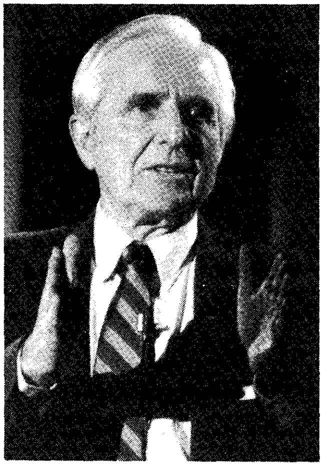
SESSION 4: 3:30–5:30

THE AUGMENTED KNOWLEDGE WORKSHOP

Doug Engelbart
Introduction by Charles Irby

When I left Glen's group, I spent a year working for Lytton Industries on the ground control system supporting a precursor to skylab. Then I went to a conference that was being held up in San Francisco. It was the Fall Joint Computer Conference. This particular conference was very, very special for me and for a lot of people because there was an hour and a half session in which Douglas Engelbart from the Augmentation Research Center at SRI in Menlo Park, California, gave a live video demonstration of a highly interactive computer graphics and computer text manipulation system that had been developed at SRI. I went to that particular session not knowing what to expect, and I was completely blown away. I happened to find afterward the particular person who seemed to be in charge technically; his name was Bill English. I cornered him and said, "This is really nifty and I think I can help you." And he. said, "We're looking for a few good men. Why don't you come by?" The next week I went by and the personnel department said, "No, we have no openings." I said, "Wrong. I'm going to sit here until Bill English comes to talk to me." (I was fairly bold in those days.) And he did. They hired me, and it was the beginning of a seven-year effort on my part at SRI with Doug Engelbart. A great many of the concepts that people now think of as commonplace, like the mouse and multiple windows, editing across windows, integrated text and graphics—all those things originated, from my point of view, from Doug and his group at SRI.

I'd like to introduce Doug Engelbart and his perspective of the last 20 years or so.



Doug Engelbart is a pioneer in the design of modern interactive computer environments. He holds the patent on the mouse; created the first two-dimensional editing system, and was the first to demonstrate such things as the use of remote procedure protocols, mixed text-graphics, and shared screen viewing.

Doug holds a B.S. in EE from Oregon State University and a Ph.D. in Electrical Engineering from the University of California at Berkeley. His career has led him from the U.S. Navy as an electronics technician to NASA's Ames Research Laboratory and then to Stanford Research Institute (now SRI International) where he led the team that designed and built the NLS "Augmented Knowledge Workshop."

From January 1977 to March 1984 Doug was a Senior Scientist at Tymshare, Inc., Cupertino, California. In 1984, Tymshare was acquired by McDonnell Douglas. Doug continues as a Senior Scientist in the Information Systems Group, promoting the type of integrated-system architecture conceived and implemented by him at SRI International.

The Augmented Knowledge Workshop

Doug Engelbart
McDonnell Douglas

Introduction

The story of my involvement with on-line workstations begins in early 1951 with a vision and a life-time professional commitment. Over 34 years of pursuit have created a lot of personal history, and the object of this historical exercise, the workstation, occupies a unique place in it.

For me, a workstation is the portal into a person's "augmented knowledge workshop"—the place in which he finds the data and tools with which he does his knowledge work, and through which he collaborates with similarly equipped workers. I consider that the large system of concepts, skills, knowledge, and methods on the human side of the workstation has to be taken into account, in a balanced way, when pursuing increased human effectiveness. So, my workstation-history story embraces a rather large sphere.

The task of writing an historical piece is unfamiliar enough to cause me difficulty by itself, but the associated stirring of old records and old memories has added a nearly overwhelming burden of dreams, events, people, stresses, pleasures, disappointments—the firsts and the failures. Now, what from all of this—and how to organize it—will make an appropriate "history" paper? I could provide a solid measure of objective reporting—events and dates. I have been an involved observer of related computer history since 1951. I watched and experienced how the supportive hardware, languages, and architecture evolved; witnessed the people and efforts that brought time-sharing into being; and was even more closely involved with the emergence of computer networks. Through all of this, I was wholly focused on what these things could do for people at workstations. And then there was office automation and personal computers; you don't have to be an old guy to have watched these emerge, but I'm sure they looked different to me than to most.

I could also provide lots of objective reporting about the events and dates associated with the things I have caused or had a direct hand in. There seems to be a lot there that is quite relevant to this "history of the workstation" theme. It was dusty, laborious work, this process of brainstorming for candidates, culling and ordering and trying to describe them in some reasonable sequence and context. But what I came to realize is that there is one, clearly dominant factor that underlies essentially every cause for any uniqueness that I might list for historical record. It isn't a technology, it isn't a science, and it isn't a marketing or business model. And I am going to give it dominant coverage in this paper. It is what I call my "Framework." My Framework is based upon an intuitive conviction, implanted in my head (apparently permanently) over 30 years ago, that the gains in human knowledge-work capability that we will achieve by properly harnessing this new technology will be very large. Metaphorically, I see the augmented organization or institution of the future as changing, not as an organism merely to be a bigger and faster snail, but to achieve such new levels of sensory capability, speed, power, and coordination as to become a new species—a cat.

Based upon this conviction about huge potential gains for mankind, my Framework explains for me generally where such gains are going to come from, and provides strategic principles that can help guide a conscious pursuit of these gains.

Genesis

I was several years out of school, possessing a B.S. in electrical engineering and two years' experience during World War II (halfway through college) as an electronics technician. I was doing odd-job electrical engineering work at Ames Research Laboratory in Mountain View, California, with the National Advisory Committee for Aeronautics (NACA, forerunner of NASA). For several months I had been devoting most of my spare time to searching for professional goals; for some reason I wanted to invest the rest of my heretofore aimless career toward making the most difference in improving the lot of the human race.

I had initially dashed off in many fanciful directions, but yet managed enough interludes of reasonably sober thinking to build up some useful, strategic generalizations. Retreading myself professionally, to become proficient and then extraordinarily productive in some new field wasn't worth considering without a significantly attractive scenario, embedded in a reasonably structured strategic framework. The high-payoff scenarios all seemed to involve creating or joining something that, however disguised, would essentially be a crusade. Crusades have many strikes against them at the outset. In particular, they don't connect to a normal source of government or business revenue. They don't have nice organizational frameworks. You can't go out on the streets and expect to find financial, production, or marketing vice-presidents interested in the crusade. Moreover, even if you accomplish the sweeping change that is the ultimate objective, chances are that in this very complex world the side effects might be bad enough to make you wish you hadn't tried.

Suddenly, up through all of this delightful, youthful abstraction bobbed the following clear realization: The complexity of the human situation was steadily increasing; not only that, but its rate of increase was increasing. Along with the increasing complexity had come a general increase in the urgency associated with the more critical problems. If one invented a measure for each of these—complexity and urgency—then for a given problem, the product of its complexity times its urgency would represent a fair measure of the difficulty mankind would find in dealing with that problem.

- FLASH-1: The difficulty of mankind's problems was increasing at a greater rate than our ability to cope. (We are in trouble.)
- FLASH-2: Boosting mankind's ability to deal with complex, urgent problems would be an attractive candidate as an arena in which a young person might try to "make the most difference." (Yes, but there's that question of what does the young electrical engineer do about it? Retread for a role as educator, research psychologist, legislator, . . . ? Is there any handle there that an electrical engineer could . . . ?)
- FLASH-3: Ahah—graphic vision surges forth of me sitting at a large CRT console, working in ways that are rapidly evolving in front of my eyes (beginning from memories of the radar-screen consoles I used to service).

The imagery of FLASH-3 evolved within a few days to a general information environment where the basic concept was a document that would include mixed text and graphic portrayals on the CRT. The imagery carried on to extensions of the symbology and methodology that we humans could employ to do our heavy thinking. There were also images of other people at consoles attached to the same computer complex, simultaneously working in a collaboration mode that would be much closer and more effective than we had ever been able to accomplish.

Within weeks I had committed my career to "augmenting the human intellect." In a few months, I left the NACA and enrolled as a graduate student at UC Berkeley, where Professor Paul Morton had started a computer science activity (although it would be many years before universities began calling it that). He was several years along in developing the California Digital Computer (CALDIC).

Within a few years I had to accept the fact that research on any kind of interactive computer applications would not provide me with a program acceptable to the university community for Ph.D. and later faculty pursuit. So, I settled for something else, got my Ph.D., and went to Stanford Research Institute (SRI) where I hoped ultimately to promote support for an augmentation program.

FRAMEWORK

That was 1957. By 1959 I was lucky enough to get a small grant from the Air Force Office of Scientific Research (AFOSR, from Harold Wooster and Rowena Swanson) that carried me for several years—not enough for my full-time work, but by 1960 SRI began pitching in the difference.

It was remarkably slow and sweaty work. I first tried to find close relevance within established disciplines. For a while I thought that the emergent AI field might provide me with an overlap of mutual interest. But in each case I found that the people I would talk with would immediately translate my admittedly strange (for the times) statements of purpose and possibility into their own discipline's framework. When rephrased and discussed from those other perceptions, the "augmentation" pictures were remarkably pallid and limited compared to the images that were driving me.

For example, I gave a paper in 1960 at the annual meeting of the American Documentation Institute, outlining the probable effects of future personal-support use of computers. I discussed how a focus on personal support would change the role of their future systems and how such a change would enable more effective roles for the documentation and information specialists.[1] I received no response at all at the meeting. One reviewer gave a very ho-hum description of the paper as the discussion of a (yet another) personal retrieval system. Later, during a visit to a high-caliber research outfit, an information-retrieval researcher got very hot under the collar because I wouldn't accept his perception that all that the personal-use augmentation support I was projecting amounted to, pure and simple, was a matter of information retrieval—and why didn't I just join their forefront problem pursuits and stop setting myself apart?

Then I discovered a great little RAND report written by Kennedy and Putt[2] that described my situation marvelously and recommended a solution. Their thesis was that when launching a project of inter- or new-discipline nature, the researcher would encounter consistent problems in approaching people in established disciplines. They wouldn't perceive your formulations and goals as relevant, and they would become disputative on the apparent basis that your positions were contrary to "accepted" knowledge or methods. The trouble, said these authors, was that each established discipline has its own "conceptual framework." The enculturation of young professionals with their discipline's framework begins in their first year of professional school. Without such a framework, tailored for the goals, values, and general environment of the respective discipline, there could be no effective, collaborative work. Furthermore, if such a conceptual framework did not already exist for a new type of research, then before effective research should be attempted, an appropriate, unique framework needs to be created. They called this framework-creation process the "Search Phase."

So, I realized that I had to develop an appropriate conceptual framework for the augmentation pursuit that I was hooked on. That search phase was not only very sweaty, but very lonely. In 1962, I published an SRI report entitled, "Augmenting Human Intellect: A Conceptual Framework."[3] With the considerable help of Rowena Swanson, this was condensed into a chapter of a book published in 1963.[4] I can appreciate that these framework documents appear to many others as unusably general and vague. But, for me, the concepts, principles, and strategies embodied in that framework look better and better every year. The genesis of most of what was and is unique about the products of the augmentation work can be traced back to this framework, which I'll return to later with a fuller description.

PROGRAM SUPPORT

I submitted many proposals before getting support to pursue the augmentation program outlined in the Framework report. Among the stream of politely phrased regrets, there was one that, in contrast to today's environment, can provide useful perspective on the environment of 1961. Four high-quality civilian experts had been enlisted by one agency as a site-visit team—a brain researcher, a psychologist, and a computer expert—and for me it was a very enjoyable day's dialog. But the subsequent letter from the agency informed me regretfully that (paraphrased) " . . . since your interesting research would require exceptionally advanced programming support, and since your Palo Alto area is so far from the centers of computer expertise, we don't think that you could staff your project adequately. . . . "

When J. C. R. Licklider ("Lick") came from Cambridge to take over ARPA's newly formed Information Processing Techniques Office (IPTO) in late 1962, I was figuratively standing at the door with the "Conceptual Framework" report and a proposal. There the unlucky fellow was, having advertised that "man-computer symbiosis," computer time-sharing, and man-computer interfaces were the new directions. How could he in reasonable consistency turn this down, even if it was way out there in Menlo Park?

Lick moved very swiftly. By early 1963 we had a funded project. But, whereas I had proposed using a local computer and building an interactive workstation, Lick asked us instead to connect a display to the System Development Corporation's (SDC's) AN/FSQ32 computer, on site in Santa Monica, to do our experimenting under the Q32's projected new time-sharing system. (Converting the Q32 to be a time-shared machine was SDC's IPTO project.)

Later that year, our project was modified to include an online data link from Menlo Park to Santa Monica, with a CDC 160A minicomputer at our end for a communication manager, supporting our small-display workstation. For various reasons, not uncommon in pioneering ventures, that first year was very unproductive relative to the purposes and plan of our project. Lick was willing to put some more support into the direct goal (more or less as originally proposed), but the support level he could offer wasn't enough to pay for both a small research staff and some interactive computer support. 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.

What saved my program from extinction then was the arrival of an out-of-the-blue support offer from Bob Taylor, who at that time was a psychologist working at NASA headquarters. I had visited him months before, leaving copies of the Framework report and our proposal. I had been unaware that meanwhile he had been seeking funds and a contracting channel to provide some support. The combined ARPA and NASA support enabled us to equip ourselves and begin developing Version 1 of what evolved into the NLS and AUGMENT systems. Paul Fuhrmeister, and later Eugene Gribble of NASA's Langley Research Center, had to stick out their necks as successive heads of Langley's large computational division to support the direction and supervise NASA's support for our program, which continued several years after Taylor left NASA to join ARPA's IPTO office.

Our ARPA support grew and was fostered by Lick's successors—Ivan Sutherland, Bob Taylor, and Larry Roberts. Meanwhile, the Air Force's Rome Air Development Center, at Rome, New York, began to supply supporting funds. By 1967, it was recognized that the respective contributions from ARPA, NASA, and RADC represented significant parts of a coordinated program. The other agencies began funneling their funds through RADC, which served for many years to both monitor and manage our contracts, as well as provide their own significant share of support funds. John McNamara and Duane Stone provided strong support and contract liaison from RADC.

NASA support ended by 1969, and ARPA and RADC provided significant support until 1977, although from 1974 the funding became even more for supporting applications and developments for other organizations, for targets formulated by others (e.g., the National Software Works). The continuing pursuit of augmentation along my strategic vector virtually stopped.

The Augmentation Research Center (ARC)

An historically important organizational cluster emerged at Stanford Research Institute in the 1960s, peaked about 1974, and was scattered in 1977—with a small core carrying forth in a commercial (and then industrial) environment to the present. It grew by ones and twos from 1963, as it collected ''permanent'' members from the SRI technical staff, and recruited new ones from the outside. By 1969 I believe we were about 18 strong; this grew steadily until by 1976 we totalled about 45. In 1973 we made two explicit subgroups, one headed by Dick Watson doing development of software (and some hardware), and one headed by Jim Norton handling operations and applications support.

SRI was organized by divisions, each containing a group of laboratories, the hierarchy being formed according to the associated disciplines. ARC grew to laboratory size and status, but it became something of a problem for SRI. Other laboratories (at least in science and engineering) operated more or less as a ''farmers' market,'' where small and changing clusters of researchers promoted and conducted research projects as a loose federation. The management structure, budgeting, accounting, and financing for the Institute had evolved to support this kind of business. But ARC was driven by a coherent, long-term pursuit. This involved the continuing evolution of an ever-larger and more sophisticated system of hardware and software. It also came to involve delivering solid support service to outside clients to provide meaningful environments for learning about the all-important process of coevolution between the human-system and tool-system components of our organizations (as per my conceptual framework).

It didn't seem unreasonable to me to pursue this course; things similar and on a grander scale are common for other researchers. It is taken for granted, for example, that funding agencies will build and operate accelerators and observatories in support of research in nuclear physics and astronomy, or will outfit ships and airplanes to support research expeditions. But whatever my perception, there were some significant problems and stresses with which our over-all environment didn't have effective ways to cope. In the particular dynamics involved, there were probably seven relevant parties: me, the ARC staff, other SRI researchers, SRI management and administration, ARC's sponsors, ARC's utility-service clients, and other groups of researchers outside of SRI. It would be an interesting historical study to try to understand the diversity of perception that must have existed among this set of players. What did the different parties perceive for the future of workstations, for the range of function and application that would come about, for the systems architectures and standards that must emerge, and for the impact on the organizations that learned how to harness these most successfully?

Even as a central party in what happened, I've not understood the dynamics. But I am pretty sure that disparities among the perceptions of all of the above parties had a major part in what to me was the "great collapse of SRI-ARC." Even if I had done everything right over the years (a laughable hypothesis), it is now fairly clear to me that it isn't the market's fault if someone fails in trying to sell it something that the market isn't ready for. In other words, I can't blame those other groups. (Which of course makes for a personal problem, since during those times of black discouragement when one wants desperately to blame someone, there is only one candidate—that guy at the head of the list.)

In 1977, SRI judged it better to move our large-system development and external-service activities out from the research institute environment and into a suitable commercial environment. They advertised, entertained prospective bidders, made a selection, and negotiated a transfer of the business to Tymshare, Inc., of Cupertino, California. The system was renamed AUGMENT and marketed as part of Tymshare's integrated Office Automation services. In 1984, McDonnell Douglas Corporation acquired Tymshare, and the small AUGMENT business is now operated as the Augmentation Systems Division of the Computer Systems Company within the MDC Information Systems Group.

SOME OF ARC'S EARLY PRODUCTS—1964 TO 1968

Let's take a look at some of the actual experiments we tried during the years from 1964 to 1968 at SRI. Around 1964 we got off the CDC-160A system, which in fact we were using as a personal system. This was our first, real, stand-alone machine.

Screen Selection Tests and the Mouse

In those days the cost of getting display systems to work was very high. My strategic plan under the above-mentioned framework was to skip the then-prevalent, interactive typewriters and focus from the outset on displays. My assumption was that there is a great deal to learn about how to harness highly interactive display capability, and by the time we really learned how, the prices would be down considerably.

We wanted to start early experimenting with screen selection. The idea of working and interacting very actively with the display meant that we had to tell the computer what we were looking at, so we needed a screen selection device. There was a lot of argument about light pens and tracking balls in those days, but none of those arguments served our needs very directly. I wanted to find the best thing that would serve us in the context in which we wanted to work—text and structured items and interactive commands.

The context was important. So we set up computer-controlled experiments oriented to our working mode, where we assumed that purposeful knowledge workers would be spending a significant portion of their time writing, studying, analyzing, and even debugging. We collected a set of candidate screen-selection devices to test. We did our experiments with our one workstation of that period, which is shown in Fig. 1, together with one of our test devices. In trying to be complete about the array of test devices, I dug up some old notes of mine describing a possibility that eventually turned into the very first mouse (Fig. 2). The tests were carefully run, and we even integrated selection errors and their correction penalties in evaluating the "goodness" of a device. The experiments and their results were fully reported,[5] and later described in a paper.[6] The graph in Fig. 3 is representative of our results.

The mouse consistently beat out the other devices for fast, accurate screen selection in our working context. For some months we left the other devices attached to the workstation so that a user could use the device of his choice, but when it became clear that everyone chose to use the mouse, we abandoned the other devices.

FIGURE 1
CDC3100 workstation at which we experimented with selection devices.

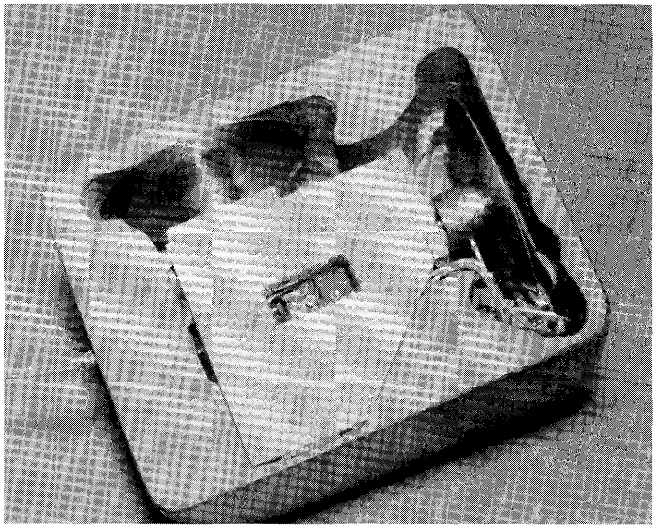


FIGURE 2
Bottom of wooden "mouse," one of the first selection devices.

No one is quite sure why it got named a "mouse," or who first started using that name. None of us would have thought that the name would have stayed with it out into the world, but the thing that none of us would have believed either was how long it would take for it to find its way out there.

We also experimented with a way to move your knee up and down or swing it sideways to move the cursor, so you could keep your hands on the keyboard (Fig. 4). I also built something that allowed one to control the cursor movement by rotating your head for sideways cursor control, or nodding your head up or down for vertical cursor control. This "nose-pointing control" of the cursor left both hands free

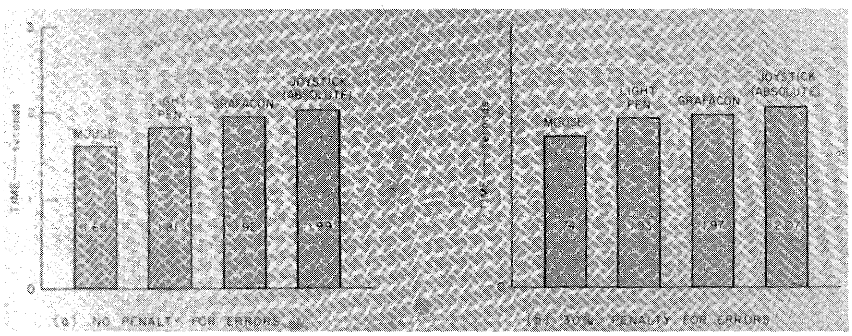


FIGURE 3
Cursor-select test graph comparing various selection devices.

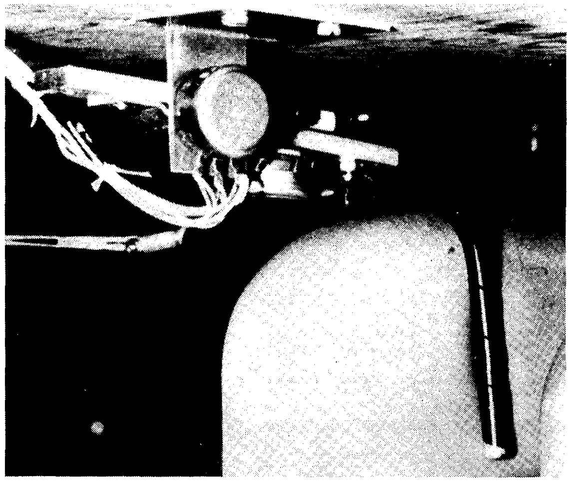


FIGURE 4
An experimental knee control device.

to operate the keyboard. In each case, some muscles would cramp up. Really, in almost any of these cases, you can get used to things like that. I'm sure there are a lot of things to explore in the future about what is going to work best for interfacing, so that you can tell the computer to which objects on the screen you want to direct its attention. However, we had many things to do, so it was a diminishing return for us to pursue these alternative devices—we stayed with the mouse. I have always assumed, though, that something better than the mouse is likely to emerge once the user market becomes more adventurous in exploring the means to higher performance.

OUR MULTI-USER COMPUTER AND DISPLAY SYSTEM, CIRCA 1968

The first time-sharing system we got was an SDS940. We considered a number of alternative ways to provide ourselves with a flexible, responsive display system, and finally designed our own. 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 (Fig. 5). 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 (Fig. 6) 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

FIGURE 5
Our early computer set up with 5-inch CRTs.

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. Figure 7 is a picture of one of our workstations—the TV monitor, with a little wooden table we made and a keyboard and a mouse and a keyset.

We explicitly designed for a detached keyboard. My workstation-design philosophy was to fix it so what you are looking at is positioned for best viewing, and the devices you use to control the computer should be located where it is best for you to operate them. Don't get caught in the anachronism that because we got used to paper and pencil and that technology, we ought to be able to have our controls right

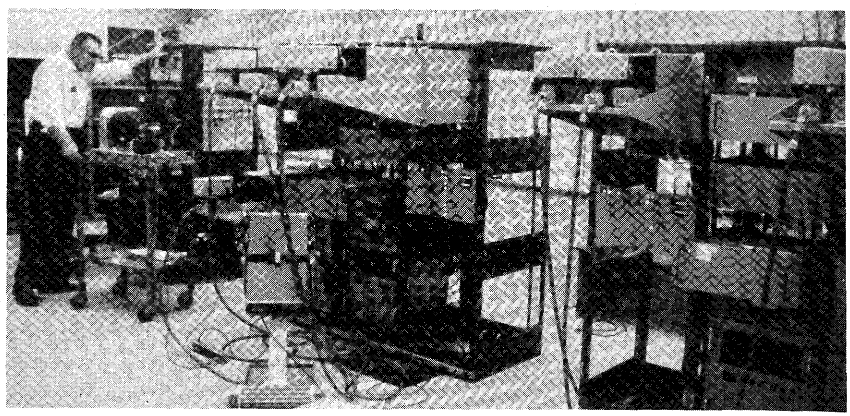
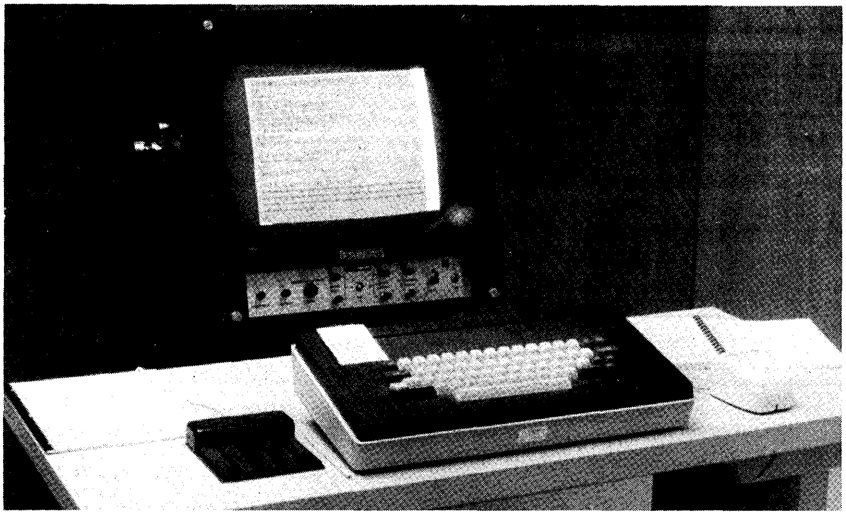


FIGURE 6
The Augmentation Project display system.

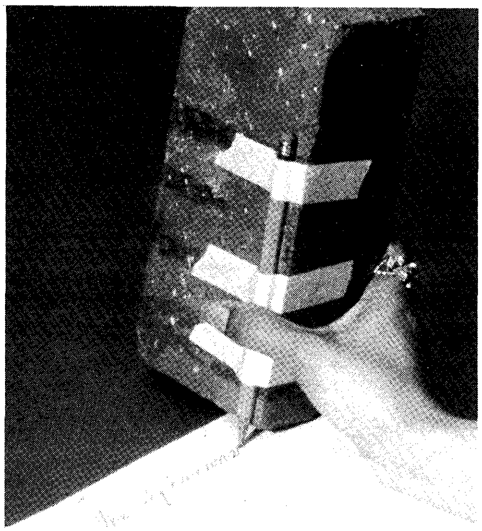
FIGURE 7
Basic workstation: table with keyset, detached keyboard, mouse, and a separate monitor.



on the surface of the thing that we're working on. It may end up that that way is best, but don't make an a priori assumption. So we didn't.

One way of explaining to somebody why it could make a significant difference if you can do things faster, is to provide a counter example. So, I had them write with a brick taped to their pencil (Fig. 8), because it's only a matter of happenstance that the scale of our body

FIGURE 8
Brick "writing" device.



and our tools and such lets us write as fast as we can. What if it were slow and tedious to write? A person doesn't have to work that way very long before starting to realize that our academic work, our books—a great deal would change in our world if that's how hard it had been to write.

What if you speed it up? The keyset shown in Fig. 9, in combination with the mouse, provides a two-handed, higher-speed option. When you strike a chord, the computer interprets it as a character—not really distinguishing between characters generated by keyset or keyboard. Our chord-character code (a binary counting scheme mapped to the alphabet) is not really very difficult, my six-year old kids took less than a week to learn it. At SRI, we had a project in the early 1960s to experiment with computer-aided, psycho-motor skill training, and we used this keyset skill for the very first thing to be learned. The experiment blew up because everybody learned it so fast we couldn't differentiate between those who did and those who didn't have special computer aids.

Figure 10 is sort of the picture that I think about when I'm told that we've got to make it easy to learn. Tricycles are ''easy to learn and natural to use''—no hard balancing problems. How much is it worth to you to extend your mobility? A few hours of learning to balance on two wheels?

By 1968 I had a workstation like the one in Fig. 11 in my office, and I just started ''living'' on it. In our lab we had six to ten more, time-shared among our group. The whole feeling was great. It was a very, very interesting sort of activity in those days. Who says we didn't do workstation research? This one, our ''Yoga Workstation'' (Fig. 12 with Bill Duval), got to be one of the favorites for some reason. This is what you saw all the time—people sitting there in their two-handed working mode, occasionally switching to type on a keyboard.

Figure 13 shows Bill English with a workstation made for us by the Herman Miller office furniture company, who were trying to experiment with us. This little console swivelled on one of the chairs and

FIGURE 9
Keyset input device.

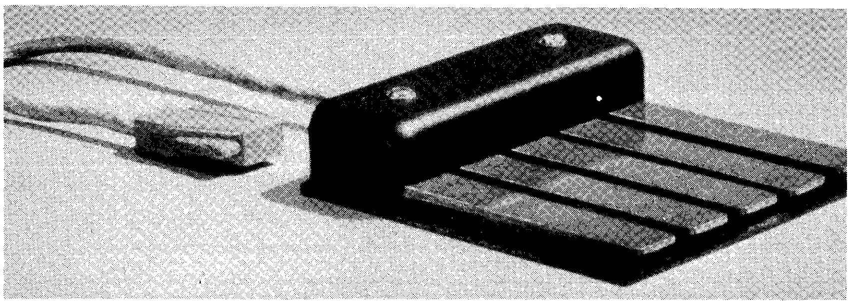
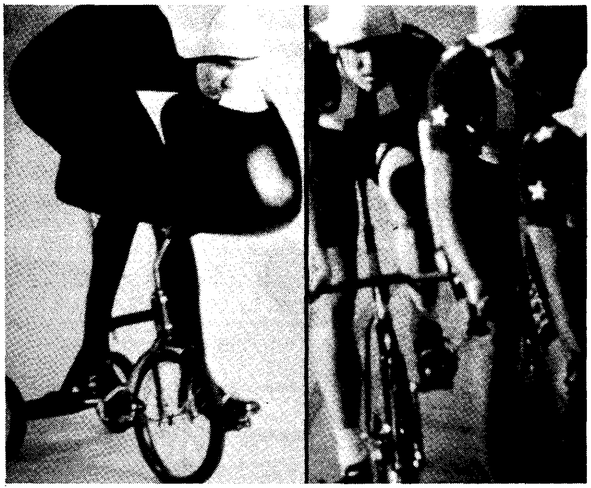
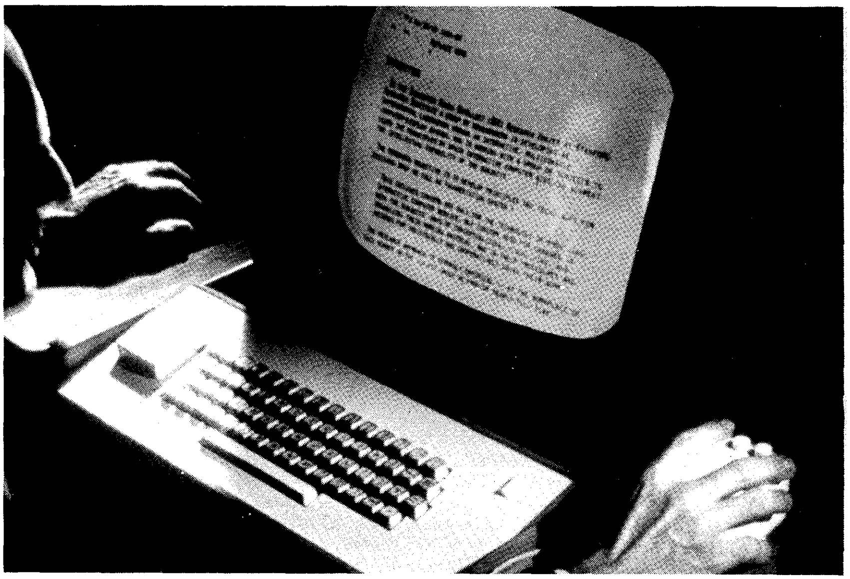


FIGURE 10
Trike/Bike.



went where you went; you could lean back and work with it very nicely. I wanted to show this workstation and Bill English, who deserves an immense amount of credit for getting things to work. I waved my hands and pointed, and somehow didn't make much progress. But Bill really made things work in those days, so I owe him a lot.

FIGURE 11
Doug's office workstation replicated 6–10 times in the lab.



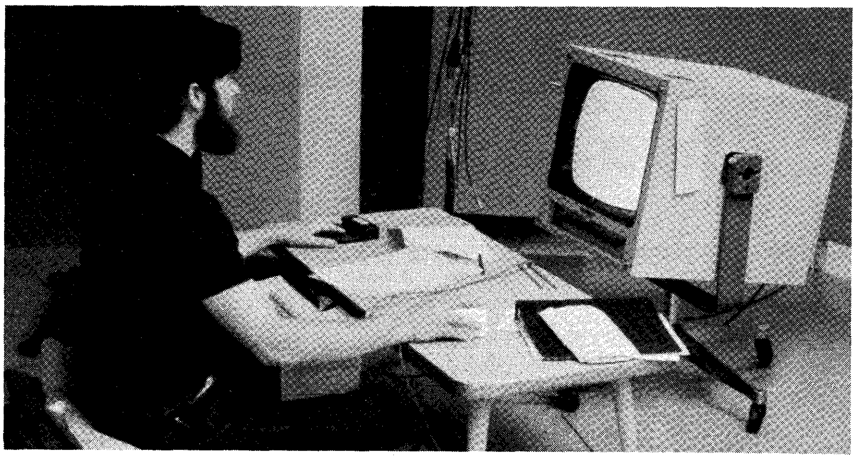


FIGURE 12
Yoga workstation—Bill Duval is pictured here.

OUR "BIG SHOW"—THE 1968 FALL JOINT COMPUTER CONFERENCE

By 1968 we had a marvelous system. We called it "NLS" (later "AUGMENT"). "NLS" stood for "online system," in contrast to "offline system," which we dubbed "FLS" just to have different acronyms. A few people would come and visit us, but we didn't seem to be getting the type of general interest that I expected. I was looking for a better way to show people, so we took an immense risk and applied for a special session at the ACM/IEEE-CS Fall Joint Computer Conference in San Francisco in December 1968.

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

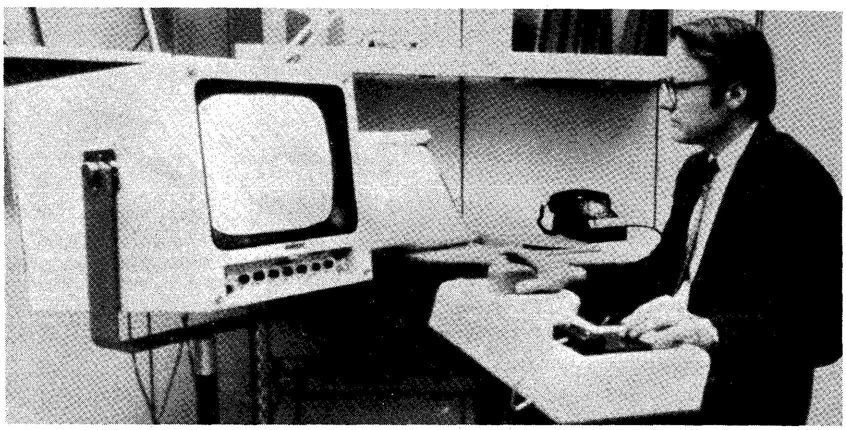


FIGURE 13
Bill English at our Herman Miller designed workstation.

video projector could put up our display images so you could read them easily from up in the balcony (Fig. 14). 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 console. We set up a folding screen as a back drop 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. It cost money—running that video projector, and getting people to help us do all of that, cost money; making the special I/O cost money; and leveraging special remote-presentation technology on top of our advanced, developmental laboratory technology created extra risk—and I was using research money. The nice people at ARPA and NASA, who were funding us, effectively had to say, ''Don't tell me!'' because if this had flopped, we would have gotten in trouble. But anyway, it worked, and the main reason was because of Bill English's genius for making things work.

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

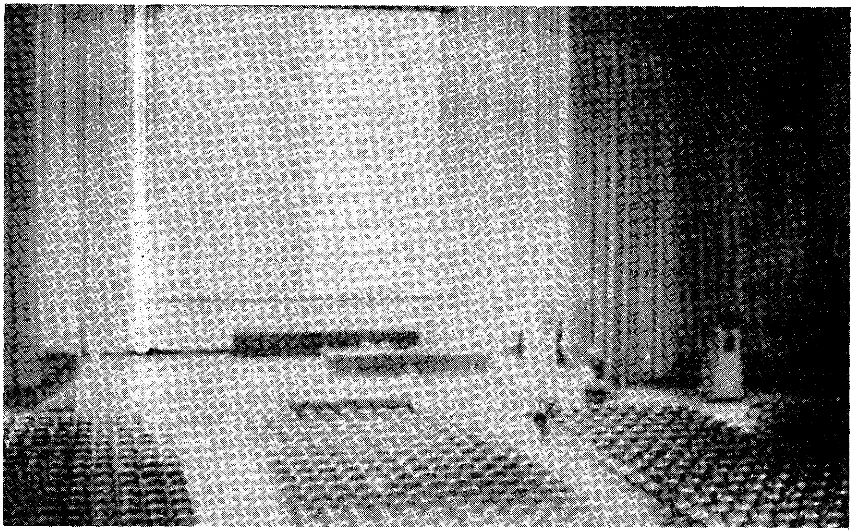


FIGURE 14
Auditorium of the ACM/IEEE-CS Fall Joint Computer Conference, December 1968.

camera people. One of our friends, Stuart Brand, who was at that time working on his first *Whole Earth Catalog,* helped as well. So it was really a group project; there were about 17 of us.

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.

We didn't use any specially made system capabilities; we were just using NLS the way it worked at that time. It had mixed text and graphics, so we could use those to display and represent things. We had the agenda in NLS, and we could run different parts and show diagrams; we could do things as examples. So it was a mix of things of: here's the script and stuff to tell you about, and here's the way it runs; we could also bring other display screens or faces, from our SRI lab, in and out on the screen. At that time we firmly imagined that this was the way future conferences would be run.

We could do screen splitting. Figure 15 shows the agenda list with a little marker to show that I'm between two particular items. In Fig. 16, I make a temporary (shopping) list. This was the beginning of our demonstrating ways of structuring ideas. The NLS system supported the user in getting the list organized into categories.

We wanted to show how the mouse works. The projected video showed Don Andrews controlling a cursor from our SRI laboratory by

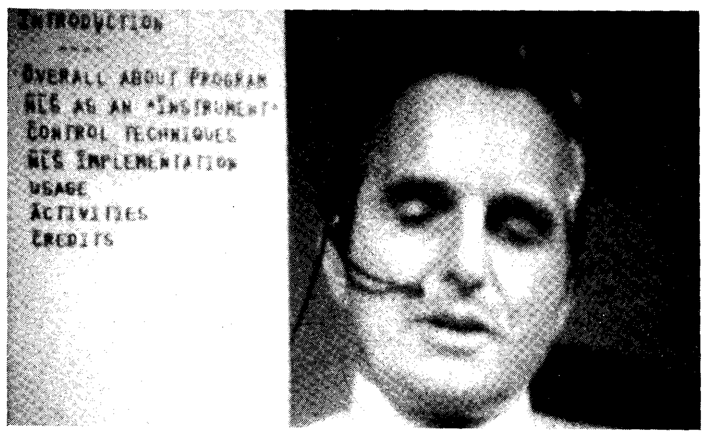


FIGURE 15
Still frame from the FJCC '68. Split screen with Doug on the right and demo agenda on the left.

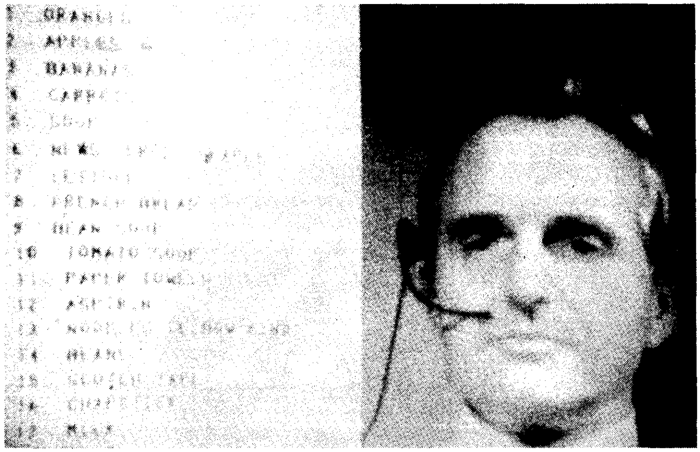


FIGURE 16
The text is now an unstructured shopping list.

moving his mouse around. The superimposed video image of the display screen showed that the cursor would follow it exactly to show how the wheels worked. Remember, this was 1968—the first public appearance of a mouse. I could also show how the simultaneous use of mouse and keyset worked in such a way that the audience could watch my hands in the lower window and see the computer action in the upper window.

Then we brought in Jeff Rulifson to tell about how the software works (Fig. 17). At the same time, his face could be brought in and out

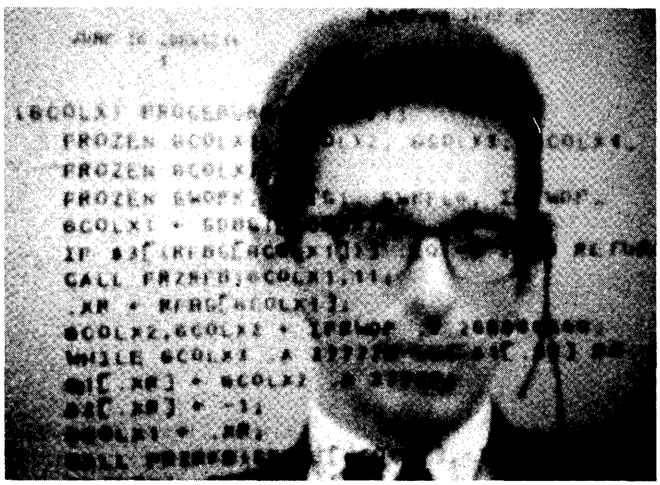


FIGURE 17
Jeff Rulifson can be seen on the screen mixed in behind code of a procedure.

behind the display image that he was working with, demonstrating NLS's power for working with very explicitly structured software. He showed graphical diagrams that were embedded in the source-code documentation. During Jeff's presentation, Bill English brought the picture from a laboratory camera that caught the view (Fig. 18) of Jeff's keyset operation as he was manipulating his demonstration images—unconscious and unhurried—a nice way to show the fluid speed offered by combined mouse and keyset use.

Toward the end, we also showed that we could cut a "hole" in the screen and see Bill Paxton's face from SRI (Fig. 19). For the computer-display part of the screen, we could switch back and forth between his work and mine; and we could also switch which of us was controlling all of this.

The associated FJCC publication about NLS[7] and other relevant references are listed at the end of this paper.

[*Editor's Note:* Engelbart's colleagues—Bill English, Charles Irby, Jeff Rulifson, Bill Duval, and Bill Paxton—all found themselves at Xerox PARC in the 1970s, creating a personal workstation that embodied these ideas.]

NLS ENHANCEMENTS—INTO THE MID-1970s

You can't imagine the relief when it worked. It went on for 90 minutes, and afterward we thought for sure that the world would be talking about everybody starting to augment now. Well, it didn't happen, but we went ahead anyway. I want to discuss a few of the things we did

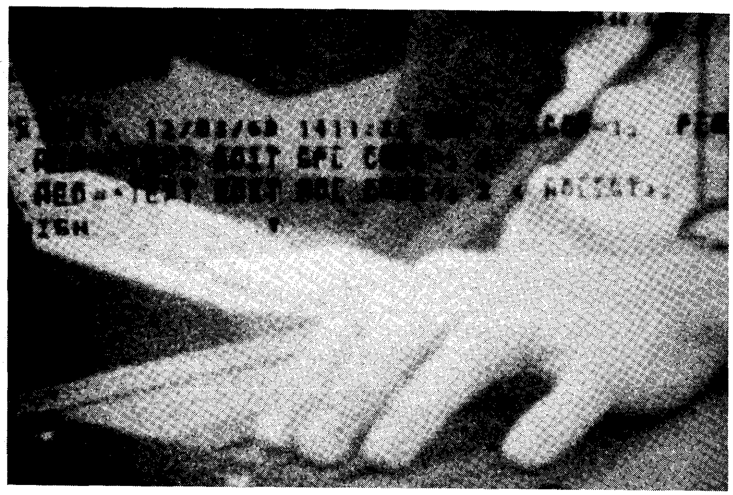


FIGURE 18
Jeff's keyset and hand behind some lines of text.

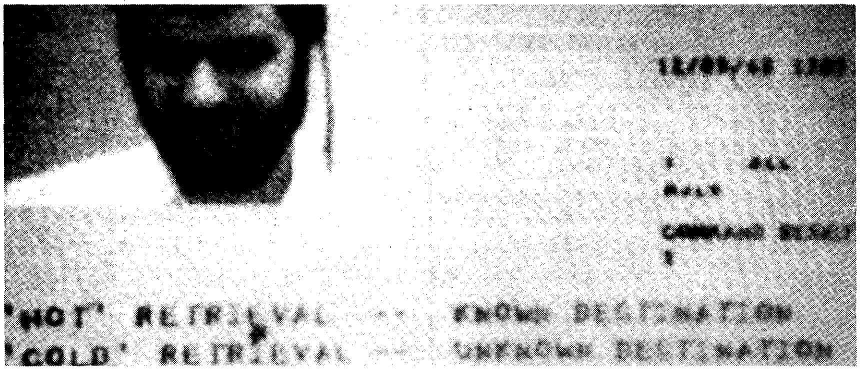


FIGURE 19
View of text retrieval with image of Bill Paxton in background.

physically to the system after that, and then go into some of the conceptual framework.

1969

- We began design of windowing capability for NLS.
- We developed concept of a user "reaching through" his personal work place (i.e., his familiar online working files and application programs) to access less basic, specialized data and application processes (and other people); that is, the "reach through" should provide access to these, translated by the integrated support system, so as to appear as coherent parts of his familiar, personal work place.
- We specified our first mail and "Journal" system as part of an explicit pursuit of a "Dialog Support System," planning for it to be part of our ARPANET-NIC service.
- We developed document-outputting capability processing our composite, text-graphic document files to drive a service-bureau, CRT-based, full-page, Stromberg-Carlson photo printer to produce documentation with graphics and text mixed on the same pages.
- We became the second host on the ARPANET with our SDS 940. (UCLA was first, UCSB next, then the University of Utah, then. . . .)

1970[8]

- Detailed use of NLS began for internal management processes of ARC: cost records, working forecasts, purchase requisitions, and so on.

- We began using the ARPANET to facilitate our reprogramming of NLS for the forthcoming PDP-10 TENEX. The University of Utah had a TENEX on the network, and we used NLS on the 940 to write our new PDP-10 code; using our tree-meta compiler, we developed a cross-compiler for our 940 that produced PDP-10 relocatable binary code. We would ship that over the net for loading and debugging on Utah's TENEX. When the two computers and the intervening network link were all working properly (lots of "flat tires" as in the early days of automobiles), our programmers would do all of this back and forth transitioning "through" the same workstation. I think that it was not only a record-making way of working, but the NLS transport task was accomplished in remarkably short time (we attributed part of the efficiency to the network, and part to the use of NLS).
- We brought NLS up on the PDP-10 TENEX with improved and new features (including multiple windows). The transfer process, and a detailed description of the design changes and new features for NLS are described in a June 1971 technical report.[9]
- We began using our Mail/Journal system within our group. Integrated into NLS, this assumed that a mail item was a document—so any part of all of an NLS document could be sent—and provided for a permanent record in explicitly retrievable form (our Journal). As an electronic-mail system, this was quite advanced. It had a directory service (our Ident System) to provide mail-relevant information about registered users; mail distribution was addressed by people's Idents, with no need to know or specify which host they used. Fields were provided for superceding other items, and for attaching keywords. An online index was provided for stored items.[10]

1972

- We began developing our first, integrated Help system.
- We formulated the "AKW Architecture," implemented in stages.[11]
- We implemented the "shared-screen," televiewing mode of online collaboration between two or more NLS users.[12]

1973

- We brought up a table subsystem in NLS.
- We designed our first, totally modular user interface system, as later described in the *OAC '82 Digest*,[13] and got it running on

a PDP-11 that talked to our TENEX through the network, via our procedure call protocol.

- We developed our line processor, as described by Don Andrews.[14] It incorporated Intel's first microprocessor (the 4004) in a special box that was inserted in the communication line between a dumb display terminal and a modem. This made use of our virtual terminal protocols, and managed a multi-window, two-dimensional screen using off-the-shelf, ''dumb'' display terminals. Our mouse and keyset input devices were plugged into the line processor, which appropriately translated their actions to control cursor position and special communications to the host. A printer port on the line-processor provided local printout service; a special communication protocol allowed the host to send printer packets mixed in with display-support packets.
- We finalized specification for our network virtual terminal, something that has become a key part of our architecture. The objective, on the one hand, was to free the application programmers from worrying about the special features of different workstations, and on the other hand, to enable more flexible evolution by users of workstations they may adopt to fit particular needs. As part of this, there was a terminal-independent display manipulation protocol for communication from application program to terminal, and an application independent input protocol for communicating from terminal to application program.
- We generalized the file structure of our document files to provide for generalized property structures associated with each addressable object, intended to accommodate composite integration of such as graphics, digitized speech, scan-coded images, or any other arbitrary data form.

1974

- We gave up our high-performance, local display system for the line-processor supported, remote display system—to make ourselves live with the same remote services as our NIC clients and Utility customers. (On principle, we gave up our integrated, direct-view graphics and the fast response of our direct-memory-access, local display generator.)
- We opened our ''Workshop Utility Service.'' Delivering NLS service over the ARPANET to DOD customers as pilot applications of office information service. We had gone out on bid for

commercial time-sharing services, selected Tymshare Inc. of Cupertino, Calif.; their host, named Office-1, provided the computer service. We fielded special trainers and application development staffs and cultivated special customer representatives into a spirited community.

1975

- We implemented our new, integrated graphics system, which could support remote display and manipulation of illustrative graphics on a Tektronix 4014 storage-tube display plugged into the line-processor's printer port. Figure 20 shows the graphic-station setup used for development in our lab. Bob Belleville, to the right in the picture, developed this "new" graphics software. (He subsequently went to Xerox and helped them with the Star hardware, and then was the project manager for the Apple MacIntosh.)

In 1973 we had generalized our file structure with provision for attribute-value property structures associated with each hierarchic node. We could then embed arbitrary data objects in our documents. The first utilization was to reinstate embedded graphics, extending our hierarchical list structure and its pointers to the text objects with, for example, an associated pointer on one of the text objects to a graphic substructure for the associated illustration. The user's concept would be shown in an associated "document-page" image. We assumed that soon we would be using digitized speech strings and executable object code as part of our composite documents. And some day, when storage would be cheaper, we would even be embedding scanned images.

An illustration produced as a plotter-driver file by any other graphics system could be picked up and attached to a specified location in an NLS document, and could be subsequently viewed and modified

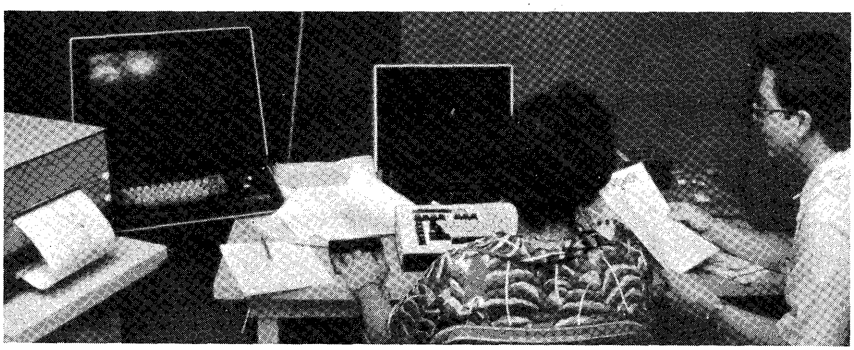


FIGURE 20
Bob Belleville at Tek graphic workstation.

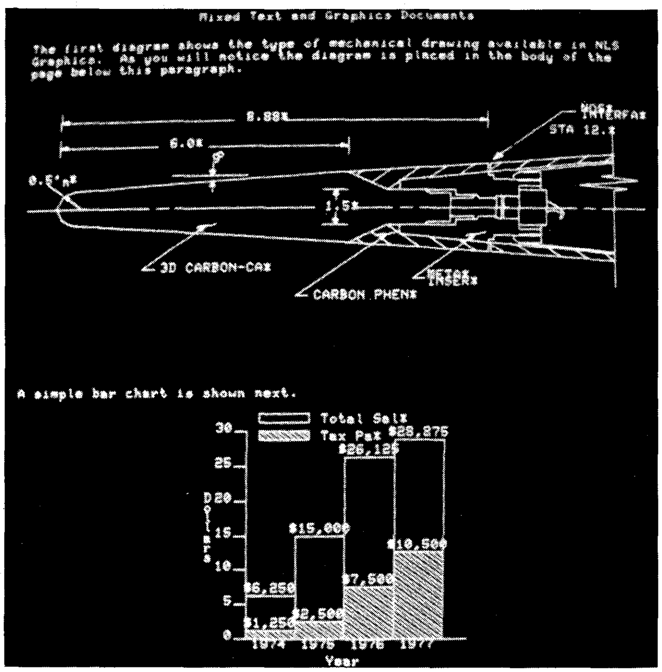
with the NLS Graphics Subsystem. Figure 21 shows two such "ingested" illustrations, as viewed in two adjacent NLS graphic windows. Our use was oriented toward "illustrative graphics," and we had a reasonably complete set of capabilities for construction and manipulation.[15]

By this time, we had a well-developed Output Processor (our "document compiler"), which acted upon a large vocabulary of embedded-text directives to provide font selection, columnation, running headers and footers, and much more.[16] In conjunction with the Graphics Subsystem, the Output Processor was enhanced so that a user could direct that a properly scaled image of any graphic illustration be located appropriately within a multi-font page layout.

All this was available by 1975–1976. But the problem at the time was that for somebody to use this, they would have to buy a $10,000 or $15,000 storage tube terminal to go with the line processor and text terminal. We couldn't get past this business of "if they don't have it, they don't know they need it; and if they don't know they need it, they don't want to buy it." It was a little difficult at the time, so the graphics sort of atrophied until recently.

The whole approach was that our files were document oriented—documents in a very general sense. These are what contain the descrip-

FIGURE 21
Tek view of mixed text-graphic, two-column page, produced with NLS.



tions, arguments, proposals, whatever, the things you're trying to map your thoughts and arguments into to form a communication.

Another thing we did, though, in 1967, was to help people collaborate in face-to-face meetings. Here again, Bill English whipped it all together very fast—special small narrow tables that you could work around and sit at in a conference meeting, where the monitors were down low enough so you could see over them and see each other well. Each monitor had the same image that was brought from our one-user 3100 at the time, but we had one workstation and some mice. Anybody who wanted to pick up a mouse and push the button could, and this would activate a large, special cursor that could be controlled and moved around, so any participant could point out things on the common display. We had a review meeting among our sponsors at the time. The picture (Fig. 22) shows Bill English, Don Andrews, Dave Hopper, and Barry Wesler, who was Bob Taylor's assistant. Bob was in attendance at the time, too, participating in this conference.

Another thing we did by 1970 was to bring up our electronic mail system as part of our collaboration. There was really a very sophisticated mail system with user identification, catalogs, and all sorts of fields that you could use to send and answer things. One extra feature was that you could send whole documents; it didn't matter whether it was a little one sentence note or a whole document.

A document could go in and be catalogued into a system called the "Journal," which was similar to the idea of pasting it down on a table (Fig. 23). We had linkages and internal addressability, so an embedded link in one document could directly cite an arbitrary pas-

FIGURE 22
1967 multi-CRT conference room. Seated are Don Andrews, Dave Hopper, Bill English, Doug, and Barry Wexler.

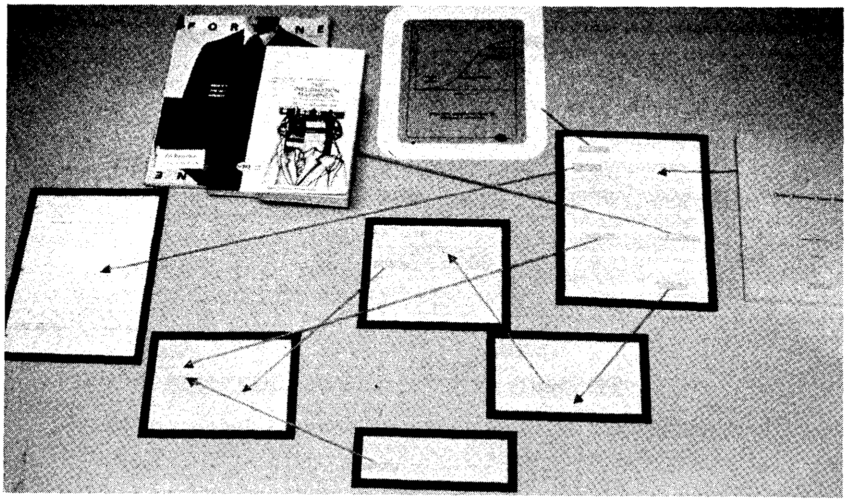


FIGURE 23
Six-document table model of a "Journal" with two linked document items.

sage in any other. Successive documents could be entered in the system and easily be cross-referenced back to each other. This supported what we called our "recorded dialog"—an important part that we assumed was needed for a community of people to work together effectively. It is an extremely powerful capability.

We originally designed our Mail/Journal system to give the user a choice as to whether to make an entry unrecorded (as in current mail systems), or to be recorded in the Journal. I knew that there would be lots of question, and some quandry, associated with the question "to record or not to record." I assumed that many fewer items would be recorded than "should be"—as might be judged after we someday would learn the value and establish criteria for recording. So, I ordained that *all* entries would be recorded—no option. It put some people under considerable strain. I think that one person actually never could bring himself to enter a memo into the Journal—the idea that it was "forever" stopped him cold. Another person, a very valuable contributor, somehow felt violently opposed to the basic concept, and it possibly hastened his departure. But after a year or so, it was used as a matter of course by essentially everyone. There were interesting and unexpected payoffs.

Up until about 1975, we made a practice of printing out every one of the stored documents—mostly as an alternate analytic process to watch the dynamics of Journal use. The documents are stored by number, in binders as shown in Fig. 24. This indicates how big our Journal collection got in about four or five years. The number now for that particular journal is well over 100,000 items. We have an arbitrary

FIGURE 24 Hardcopy of the Journal filled four shelves.

number of other journal systems that customer groups can install and administer themselves, a very powerful potential archive for collaborative work.

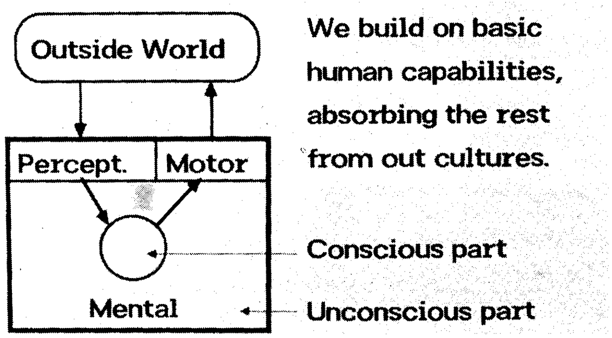
FRAMEWORK—TO 1968 NLS

Let's now shift back to the conceptual framework, originally documented in a 1962 paper.[17] I had this immensely intuitive feeling that humans were going to be able to derive a great deal of capability from computer systems. I had very real images in my mind of sitting at a display console, interacting with a computer, seeing all sorts of strange symbology coming up that we could invent and develop to facilitate our thinking. We would no longer be limited to working with paper and other such laborious means. Other people could be sitting at similar consoles tied to their machine and we could be collaborating in brand new, exciting ways. We could be doing all sorts of things to control a computer.

At that time, even though I didn't know how the innards of a computer worked, I had enough engineering background to know that if a computer could read a card, it could sense keys and any other action I might want to do. If it could drive a printer or card punch, it could put whatever I wanted onto a display. What I didn't understand at the time was the economics and all that, but I said, "Look, I've got a whole career ahead of me, let's go after all of this."

By 1959 or so, I got a chance to sit down and say, "How would that really work? What are the basics?" As an engineer, I ended up with a simplifying model (Fig. 25). Here's a human wanting to do this

FIGURE 25
Starting to think about augmenting the human intellect by beginning with basics.

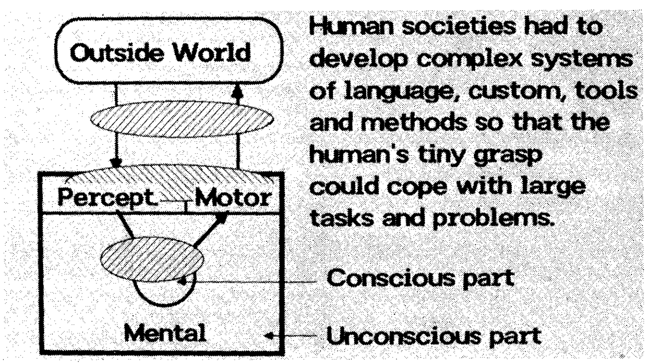


knowledge work; he's got capabilities within his skin that we can make use of, a lot of mental capabilities we know of, and some of it he's even conscious of. Those are marvelous machines there—motor machinery to actuate things in the outside world, and sensor and perceptual machinery to get the idea of what's going on. And that's what he has to support his interaction with the outside world.

How can we improve the human's capability (Fig. 26)? Well, it turns out that there have been a lot of people working on this problem for many generations. And we've got a whole "culture-full" of things that we are indoctrinated and trained into, both conscious things and unconscious things. We have lots of skills, motorwise and perception wise, that we're not even aware of. For example, just how long do you think it took to learn to brush your teeth? It takes quite a while; it's a skill. These sensory-motor things all developed in order to help us interact with the layers of other things that our culture provides.

Many such things are available to us, tools and methods that let us live within a social structure and be effective in our interactions.

FIGURE 26
But our basic mental-motor-perceptual machinery can't do much by itself.

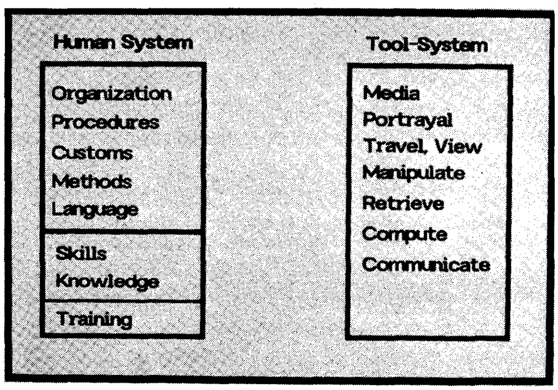


And there's a whole subset of tools and methods that help us be effective in dealing with knowledge work. So take all those things together and call them an "augmentation system" (Fig. 27). That's what augments humans. And for good, practical purposes, let's divide the system into two parts. One part has all the technology in it and the other has all the rest. So I called these the "tool system" and "human system."

The *human system* includes training, knowledge, and skills that have to be installed as well as language, an extremely important invention that transcends, as an invention, anything else we have come up with. The methods, and all that we use to knit together all the little steps that we take during a day, are extremely important. Our customs for working, our procedures, the way our organizations are run, they're all done so that humans can realize effective results. Within this framework, any given capability that a human has is really a composite. The human capability is made up of the use of a lot of things and skills and training and conditioning, in addition to all the customs we just accept and the language that we've learned. It's this composite that we need to find ways to accentuate.

So along comes a lot of new technology for our tool system, which is great. But the technology side, by itself, is not sufficient. Our real capabilities are essentially hierarchical (Fig. 28). We learn a lot of lower-order capabilities, like writing and typing and reading. And we have built up many higher capabilities on top of these. So, if we bring in some new technology, like a longer lasting pen, it's going to make a little bit of effect. But if we bring in the kind of digital technology that was predictable, even in 1960, then potential changes throughout the whole system, affecting significantly the entire capability hierarchy, can begin to take place.

FIGURE 27
It is important to treat it as a two-part augmentation system; one part technology, the other the rest.



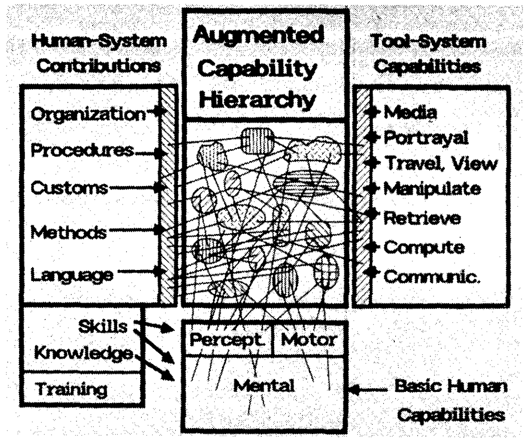


FIGURE 28 Capabilities grow hierarchically.

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. Whenever you hear somebody say it has to be "easy to learn and natural to use," put up a little flag and go question it. What's "natural"? Is there a natural way to guide a vehicle, as with reins? Well, that lasted a long time.

No! What's natural is what we have grown to accept. And if we look at how much learning it took to drive automobiles, and own and operate them, it would make ridiculous the things people say now regarding what they expect their computer system's learning to cost them. If it's going to be the kind of working companion that it's bound to be, then the learning part of it is relatively trivial. I know it's what sells now, because the market isn't very mature for people to buy things that look like they're going to be hard to learn. But I'm talking about the long-term trends, and the responsibilities of people that are doing the research and downstream planning. I think they should start looking much more seriously for really significant gains in human performance and consider many more candidates for change, with special attention to the much-neglected human system candidates. This will bring up lots of things that might not have been even thought of before, because now there is explicit, active "prospecting" for ways to do things differently.

The mouse and the keyset came from trying to do something new in the tool system (similarly for structured files and their viewing and linking). I didn't realize at the time how strange they'd seem and how long it would take for people to start considering them.

So then, how does the change take place? In a large organization (Fig. 29) there are lots of different parties taking part in a change. An idea for change in one place often "needs" help from another before the original idea can be implemented—for example, one might ask if the mail room could make one more daily delivery. Then, when such a need is fulfilled by a change in capability of one of the "lower" parts, it provides new "possibilities" for change among the "higher" parts that depend upon it. Evolution proceeds by reverberation: needs propagate downward, and when fulfilled, a new possibility propagates upward. Correspondingly, a possibility propagated by a new capability in a lower-level place can trigger a new idea in a higher place. Continuing the example, we can improve our operation by taking advantage of the extra mail delivery, but we'd need the copy center to change. . . . Possibilities tend to stimulate new needs.

So when we've got a fairly large organization, or large system of things, with specialists working all over the place that are responsible for changes in certain areas, there will have to be some extraordinary

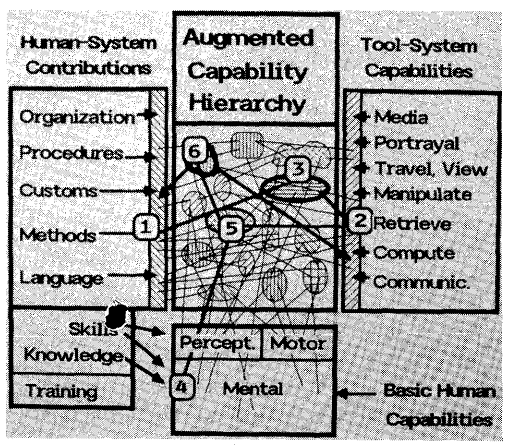


FIGURE 29
Coevolution by reverberation—needs propagate downward and a new possibility propagates upward.

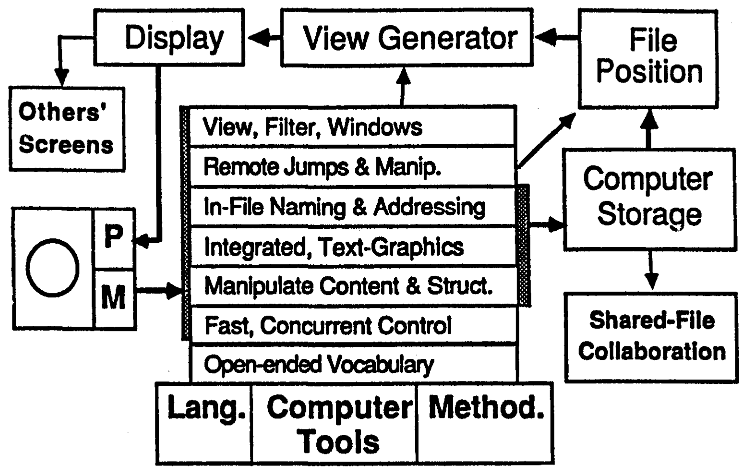
communicating to provide decade-frame evolution on a scale previously requiring centuries. Changes once took place so slowly that we weren't really aware of the evolutionary process. People moved and finally heard about something and tried it. But now, with a catapulting rate of change, and the pressures to become more effective, the changes within our organizations are just going to exceed the rate that we know how to deal with. Unless people start getting conscious and understanding about the evolution, for many, many structures this fast changing rate is going to exceed the elastic limit, and things are going to break.

So I said, "What better place could you start putting to work the new tools and things than in the process that is going to facilitate the evolution you have to go through." That produced a strong push toward computerized documents, and toward collaboration among groups.

One way to look at how to use the computer to help work with documents would be the possibility of a conventional word-processor approach. It's a very straightforward way. The orientation is to simulate paper on a display, targetted solely to produce hard copy. A considerable advantage in many situations, but it is a very anemic example of what the above framework promises.

It didn't even enter my mind to go with that picture. Instead, what my framework produced is shown in Fig. 30. 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 the special modes indicated. The result is quite a bit different from "word processing" and "office automation."

FIGURE 30



For instance, we should have an open-ended command vocabulary. Once we get hooked up to running in a more flexible environment, the computer tools must provide us with more and more functionality. Since we've got a very powerful beast that can do things, let's really look for fast control means where, for instance, we aren't limited to doing things sequentially, but can do things with both hands, concurrently. This stimulated the chord-keyset option.

I thought we should make it so that both content and structure can be stored and explicitly manipulated. Bring text and graphics together, because they're both important.

Every object in a file should be addressable, because I wanted to do remote jumping and manipulation. So we developed a very flexible addressing scheme that seems to fit well with a user's mental map of his working domain and offers handy addressing options that, in any command, can optionally be used in place of cursor selection. One should be able to move around in existing files rapidly and precisely, and easily jump across any intervening ''file or content space'' to an explicitly prescribed position. The computer should help navigate throughout the entire working space.

When I am positioned at a desired file object, I want to generate a view that will best serve my purpose of the moment. So, we evolved a flexible set of ''view specifications'' that can be invoked at any time—and an explicit opportunity is offered the user at any ''jump'' operation to designate ''ViewSpecs.'' For example, ''in this window, show only the first line of each statement, no blank lines between statements, show location addresses (e.g., ''3b4'') in front of each statement, show only the statements hierarchically ''under'' the targeted statement, and only those that are in the first two sub-levels.'' A content filter, of any degree of sophistication, can be invoked within any such ViewSpec so that, among the candidate statements already specified, only those that have a given content will be shown. Simple filters (e.g., to find a given embedded string) can be keyed in at any time and compiled on the fly. More sophisticated filter patterns can be stored as text strings that a user can specify with a ''Set Content Pattern'' command. Or, a programmer can write and compile very sophisticated filters that a user can easily designate by name to be instituted.

With a comprehensive addressing scheme it is easy to implement citation links, special text strings that both user and computer can interpret as addressing some object and also optionally specifying a particular view to be employed. ''Jumping on a link'' is a basic command, taking the user directly to the target object. A link can also be employed as part of the addressing in any other command where some file object is to be specified.

If I am moving around in somebody else's stuff, so I can study and analyze it much more effectively, I want to be able to train the displays myself, because a display may not look as I expect it to look when I'm looking at it straight down on paper, and indeed it doesn't. And do I want it also so that I can share that display with others, so that we can collaborate? And share files? So that's the image, and that's why NLS was designed as it was.

ARCHITECTURE—TO SPECTRUM OF FUNCTION

Now to discuss architecture. I'll use a series of simple illustrations to lead up to the general approach we settled upon. Consider, as in Fig. 31, an application program on top of an operating system in a computer, serving a terminal. For any such application program, there are two facets: an interface process and the actual process that does the substantive work—two different parts. Let's think about them as two distinct but related design issues. For instance, I don't want the smart programmer who knows all about how this program works internally to think that he's the one to tell the world how to interface with it.

By 1968 we had begun evolving the programming language so that it was different for each part, and we could actually think and design for two separate modules (Fig. 32). The next step was to ask, Why, for each different application package, should you have a different front end? Frontends should be universal things, as in Fig. 33, to serve multiple (or all) applications for the user. So our language ideas were evolving to handle this approach. The system that we brought up on the SDS940 in 1968 was organized along these lines, as shown in Fig. 34. All the subroutines that did the application work were written with our special, MOL940 language that we had to develop ourselves. 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. We had a tree-meta translator that let

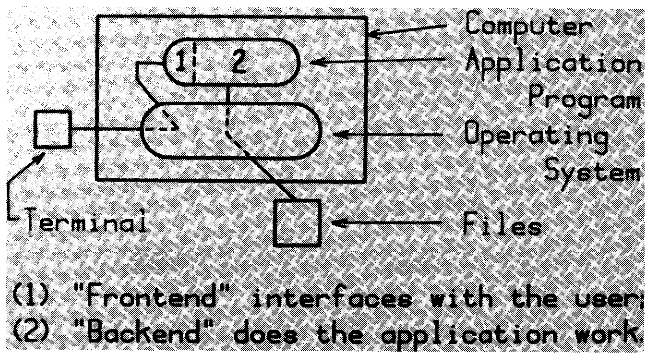


FIGURE 31
An application program has two different tasks: the frontend and the backend.

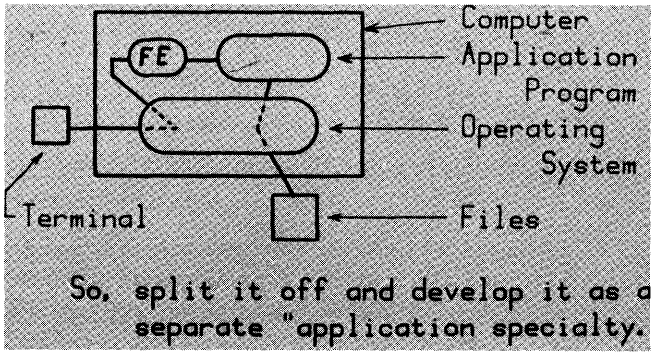


FIGURE 32
Frontend is actually a specialized application program divided into the interface part and actual process work.

us do our compiler compiling. We described a new compiler in a meta-compiler language, then compiled it with the tree-meta translator into the new, running compiler.

Incidentally, in those days I would talk about control language and control metalanguage rather than the command language because I felt that we were doing a lot of things that normally people don't think of as commands. But the pressure of external-world usage pulled us around so now we call it command language.

It was really fortunate for us to be involved in the ARPANET from the beginning. My early ideas of "community" support services could be made explicit in planning for the Network Information Center. One of the papers I wrote[18] pointed out that besides allowing us to share data and process resources, the emergent networks will also provide us with a knowledge marketplace that's wide open for people sitting at their terminals all over the world. Topologically, Fig. 35 depicts what we assumed by the early 1970s would be the future environment for knowledge workers.

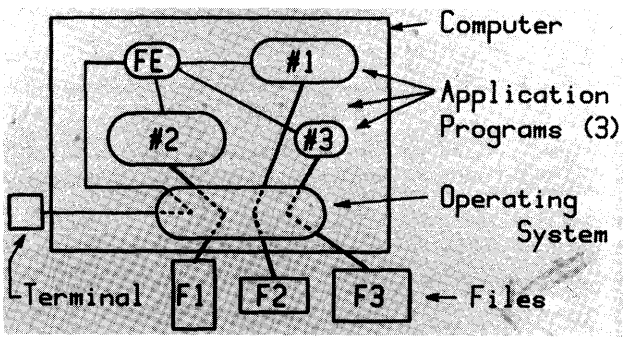
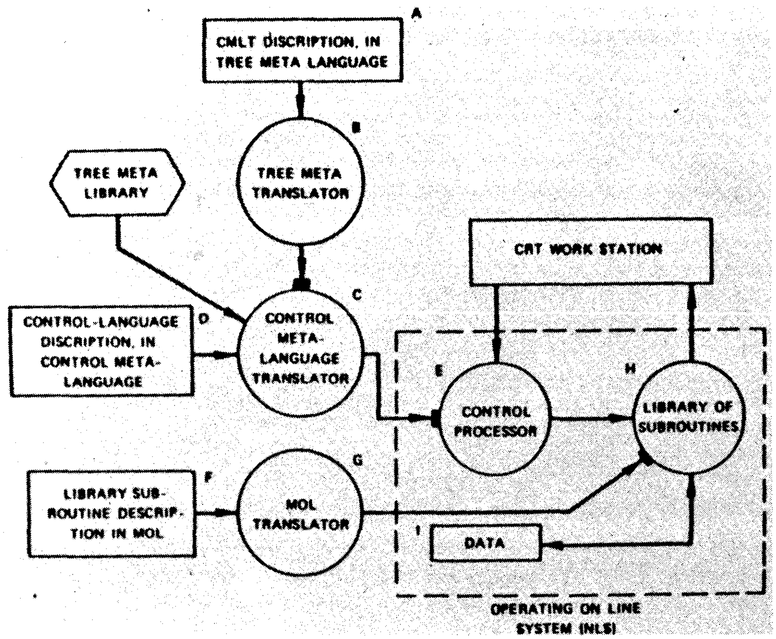


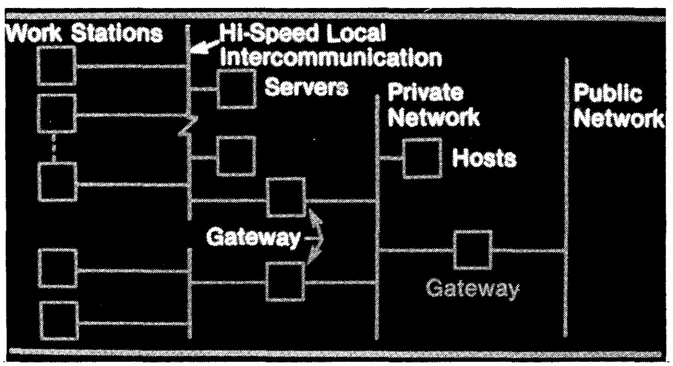
FIGURE 33
Why not provide a general purpose frontend, an all-application "User Interface System"?

FIGURE 34
FJCC'68 system architecture.



Let's not argue about how much functionality is in any one place. To the user, it doesn't matter whether the workstations are smart or not, as long as they do what he wants them to do. So let's look at topology. The topology that we wanted (Fig. 36), involved a user interface system (UIS) that's between the user's physical interface hardware (display, keyboard, mouse) and all the "smart" application

FIGURE 35
Our expected Tool System architecture (network of networks).



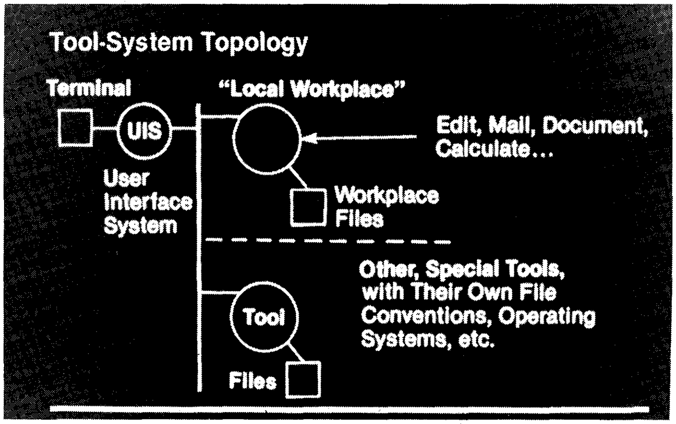


FIGURE 36
Desired Tool System topology.

software. I don't care how much of these smarts are in his local workstation, but I'm never going to say that it all has to be there.

Between the user interface system and all of the application systems is a ''virtual bus''—some UIS communication will be to applications in the local workstation, some to applications on the local-area network, and some may be far out through gateways to the UIS of a colleague. An important part of what we wanted to provide was a set of functions that the user thinks of as his private or ''local'' (topologically) workplace where he does his composing, studying, mail management, and calculations. But also he should be able to ''reach through'' his local workplace to get at all the other services.

The internal architecture of the UIS (Fig. 37) contains a virtual terminal controller (VTC) so all of the applications are programmed to deal with a standard, virtual terminal. The VTC translates to and from particular physical-terminal I/O streams, enabling different classes of terminal equipment for different classes of users—and also, importantly, makes evolution within the whole system easier.

The command language interpreter (CLI) interprets the user actions according to the command-language specification coded into the currently attached grammar file, which was created from a command metalanguage description via the command metalanguage compiler. The CLI also deals with a user-specific, user-profile file that enables individuals and classes of users to have independent control options.

The procedure call interface (PCI) modules translate back and forth between the procedure-call conventions of the various larger modules and the remote procedure call protocol we developed for use between arbitrary modules (including those connected via byte-sequential network circuits).

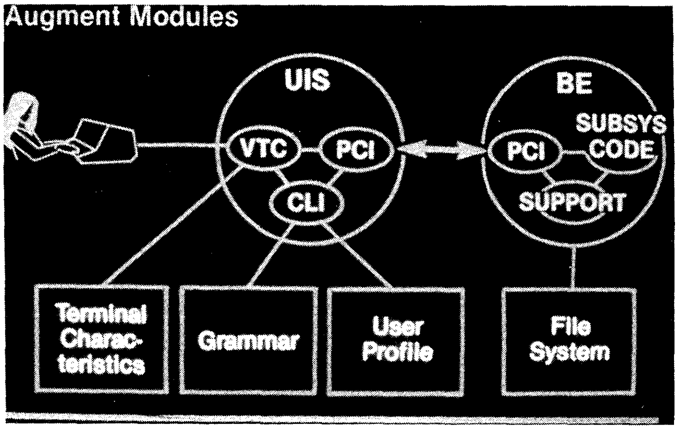


FIGURE 37 AUGMENT Modules (User Interface System with VTC, CLT, PCI, and grammar).

We called this architectural configuration "The Augmented Knowledge Workshop," and figured that all knowledge workers in the future would work in some such environment. The early framework concepts led us to believe that open-ended functionality was inevitable. Also, it emphasized how essential it was to facilitate the coevolution of the human and tool systems. One important objective in this architectural approach was to support this coevolution: Hardware and software could be changed with minimum disturbance to the human system and, conversely, changes in terminology, methodology, and functional dependence upon the tools could evolve with minimum disturbance to the tool system.

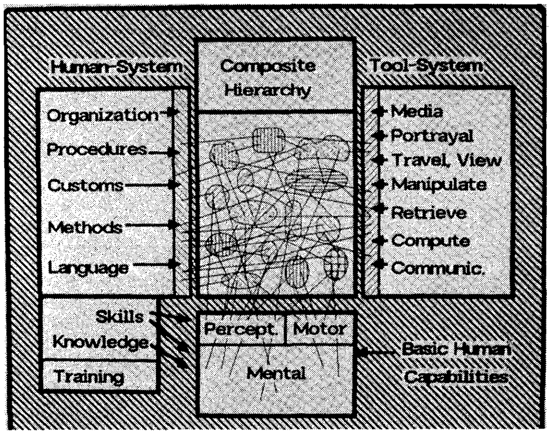
One way to illustrate payoff from this architecture is to consider the different profiles of functionality that different classes of users would likely want to employ as they look through their respective classes of terminals into their "knowledge workshops." A high-level project manager, a support clerk, or a skilled, heavy-working professional can each work with grammar and user-profile files that provide the functionality he or she needs, with command terminology and interaction modes suited to skill levels and ways of thinking.

All of this architecture was working by 1976, although it has only been recently that we could interest user organizations in trying to harness it toward an integrated knowledge-work environment. A number of our publications explicate various aspects of this architecture.[19]

Human Unit, Evolution, and Communities

It is important that the evolution of the user side should go on maximumly; it has been badly neglected. The "basic human unit" is shown in Fig. 38. How are we going to evolve it? The reverberation concept

FIGURE 38
The basic human unit.



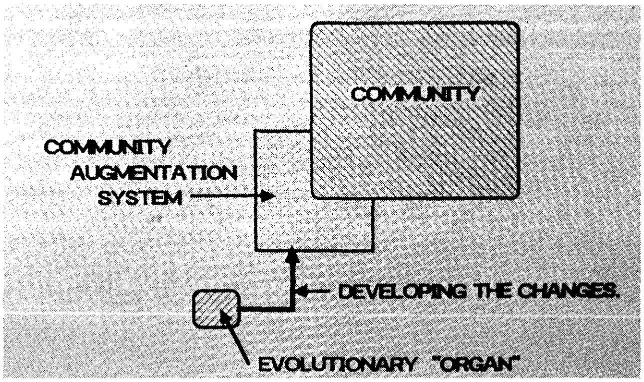
of its evolution is very important in my framework, and I have come to believe that it is only done by what you'd call "communities." Even in a large, highly structured organization much of the change process must involve stakeholders in groupings that are different from the line-management structure (i.e., like a community).

This is a big, important concept that started in the mid-1960s. If we depend critically upon a community that must interact in really effective collaboration, we need to build support systems especially designed for this purpose. Part of the conscious evolutionary process for our large organizations and institutions must therefore be to provide effective collaboration support for widely dispersed communities (Fig. 39).

But how was I going to promote an R&D program, with a "pilot community," to learn how to develop and provide effective "community support" tools and associated new collaborative methods? Well, in the spring of 1967, at an ARPA principal investigators meeting, Bob Taylor and Larry Roberts told us that ARPA was going to make computer network R&D a major program thrust, and that our "research computers" were going to be the ones connected by an experimental "ARPA Network." Even though many others were disturbed by the idea (because of perceived interference with their major research thrusts), I was thrilled. Finally, after listening to the initial interactions, I volunteered to develop and operate what became the ARPANET Network Information Center (NIC).

What I wanted was for the NIC to become a community support center that would really go after the development of collaboration-support tools and methods, and would provide services to encourage the ARPANET R&D folks to evolve their working ways accordingly.

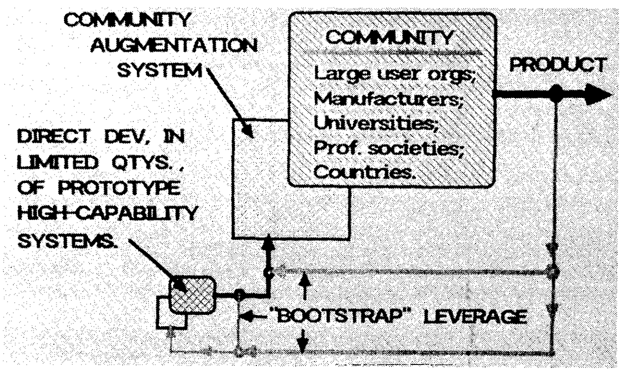
FIGURE 39
An augmented community needs active, explicit, evolutionary mechanism!



Hopefully, there would emerge a subcommunity out there composed of those interested in the various aspects of augmenting (Fig. 40). Just consider the kind of leverage you get this way. So I've talked about a ''bootstrap community'' in my notes for over 15 years now, and it's something I still very much would like to see established (Fig. 41). Many features and capabilities built into NLS/AUGMENT were directly motivated by these community-support and distributed-collaboration concepts.

Unfortunately, the ARPANET grew so fast that the Network Information Center had to trim down what it could do functionally. We couldn't provide the extensive support services we had planned (discussed at some length in a 1972 paper[20]), such as what we could do to support a community by integrating a lot of its dialog, and getting an intelligence system there; handbooks that evolved to integrate what to

FIGURE 40
Needed: A community for pursuit of maximum, whole-system capability!



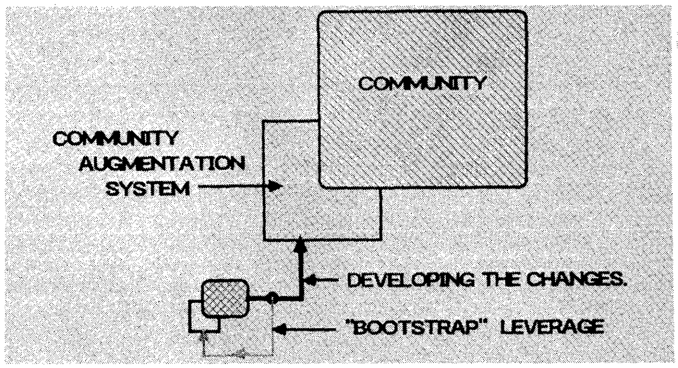


FIGURE 41
Strategy: Early augmentation system changes that also facilitate the evolution process.

do; and professional facilitation staff, which adds important value. There is a lot that can be embedded in this.

NLS/AUGMENT was built to be able to handle external document (XDOC) control, the community intelligence collection that everyone contributes to and participates in, and indexes to it. When the community has a special mission or disciplinary interest, we also could significantly facilitate the development and maintenance of a ''dynamic community handbook'' that integrates current status (terminology, hypotheses, conventions, plans, expectations, and so forth) in a coherent, self-consistent fashion. Figure 42 portrays all of this community support in a fashion peculiar to the NLS/AUGMENT set of features and capabilities. While each user had his own collection of working files, there would be a large collection of shared information—all of it

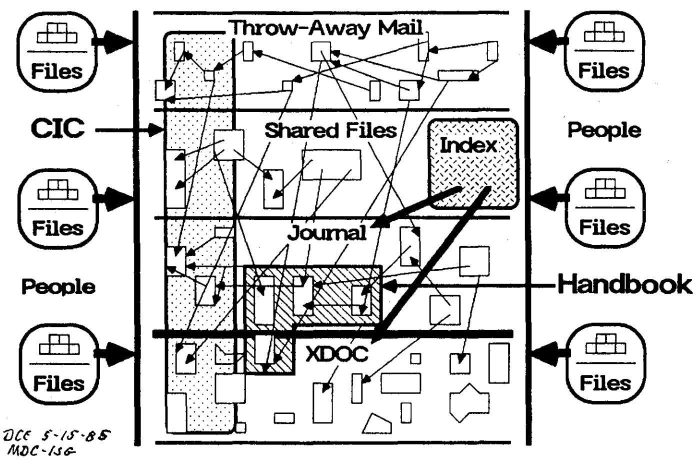


FIGURE 42
A community's handbook would be a periodically updated on/off-line publication.

embedded in uniform, composite-document structures. The generalized citation-link capability interconnects passages of any of these documents in meaningful ways as evolved with user conventions and collaborative methods. Ordinary, unrecorded mail and shared files gain significant value thereby. The Journal system provides its own unique value, considerably amplified with linkage use.

A "community intelligence collection" (CIC) can be distributed over all of the document types—embodying useful information and discussion about external activities relevant to the community's interests. Special indexing into this collection is again much enhanced with links. The Community Handbook fits into the picture nicely; any given "edition" is "published" in the Journal (and is probably available also in corresponding hard copy), which is controlled with the XDOC system.

I'm going to terminate at this point, since after 1976 we really had no chance to continue pursuing this "augmentation framework." It seemed no longer to fit in the pattern of the research at ARPA, or with what SRI wanted to do. When we landed out in the commercial world, we found it wasn't what people there wanted to do, either. The AUGMENT system stayed alive in sort of a funny, dumb way, often like taking a bulldozer in to help people work in their back yards. Then, McDonnell-Douglas bought Tymshare, and inside of its aerospace organization it's a very different situation because of the very heavy knowledge work involved. For a year I've been going out and talking with all those people involved in big projects and CAD systems, and finding out that these concepts are directly relevant to the needs and problems now being recognized there.

We're starting this year to build special interest communities. The first one is the AI community; possibly followed by the Ada™ community. Also, explicit consideration of integrated architectures similar to ours is under way, including not only virtual terminals, command interpreters, remote procedure calls, and shared-screen support, but also composite documents with addressable objects and citation links.

So that's a quick pass over my historical record.

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Participants Discussion

Hank Strub

I'd like to hear your feelings on why it took so long for the mouse to be adopted into personal workstation technology, and why that hasn't happened yet with the chord keyset?

Engelbart

It's part of a larger story that I think fits in with culture. If you looked at the whole map I drew you would see that on the human system side all the opportunities have changed; the technology side has grown way out of proportion, in my view, just stupendously so. Fifth generation and all the hoopla about it is just all the more pushed in there, so there's got to be a balance. There's a reason that in our culture we grew up and absorbed all of the human system side that we used without even questioning it or thinking of it—they didn't come to us as inventions. We look upon other cultures where there is not the idea of "progress," and we laugh at them. But all we have to do is turn and look at ourselves to realize that our culture has not yet understood that the human side is open for progress and change. We more or less resist the change and say, "Boy, I'll be damned if I'm going to let that computer make me change; if it's so smart it ought to do it for me." We're totally missing the point, in my estimation. Well, people look at the mouse and say, "Geez, who wants to do all that?" Or they say the keyset is even worse. It's part of the culture.

The biggest challenge that's ahead for us, if we want to make progress, is to start affecting the perceptions that people have about what potential is there. We need to start looking for change and finding out a rational way to do the evolution so it doesn't break us apart. I just love to get into a dialog with people about the strategies for that evolution. I found people at McDonnell Douglas who were talking about it. There are top level guys who say, "We're going to remake the corporation." That's given people at many of the other levels the courage to go ahead and try. I come and say, strategically, we ought to do this; so they're sticking their necks out and giving me a chance to start.

Greg Heil

I'd like to ask you, have you considered combining the mouse and the keyset into a single device, a handwriting recognition system?

Engelbart

Yes, I thought I'd have a mouse and a keyset in each hand. There's a lot of potential to that, and people say, "Hey, what about this number of buttons on a keyset? Why did you pick three buttons on your mouse?" Why, it was all we could get in at the time. So, yes, I'd go for more. There's a lot to learn. I did a lot of thinking one time about the ways you could get transducers to pick up almost any kind of a signal that your motor system or nerve system could produce and translate that into actions you want; it's a whole new control language you could learn. I was just wondering about the bandwidth and the effect of that, and I could just picture really going through space—it's wide open.

Greg Heil

My suggestion was not to increase the number of transducers, but to decrease them to a single one, to a handwriting recognizer, so that you don't have extra buttons; you only use one hand to do it.

Engelbart

Well, that's a pretty slow way to enter characters, at least for English. Try it, but I think that if you've got such a marvelous machine there, you don't want to keep driving it with reins. And that's what I think would happen with the handwriting recognizer. I feel similarly about speech recognition. It's very nice in a lot of ways, but you couldn't control a system like we had with speech commands; you couldn't go fast enough unless you got some very sophisticated signals.

Charles Irby

I have two questions, one is on the tool system side and the other is on the human system side. Let's take the human system side first: Given the work that you've done in this area, what insights do you have about the changes that are going to be required in the human system, given the changes in technology in the tool side that we are experiencing today?

Engelbart

Well, I've got a lot of general ideas and I can tell you some of those. The main need is to find an evolutionary process that starts the exploration. Many people and many things to try. An example is that our organizations can get much flatter. The kind of communication can be so much greater, that if I could just go like this, and be in voice contact with you, same screens, diving around the information we're familiar with, you can be in any place in the country. It can change considerably the kind of roles that we can have, lots of specialty roles that can flip in and out of your work to help you from any place in the country. There isn't any way it would be practical with the kind of time it would take for you to get together and look at your stuff. Administrative and managerial structures can be different, and things like the matrix organizations, which have a lot of appeal in project-oriented environment but are difficult to administer, have a whole new breath of life coming to them because of the kind of coordination communication. Working groups that can be separated geographically. We do it a lot of ways now, but no one has been really focusing on the pursuit of ways to collaborate.

Charles Irby

On the tools side, a lot of the technology that was developed at SRI has readily transferred into other commercial products. Yet there are some, such as the structured text and the view controls that you had over the structured text, the linking mechanism from one place in the document to another place in possibly another document, and the notion of a mail system that is supported by a database, automatically cataloging all of the mail that has been sent. These things haven't readily transferred into other products. Why is that?

Engelbart

I was hoping the historians would answer that. I don't know, it's puzzled me. I used to take it personally and every once in a while it flashes . . . all I can say is that it just didn't fit cultural perceptions. When the computers first started becoming really available—personal computers or time-sharing—it was enough for people to make the adjustment to start interacting with them. If the marketplace isn't ready for something like that, who's going to invest money in trying to get it out there? Who has to decide to invest the money? It's guys who have been in the business for a while, and they have to depend upon consultants. They're experienced and familiar with things that aren't very often the ones that are in the vanguard. The whole process of who gets it out there and decides they are going to invest the money in it and risks it or goes out there and tries to train the customers. Once you get a system built, then you've got to put a lot of money into PR that tells everybody that's the best. So, you're doing yourself in down the way if, later on, you come back and say, now this is the best. So anyway, a big part of the user organizations have to get in gear and start saying, "Quit coddling us, we're ready to change. We're looking for what to do better, don't give us this bull about what's easy to learn."

Larry Press

I notice in reading one of your early reports that you paid a lot of respect, I guess, and commented a lot on Vannevar Bush's suggestions. And I just wondered if you could comment on how important you feel he was, his thinking and also his work, to the development of all this interactive computing.

Engelbart

I don't know about other people in that respect. For me, it was part of a singular thing, because I was a little navy boy, an electronics technician in World War II out in the Philipines, and getting moved from one place to another. They stuck you on an island to wait to get you assigned to somebody else. Somebody said there was a library there. It was a Red Cross library, up on stilts in a native hut, really neat, nobody there. I was poking around and found this article in *Life* magazine about his memex, and it just thrilled the hell out of me that people were thinking about something like that. So I didn't really act on that, but I'm sure later, as I got into this, that it started to affect me. Later, when we were starting the parts of the way NLS was built, there's a thing called a sequence generator that you could flip in your own user choices of a sequence that goes and picks you this thing and that; the links were a lot coming from Bush's idea of trail generation, through his documents. So it was a very explicit connection in that respect. I wish I could have met him, but by the time I caught on to the work, he was already in a nursing home and wasn't available. History is moving faster nowadays, incidentally, so you can find some of us old fossils that are still alive.

REPRINT OF HISTORICALLY SIGNIFICANT PAPER

As We May Think

Vannevar Bush

From *The Atlantic Monthly,* July 1945: 101–108. Reprinted with permission.

This has not been a scientist's war; it has been a war in which all have had a part. The scientists, burying their old professional competition in the demand of a common cause, have shared greatly and learned much. It has been exhilarating to work in effective partnership. Now, for many, this appears to be approaching an end. What are the scientists to do next?

For the biologists, and particularly for the medical scientists, there can be little indecision, for their war work has hardly required them to leave the old paths. Many indeed have been able to carry on their war research in their familiar peacetime laboratories. Their objectives remain much the same.

It is the physicists who have been thrown most violently off stride, who have left academic pursuits for the making of strange destructive gadgets, who have had to devise new methods for their unanticipated assignments. They have done their part on the devices that made it possible to turn back the enemy. They have worked in combined effort with the physicists of our allies. They have felt within themselves the stir of achievement. They have been part of a great team. Now, as peace approaches, one asks where they will find objectives worthy of their best.

1

Of what lasting benefit has been man's use of science and of the new instruments which his research brought into existence? First, they have increased his control of his material environment. They have improved his food, his clothing, his shelter; they have increased his security and released him partly from the bondage of bare existence. They have given him increased knowledge of his own biological processes so that he has had a progressive freedom from disease and an increased span of life. They are illuminating the interactions of his physiological and psychological functions, giving the promise of an improved mental health.

Science has provided the swiftest communication between individuals; it has provided a record of ideas and has enabled man to manipulate and to make extracts from that record so that knowledge evolves and endures throughout the life of a race rather than that of an individual.

There is a growing mountain of research. But there is increased evidence that we are being bogged down today as specialization extends. The investigator is staggered by the findings and conclusions of thousands of other workers—conclusions which he cannot find time to grasp, much less to remember, as they appear. Yet specialization becomes increasingly necessary for progress, and the effort to bridge between disciplines is correspondingly superficial.

Professionally our methods of transmitting and reviewing the results of research are generations old and by now are totally inadequate for their purpose. If the aggregate time spent in writing scholarly works and in reading them could be evaluated, the ratio between these amounts of time might well be startling. Those who conscientiously attempt to keep abreast of current thought, even in restricted fields, by close and continuous reading might well shy away from an examination calculated to show how much of the previous month's efforts could be produced on call. Mendel's concept of the laws of genetics was lost to the world for a generation because his publication did not reach the few who were capable of grasping and extending it; and this sort of catastrophe is undoubtedly being repeated all about us, as truly significant attainments become lost in the mass of the inconsequential.

The difficulty seems to be, not so much that we publish unduly in view of the extent and variety of present-day interests, but rather that publication has been extended far beyond our present ability to make real use of the record. The summation of human experience is being expanded at a prodigious rate, and the means we use for threading through the consequent maze to the momentarily important item is the same as was used in the days of square-rigged ships.

But there are signs of a change as new and powerful instrumentalities come into use. Photocells capable of seeing things in a physical sense, advanced photography which can record what is seen or even what is not, thermionic tubes capable of controlling potent forces under the guidance of less power than a mosquito uses to vibrate his wings, cathode ray tubes rendering visible an occurrence so brief that by comparison a microsecond is a long time, relay combinations which will carry out involved sequences of movements more reliably than any human operator and thousands of times as fast—there are plenty of mechanical aids with which to effect a transformation in scientific records.

Two centuries ago Leibnitz invented a calculating machine which embodied most of the essential features of recent keyboard devices, but it could not then come into use. The economics of the situation were against it: the labor involved in constructing it, before the days of mass production, exceeded the labor to be saved by its use, since all it could accomplish could be duplicated by sufficient use of pencil and paper. Moreover, it would have been subject to frequent breakdown, so that it could not have been depended upon; for at that time and long after, complexity and unreliability were synonymous.

Babbage, even with remarkably generous support for his time, could not produce his great arithmetical machine. His idea was sound enough, but construction and maintenance costs were then too heavy. Had a Pharaoh been given detailed and explicit designs of an automobile, and had he understood them completely, it would have taxed the resources of his kingdom to have fashioned the thousands of parts for a single car, and that car would have broken down on the first trip to Giza.

Machines with interchangeable parts can now be constructed with great economy of effort. In spite of much complexity, they perform reliably. Witness the humble typewriter, or the movie camera, or the automobile. Electrical contacts have ceased to stick when thoroughly understood. Note the automatic telephone exchange, which has hundreds of thousands of such contacts, and yet is reliable. A spider web of metal, sealed in a thin glass container, a wire heated to brilliant glow, in short, the thermionic tube of radio sets, is made by the hundred million, tossed about in packages, plugged into sockets—and it works! Its gossamer parts, the precise location and alignment involved in its construction, would have occupied a master craftsman of the guild for months; now it is built for thirty cents. The world has arrived at an age of cheap complex devices of great reliability; and something is bound to come of it.

2

A record, if it is to be useful to science, must be continuously extended, it must be stored, and above all it must be consulted. Today we make the record conventionally by writing and photography, followed by printing; but we also record on film, on wax disks, and on magnetic wires. Even if utterly new recording procedures do not appear, these present ones are certainly in the process of modification and extension.

Certainly progress in photography is not going to stop. Faster material and lenses, more automatic cameras, finer-grained sensitive compounds to allow an extension of the mini-camera idea, are all imminent. Let us project this trend ahead to a logical, if not inevitable, outcome. The camera hound of the future wears on his forehead a lump a little larger than a walnut. It takes pictures 3 millimeters square, later to be projected or enlarged, which after all involves only a factor of 10 beyond present practice. The lens is of universal focus, down to any distance accommodated by the unaided eye, simply because it is of short focal length. There is a built-in photocell on the walnut such as we now have on at least one camera, which automatically adjusts exposure for a wide range of illumination. There is film in the walnut for a hundred exposures, and the spring for operating its shutter and shifting its film is wound once for all when the film clip is inserted. It produces its result in full color. It may well be stereoscopic, and record with two spaced glass eyes, for striking improvements in stereoscopic technique are just around the corner.

The cord which trips its shutter may reach down a man's sleeve within easy reach of his fingers. A quick squeeze, and the picture is taken. On a pair of ordinary glasses is a square of fine lines near the top of one lens, where it is out of the way of ordinary vision. When an object appears in that square, it is lined up for its picture. As the scientist of the future moves about the laboratory or the field, every time he looks at something worthy of the record, he trips the shutter and in it goes, without even an audible click. Is this all fantastic? The only fantastic thing about it is the idea of making as many pictures as would result from its use.

Will there be dry photography? It is already here in two forms. When Brady made his Civil War pictures, the plate had to be wet at the time of exposure. Now it has to be wet during development instead. In the future perhaps it need not be wetted at all. There have long been films impregnated with diazo dyes which form a picture without development, so that it is already there as soon as the camera has been operated. An exposure to ammonia gas destroys the unexposed dye, and the picture can then be taken out into the light and examined. The process is now slow, but someone may speed it up, and it has no grain difficulties such as now keep photographic researchers busy. Often it would be advantageous to be able to snap the camera and to look at the picture immediately.

Another process now in use is also slow, and more or less clumsy. For fifty years impregnated papers have been used which turn dark at every point where an electrical contact touches them, by reason of the chemical change thus produced in an iodine compound included in the paper. They have been used to make records, for a pointer moving across them can leave a trail behind. If the electrical potential on the pointer is varied as it moves, the line becomes light or dark in accordance with the potential.

This scheme is now used in facsimile transmission. The pointer draws a set of closely spaced lines across the paper one after another. As it moves, its potential is varied in accordance with a varying current received over wires from a distant station, where these variations are produced by a photocell which is similarly scanning a picture. At every instant the darkness of the line being drawn is made equal to the darkness of the point on the picture being observed by the photocell. Thus, when the whole picture has been covered, a replica appears at the receiving end.

A scene itself can be just as well looked over line by line by the photocell in this way as can a photograph of the scene. This whole apparatus constitutes a camera, with the added feature, which can be dispensed with if desired, of making its picture at a distance. It is slow, and the picture is poor in detail. Still, it does give another process of dry photography, in which the picture is finished as soon as it is taken.

It would be a brave man who would predict that such a process will always remain clumsy, slow, and faulty in detail. Television equipment today transmits sixteen reasonably good pictures a second, and it involves only two essential differences from the process described above. For one, the record is made by a moving beam of electrons rather than a moving pointer, for the reason that an electron beam can sweep across the picture very rapidly indeed. The other difference involves merely the use of a screen which glows momentarily when the electrons hit, rather than a chemically treated paper or film which is permanently altered. This speed is necessary in television, for motion pictures rather than stills are the object.

Use chemically treated film in place of the glowing screen, allow the apparatus to transmit one picture only rather than a succession, and a rapid camera for dry photography results. The treated film needs to be far faster in action than present examples, but it probably could be. More serious is the objection that this scheme would involve putting the film inside a vacuum chamber, for electron beams behave normally only in such a rarefied environment. This difficulty could be avoided by allowing the electron beam to play on one side of a partition, and by pressing the film against the other side, if this partition were such as to allow the electrons to go through perpendicular to its surface, and to prevent them from spreading out sideways. Such partitions, in crude form, could certainly be constructed, and they will hardly hold up the general development.

Like dry photography, microphotography still has a long way to go. The basic scheme of reducing the size of the record, and examining it by projection rather than directly, has possibilities too great to be ignored. The combination of optical projection and photographic reduction is already producing some results in microfilm for scholarly purposes, and the potentialities are highly suggestive. Today, with microfilm, reductions by a linear factor of 20 can be employed and still produce full clarity when the material is re-enlarged for examination. The limits are set by the graininess of the film, the excellence of the optical system, and the efficiency of the light sources employed. All of these are rapidly improving.

Assume a linear ratio of 100 for future use. Consider film of the same thickness as paper, although thinner film will certainly be usable. Even under these conditions there would be a total factor of 10,000 between the bulk of the ordinary record on books, and its microfilm replica. The *Encyclopœdia Britannica* could be reduced to the volume of a matchbox. A library of a million volumes could be compressed into one end of a desk. If the human race has produced since the invention of movable type a total record, in the form of magazines, newspapers, books, tracts, advertising blurbs, correspondence, having a volume corresponding to a billion books, the whole affair, assembled and compressed, could be lugged off in a moving van. Mere compression, of course, is not enough; one needs not only to make and store a record but also be able to consult it, and this aspect of the matter comes later. Even the modern great library is not generally consulted; it is nibbled at by a few.

Compression is important, however, when it comes to costs. The material for the microfilm *Britannica* would cost a nickel, and it could be mailed anywhere for a cent. What would it cost to print a million copies? To print a sheet of newspaper, in a large edition, costs a small fraction of a cent. The entire material of the *Britannica* in reduced microfilm form would go on a sheet eight and one-half by eleven inches. Once it is available, with the photographic reproduction methods of the future, duplicates in large quantities could probably be turned out for a cent apiece beyond the cost of materials. The preparation of the original copy? That introduces the next aspect of the subject.

3

To make the record, we now push a pencil or tap a typewriter. Then comes the process of digestion and correction, followed by an intricate process of typesetting, printing, and distribution. To consider the first stage of the procedure, will the author of the future cease writing by hand or typewriter and talk directly to the record? He does so indirectly, by talking to a stenographer or a wax cylinder; but the elements are all present if he wishes to have his talk directly produce a typed record. All he needs to do is to take advantage of existing mechanisms and to alter his language.

At a recent World Fair a machine called a Voder was shown. A girl stroked its keys and it emitted recognizable speech. No human vocal chords entered into the procedure at any point; the keys simply combined some electrically produced vibrations and passed these on to a loud-speaker. In the Bell Laboratories there is the converse of this machine, called a Vocoder. The loud-speaker is replaced by a microphone, which picks up sound. Speak to it, and the corresponding keys move. This may be one element of the postulated system.

The other element is found in the stenotype, that somewhat disconcerting device encountered usually at public meetings. A girl strokes its keys languidly and looks about the room and sometimes at the speaker with a disquieting gaze. From it emerges a typed strip which records in a phonetically simplified language a record of what the speaker is supposed to have said. Later this strip is retyped into ordinary language, for in its nascent form it is intelligible only to the initiated. Combine these two elements, let the Vocoder run the stenotype, and the result is a machine which types when talked to.

Our present languages are not especially adapted to this sort of mechanization, it is true. It is strange that the inventors of universal languages have not seized upon the idea of producing one which better fitted the technique for transmitting and recording speech. Mechanization may yet force the issue, especially in the scientific field; whereupon scientific jargon would become still less intelligible to the layman.

One can now picture a future investigator in his laboratory. His hands are free, and he is not anchored. As he moves about and observes, he photographs and comments. Time is automatically recorded to tie the two records together. If he goes into the field, he may be connected by radio to his recorder. As he ponders over his notes in the evening, he again talks his comments into the record. His typed record, as well as his photographs, may both be in miniature, so that he projects them for examination.

Much needs to occur, however, between the collection of data and observations, the extraction of parallel material from the existing record, and the final insertion of new material into the general body of the common record. For mature thought there is no mechanical substitute. But creative thought and essentially repetitive thought are very different things. For the latter there are, and may be, powerful mechanical aids.

Adding a column of figures is a repetitive thought process, and it was long ago properly relegated to the machine. True, the machine is sometimes controlled by a keyboard, and thought of a sort enters in reading the figures and poking the corresponding keys, but even this is avoidable. Machines have been made which will read typed figures by photocells and then depress the corresponding keys; these are combinations of photocells for scanning the type, electric circuits for sorting the consequent variations, and relay circuits for interpreting the result into the action of solenoids to pull the keys down.

All this complication is needed because of the clumsy way in which we have learned to write figures. If we recorded them positionally, simply by the configuration of a set of dots on a card, the automatic reading mechanism would become comparatively simple. In fact, if the dots are holes, we have the punched-card machine long ago produced by Hollorith for the purposes of the census, and now used throughout business. Some types of complex businesses could hardly operate without these machines.

Adding is only one operation. To perform arithmetical computation involves also subtraction, multiplication, and division, and in addition some method for temporary storage of results, removal from storage for further manipulation, and recording of final results by printing. Machines for these purposes are now of two types: keyboard machines for accounting and the like, manually controlled for the insertion of data, and usually automatically controlled as far as the sequence of operations is concerned; and punched-card machines in which separate operations are usually delegated to a series of machines, and the cards then transferred bodily from one to another. Both forms are very useful; but as far as complex computations are concerned, both are still in embryo.

Rapid electrical counting appeared soon after the physicists found it desirable to count cosmic rays. For their own purposes the physicists promptly constructed thermionic-tube equipment capable of counting electrical impulses at the rate of 100,000 a second. The advanced arithmetical machines of the future will be electrical in nature, and they will perform at 100 times present speeds, or more.

Moreover, they will be far more versatile than present commercial machines, so that they may readily be adapted for a wide variety of operations. They will be controlled by a control card or film, they will select their own data and manipulate it in accordance with the instructions thus inserted, they will perform complex arithmetical computations at exceedingly high speeds, and they will record results in such form as to be readily available for distribution or for later further manipulation. Such machines will have enormous appetites. One of them will take instructions and data from a whole roomful of girls armed with simple keyboard punches, and will deliver sheets of computed results every few minutes. There will always be plenty of things to compute in the detailed affairs of millions of people doing complicated things.

4

The repetitive processes of thought are not confined, however, to matters of arithmetic and statistics. In fact, every time one combines and records facts in accordance with established logical processes, the creative aspect of thinking is concerned only with the selection of the data and the process to be employed, and the manipulation thereafter is repetitive in nature and hence a fit matter to be relegated to the machines. Not so much has been done along these lines, beyond the bounds of arithmetic, as might be done, primarily because of the economics of the situation. The needs of business, and the extensive market obviously waiting, assured the advent of mass-produced arithmetical machines just as soon as production methods were sufficiently advanced.

With machines for advanced analysis no such situation existed; for there was and is no extensive market; the users of advanced methods of manipulating data are a very small part of the population. There are, however, machines for solving differential equations—and functional and integral equations, for that matter. There are many special machines, such as the harmonic synthesizer which predicts the tides. There will be many more, appearing certainly first in the hands of the scientist and in small numbers.

If scientific reasoning were limited to the logical processes of arithmetic, we should not get far in our understanding of the physical world. One might as well attempt to grasp the game of poker entirely by the use of the mathematics of probability. The abacus, with its beads strung on parallel wires, led the Arabs to positional numeration and the concept of zero many centuries before the rest of the world; and it was a useful tool—so useful that it still exists.

It is a far cry from the abacus to the modern keyboard accounting machine. It will be an equal step to the arithmetical machine of the future. But even this new machine will not take the scientist where he needs to go. Relief must be secured from laborious detailed manipulation of higher mathematics as well, if the users of it are to free their brains for something more than repetitive detailed transformations in accordance with established rules. A mathematician is not a man who can readily manipulate figures; often he cannot. He is not even a man who can readily perform the transformations of equations by the use of calculus. He is primarily an individual who is skilled in the use of symbolic logic on a high plane, and especially he is a man of intuitive judgment in the choice of the manipulative processes he employs.

All else he should be able to turn over to his mechanism, just as confidently as he turns over the propelling of his car to the intricate mechanism under the hood. Only then will mathematics be practically effective in bringing the growing knowledge of atomistics to the useful solution of the advanced problems of chemistry, metallurgy, and biology. For this reason there will come more machines to handle advanced mathematics for the scientist. Some of them will be sufficiently bizarre to suit the most fastidious connoisseur of the present artifacts of civilization.

5

The scientist, however, is not the only person who manipulates data and examines the world about him by the use of logical processes, although he sometimes preserves this appearance by adopting into the fold anyone who becomes logical, much in the manner in which a British labor leader is elevated to knighthood. Whenever logical processes of thought are employed—that is, whenever thought for a time runs along an accepted groove—there is an opportunity for the machine. Formal logic used to be a keen instrument in the hands of the teacher in his trying of students' souls. It is readily possible to construct a machine which will manipulate premises in accordance with formal logic, simply by the clever use of relay circuits. Put a set of premises into such a device and turn the crank, and it will readily pass out conclusion after conclusion, all in accordance with logical law, and with no more slips than would be expected of a keyboard adding machine.

Logic can become enormously difficult, and it would undoubtedly be well to produce more assurance in its use. The machines for higher analysis have usually been equation solvers. Ideas are beginning to appear for equation transformers, which will rearrange the relationship expressed by an equation in accordance with strict and rather advanced logic. Progress is inhibited by the exceedingly crude way in which mathematicians express their relationships. They employ a symbolism which grew like Topsy and has little consistency; a strange fact in that most logical field.

A new symbolism, probably positional, must apparently precede the reduction of mathematical transformations to machine processes. Then, on beyond the strict logic of the mathematician, lies the application of logic in everyday affairs. We may some day click off arguments on a machine with the same assurance that we now enter sales on a cash register. But the machine of logic will not look like a cash register, even of the streamlined model.

So much for the manipulation of ideas and their insertion into the record. Thus far we seem to be worse off than before—for we can enormously extend the record; yet even in its present bulk we can hardly consult it. This is a much larger matter than merely the extraction of data for the purposes of scientific research; it involves the entire process by which man profits by his inheritance of acquired knowledge. The prime action of use is selection, and here we are halting indeed. There may be millions of fine thoughts, and the account of the experience on which they are based, all encased within stone walls of acceptable architectural form; but if the scholar can get at only one a week by diligent search, his syntheses are not likely to keep up with the current scene.

Selection, in this broad sense, is a stone adze in the hands of a cabinetmaker. Yet, in a narrow sense and in other areas, something has already been done mechanically on selection. The personnel officer of a factory drops a stack of a few thousand employee cards into a selecting machine, sets a code in accordance with an established convention, and produces in a short time a list of all employees who live in Trenton and know Spanish. Even such devices are much too slow when it comes, for example, to matching a set of fingerprints with one of five million on file. Selection devices of this sort will soon be speeded up from their present rate of reviewing data at a few hundred a minute. By the use of photocells and microfilm they will survey items at the rate of a thousand a second, and will print out duplicates of those selected.

This process, however, is simple selection: it proceeds by examining in turn every one of a large set of items, and by picking out those which have certain specified characteristics. There is another form of selection best illustrated by the automatic telephone exchange. You dial a number and the machine selects and connects just one of a million possible stations. It does not run over them all. It pays attention only to a class given by a first digit, then only to a subclass of this given by the second digit, and so on; and thus proceeds rapidly and almost unerringly to the selected station. It requires a few seconds to make the selection, although the process could be speeded up if increased speed were economically warranted. If necessary, it could be made extremely fast by substituting thermionic-tube switching for mechanical switching, so that the full selection could be made in one one-hundredth of a second. No one would wish to spend the money necessary to make this change in the telephone system, but the general idea is applicable elsewhere.

Take the prosaic problem of the great department store. Every time a charge sale is made, there are a number of things to be done. The inventory needs to be revised, the salesman needs to be given credit for the sale, the general accounts need an entry, and, most important, the customer needs to be charged. A central records device has been developed in which much of this work is done conveniently. The salesman places on a stand the customer's identification card, his own card, and the card taken from the article sold—all punched cards. When he pulls a lever, contacts are made through the holes, machinery at a central point makes the necessary computations and entries, and the proper receipt is printed for the salesman to pass to the customer.

But there may be ten thousand charge customers doing business with the store, and before the full operation can be completed someone has to select the right card and insert it at the central office. Now rapid selection can slide just the proper card into position in an instant or two, and return it afterward. Another difficulty occurs, however. Someone must read a total on the card, so that the machine can add its computed item to it. Conceivably the cards might be of the dry photography type I have described. Existing totals could then be read by photocell, and the new total entered by an electron beam.

The cards may be in miniature, so that they occupy little space. They must move quickly. They need not be transferred far, but merely into position so that the photocell and recorder can operate on them. Positional dots can enter the data. At the end of the month a machine can readily be made to read these and to print an ordinary bill. With tube selection, in which no mechanical parts are involved in the switches, little time need be occupied in bringing the correct card into use—a second should suffice for the entire operation. The whole record on the card may be made by magnetic dots on a steel sheet if desired, instead of dots to be observed optically, following the scheme by which Poulsen long ago put speech on a magnetic wire. This method has the advantage of simplicity and ease of erasure. By using photography, however, one can arrange to project the record in enlarged form, and at a distance by using the process common in television equipment.

One can consider rapid selection of this form, and distant projection for other purposes. To be able to key one sheet of a million before an operator in a second or two, with the possibility of then adding notes thereto, is suggestive in many ways. It might even be of use in libraries, but that is another story. At any rate, there are now some interesting combinations possible. One might, for example, speak to a microphone, in the manner described in connection with the speech-controlled typewriter, and thus make his selections. It would certainly beat the usual file clerk.

6

The real heart of the matter of selection, however, goes deeper than a lag in the adoption of mechanisms by libraries, or a lack of development of devices for their use. Our ineptitude in getting at the record is largely caused by the artificiality of systems of indexing. When data of any sort are placed in storage, they are filed alphabetically or numerically, and information is found (when it is) by tracing it down from subclass to subclass. It can be in only one place, unless duplicates are used; one has to have rules as to which path will locate it, and the rules are cumbersome. Having found one item, moreover, one has to emerge from the system and re-enter on a new path.

The human mind does not work that way. It operates by association. With one item in its grasp, it snaps instantly to the next that is suggested by the association of thoughts, in accordance with some intricate web of trails carried by the cells of the brain. It has other characteristics, of course; trails that are not frequently followed are prone to fade, items are not fully permanent, memory is transitory. Yet the speed of action, the intricacy of trails, the detail of mental pictures, is awe-inspiring beyond all else in nature.

Man cannot hope fully to duplicate this mental process artificially, but he certainly ought to be able to learn from it. In minor ways he may even improve, for his records have relative permanency. The first idea, however, to be drawn from the analogy concerns selection. Selection by association, rather than by indexing, may yet be mechanized. One cannot hope thus to equal the speed and flexibility with which the mind follows an associative trail, but it should be possible to beat the mind decisively in regard to the permanence and clarity of the items resurrected from storage.

Consider a future device for individual use, which is a sort of mechanized private file and library. It needs a name, and, to coin one at random, "memex" will do. 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 sets of buttons and levers. Otherwise it looks like an ordinary desk.

In one end is the stored material. The matter of bulk is well taken care of by improved microfilm. Only a small part of the interior of the memex is devoted to storage, the rest to mechanism. Yet if the user inserted 5000 pages of material a day it would take him hundreds of years to fill the repository, so he can be profligate and enter material freely.

Most of the memex contents are purchased on microfilm ready for insertion. Books of all sorts, pictures, current periodicals, newspapers, are thus obtained and dropped into place. Business correspondence takes the same path. And there is provision for direct entry. On the top of the memex is a transparent platen. On this are placed longhand notes, photographs, memoranda, all sorts of things. When one is in place, the depression of a lever causes it to be photographed onto the next blank space in a section of the memex film, dry photography being employed.

There is, of course, provision for consultation of the record by the usual scheme of indexing. If the user wishes to consult a certain book, he taps its code on the keyboard, and the title page of the book promptly appears before him, projected onto one of his viewing positions. Frequently-used codes are mnemonic, so that he seldom consults his code book; but when he does, a single tap of a key projects it for his use. Moreover, he has supplemental levers. On deflecting one of these levers to the right he runs through the book before him, each page in turn being projected at a speed which just allows a recognizing glance at each. If he deflects it further to the right, he steps through the book 10 pages at a time; still further at 100 pages at a time. Deflection to the left gives him the same control backwards.

A special button transfers him immediately to the first page of the index. Any given book of his library can thus be called up and consulted with far greater facility than if it were taken from a shelf. As he has several projection positions, he can leave one item in position while he calls up another. He can add marginal notes and comments, taking advantage of one possible type of dry photography, and it could even be arranged so that he can do this by a stylus scheme, such as is now employed in the telautograph seen in railroad waiting rooms, just as though he had the physical page before him.

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All this is conventional, except for the projection forward of present-day mechanisms and gadgetry. It affords an immediate step, however, to associative indexing, the basic idea of which is a provision whereby any item may be caused at will to select immediately and automatically another. This is the essential feature of the memex. The process of tying two items together is the important thing.

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. In each code space appears the code word. Out of view, but also in the code space, is inserted a set of dots for photocell viewing; and on each item these dots by their positions designate the index number of the other item.

Thereafter, at any time, when one of these items is in view, the other can be instantly recalled merely by tapping a button below the corresponding code space. Moreover, when numerous items have been thus joined together to form a trail, they can be reviewed in turn, rapidly or slowly, by deflecting a lever like that used for turning the pages of a book. It is exactly as though the physical items had been gathered together from widely separated sources and bound together to form a new book. It is more than this, for any item can be joined into numerous trails.

The owner of the memex, let us say, is interested in the origin and properties of the bow and arrow. Specifically he is studying why the short Turkish bow was apparently superior to the English long bow in the skirmishes of the Crusades. He has dozens of possibly pertinent books and articles in his memex. First he runs through an encyclopedia, finds an interesting but sketchy article, leaves it projected. Next, in a history, he finds another pertinent item, and ties the two together. Thus he goes, building a trail of many items. Occasionally he inserts a comment of his own, either linking it into the main trail or joining it by a side trail to a particular item. When it becomes evident that the elastic properties of available materials had a great deal to do with the bow, he branches off on a side trail which takes him through textbooks on elasticity and tables of physical constants. He inserts a page of longhand analysis of his own. Thus he builds a trail of his interest through the maze of materials available to him.

And his trails do not fade. Several years later, his talk with a friend turns to the queer ways in which a people resist innovations, even of vital interest. He has an example, in the fact that the outranged Europeans still failed to adopt the Turkish bow. In fact he has a trail on it. A touch brings up the code book. Tapping a few keys projects the head of the trail. A lever runs through it at will, stopping at interesting items, going off on side excursions. It is an interesting trail, pertinent to the discussion. So he sets a reproducer in action, photographs the whole trail out, and passes it to his friend for insertion in his own memex, there to be linked into the more general trail.

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Wholly new forms of encyclopedias will appear, ready-made with a mesh of associative trails running through them, ready to be dropped into the memex and there amplified. The lawyer has at his touch the associated opinions and decisions of his whole experience, and of the experience of friends and authorities. The patent attorney has on call the millions of issued patents, with familiar trails to every point of his client's interest. The physician, puzzled by a patient's reactions, strikes the trail established in studying an earlier similar case, and runs rapidly through analogous case histories, with side references to the classics for the pertinent anatomy and histology. The chemist, struggling with the synthesis of an organic compound, has all the chemical literature before him in his laboratory, with trails following the analogies of compounds, and side trails to their physical and chemical behavior.

The historian, with a vast chronological account of a people, parallels it with a skip trail which stops only on the salient items, and can follow at any time contemporary trails which lead him all over civilization at a particular epoch. There is a new profession of trail blazers, those who find delight in the task of establishing useful trails through the enormous mass of the common record. The inheritance from the master becomes, not only his additions to the world's record, but for his disciples the entire scaffolding by which they were erected.

Thus science may implement the ways in which man produces, stores, and consults the record of the race. It might be striking to outline the instrumentalities of the future more spectacularly, rather than to stick closely to methods and elements now known and undergoing rapid development, as has been done here. Technical difficulties of all sorts have been ignored, certainly, but also ignored are means as yet unknown which may come any day to accelerate technical progress as violently as did the advent of the thermionic tube. In order that the picture may not be too commonplace, by reason of sticking to present-day patterns, it may be well to mention one such possibility, not to prophesy but merely to suggest, for prophecy based on extension of the known has substance, while prophecy founded on the unknown is only a doubly involved guess.

All our steps in creating or absorbing material of the record proceed through one of the senses—the tactile when we touch keys, the oral when we speak or listen, the visual when we read. Is it not possible that some day the path may be established more directly?

We know that when the eye sees, all the consequent information is transmitted to the brain by means of electrical vibrations in the channel of the optic nerve. This is an exact analogy with the electrical vibrations which occur in the cable of a television set: they convey the picture from the photocells which see it to the radio transmitter from which it is broadcast. We know further that if we can approach that cable with the proper instruments, we do not need to touch it; we can pick up those vibrations by electrical induction and thus discover and reproduce the scene which is being transmitted, just as a telephone wire may be tapped for its message.

The impulses which flow in the arm nerves of a typist convey to her fingers the translated information which reaches her eye or ear, in order that the fingers may be caused to strike the proper keys. Might not these currents be intercepted, either in the original form in which information is conveyed to the brain, or in the marvelously metamorphosed form in which they then proceed to the hand?

By bone conduction we already introduce sounds into the nerve channels of the deaf in order that they may hear. Is it not possible that we may learn to introduce them without the present cumbersomeness of first transforming electrical vibrations to mechanical ones, which the human mechanism promptly transforms back to the electrical form? With a couple of electrodes on the skull the encephalograph now produces pen-and-ink traces which bear some relation to the electrical phenomena going on in the brain itself. True, the record is unintelligible, except as it points out certain gross misfunctioning of the cerebral mechanism; but who would now place bounds on where such a thing may lead?

In the outside world, all forms of intelligence, whether of sound or sight, have been reduced to the form of varying currents in an electric circuit in order that they may be transmitted. Inside the human frame exactly the same sort of process occurs. Must we always transform to mechanical movements in order to proceed from one electrical phenomenon to another? It is a suggestive thought, but it hardly warrants prediction without losing touch with reality and immediateness.

Presumably man's spirit should be elevated if he can better review his shady past and analyze more completely and objectively his present problems. He has built a civilization so complex that he needs to mechanize his records more fully if he is to push his experiment to its logical conclusion and not merely become bogged down part way there by overtaxing his limited memory. His excursions may be more enjoyable if he can reacquire the privilege of forgetting the manifold things he does not need to have immediately at hand, with some assurance that he can find them again if they prove important.

The applications of science have built man a well-supplied house, and are teaching him to live healthily therein. They have enabled him to throw masses of people against one another with cruel weapons. They may yet allow him truly to encompass the great record and to grow in the wisdom of race experience. He may perish in conflict before he learns to wield that record for his true good. Yet, in the application of science to the needs and desires of man, it would seem to be a singularly unfortunate stage at which to terminate the process, or to lose hope as to the outcome.