old attitudes, and adopt different methods of working together and with the technology. Thus, the augmentation project became very difficult for the development team, who, in addition to developing the technology, were also the experimental subjects for the bootstrapping process. Psychologists and sociologists were brought in to serve as observers and facilitators; and they became as important to the team as the hardware and software developers.

The psychologists observed, first, that people are resistant to change in the workplace. Second, people who initially opposed learning a system become equally unwilling to give it up after they have learned it. Initial resistance to technological change is partially grounded in a general fear of the unknown. This resistance to change is an essential part of introducing new technologies into established organizational settings. The psychological and organizational tensions created by resistance to change were apparent in Engelbart's team. Team members were required to observe themselves in order to create methodologies and procedures that advanced with the developing computer technologies. As a result of these pressures, a number of team members left ARC to work at Xerox PARC.

In the early 1970s, he envisioned a future in which collaborative human communication was built on a foundation of computer networks.

Although members of Engelbart's team moved on to other research projects, NLS continued to be developed. It developed at SRI over a 13-year span and was then sold when the ARPA funding ended. At the point when the ARPA funding stopped, Engelbart had more or less invented half the concepts of modern computing. Without funding, the staff went from a high of approximately 35 people down to a dozen, and finally Engelbart was left alone with the software. In 1978, the commercial rights to the NLS system (renamed Augment) were transferred to the Tymshare Corporation (owned by McDonnell-Douglas), and the system continued to be developed for another 12 years in a commercial form. At Tymshare, solid enhancements were made to the Conference Subsystem, the Mail System, and the Journal System. Augment was then marketed as an integrated office automation system and used by the U.S. Air Force. However, the Augment software ran on big computers, and business waned when personal computers proliferated in the 1980s. In 1988, Engelbart recalled:

> while it was exciting to see bits and pieces of the original NLS . . . appear commercially over the years, many of the system's conceptual core [ideas] have only recently been recognized: outline editors (for easy manipulation of ideas); hypertextual linking capabilities fully integrated into the system; a system of recorded dialogue that transcends most mail systems; user programmability and customizability of the system; and most important, tools for augmenting not just individual knowledge workers but also teams of people both coresident and distributed over the world interacting through a networked environment.[25]

Engelbart-originated ideas have played a major role in the development of the computer industry. But Engelbart is not rich or famous, despite the fact that he originally developed many of the concepts and techniques embedded in personal computers and the World Wide Web. Today, Engelbart's vision of using computers to enable people to better handle complexity and urgency continues to evolve. Currently he has expanded his original conceptual framework and is exploring how to create high-performance human organizations through the use of computer tools such as groupware. Engelbart states:

> My own vision about pursuing high-performance organizations has matured over the years into a quite comprehensive, multi-faceted, strategic framework. It may seem a bit radical

in nature, but my continuing hope is that it will be merged into such a shared community vision.[26]

Presently, Engelbart is head of the Bootstrap Institute, which he founded in 1989 and runs with his daughter Christina. He divides his time among research and development, writing publications, consulting, public speaking, and leading seminars. Information describing Engelbart's current concepts about computing and the Bootstrap Institute can be found on his web site: http://www.bootstrap.org.

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