

<< 9 >> "Augmenting Human Intellect: A Conceptual Framework" (1962)

Douglas Engelbart

<< Douglas Engelbart is one of the most influential thinkers in the history of personal computing. He is best known as the groundbreaking engineer who invented such mainstays of the personal computer as the mouse, windows, email, and the word processor. He has received less recognition for his pioneering concepts behind the interactive computer networks that are the basis for the Internet. Engelbart led one of the most important projects funded by ARPA in the 1960s: a networked environment designed to support collaborative interaction between people using computers. It was dubbed the oNLine System (NLS). This historic prototype, developed at the Augmentation Research Center of the Stanford Research Institute (SRI) and unveiled in 1968 at the Fall Joint Computer Conference in San Francisco, influenced the development of the first personal computer and the graphical user interface at Xerox PARC in the early 1970s.

led to Macos

Engelbart's experience as a radar specialist in wartime led him to consider the potential for a computer connected to a monitor display and an input device (such as a keyboard), which, in the fifties and sixties, transformed the way people interacted with computers. In this paper, Engelbart describes in detail how such a computer might function—a description that predicts in remarkable detail the fundamental qualities of a modern personal computer. The linking of people and computers using this approach to interactivity would result in the use of computers to "solve the world's problems," Engelbart wrote, by boosting the capacities of the mind's intellectual faculties.

Engelbart reasoned that networked computing would not only make individuals more intellectually effective; it would enable a collaborative method of sharing knowledge. At the time, the idea that computers could be operated intuitively by teams engaged in creative work was highly unorthodox. Engelbart proposed a language, process, methodology, and conceptual framework for the real-time interaction of collaborative computing. He was among the first to consider using computer networks to create collective knowledge bases among groups of professionals. This approach has since transformed many of our institutions, including the military, universities, museums, and libraries, as they have extended their reach into cyberspace. Engelbart's theories about the power of collective knowledge via a real-time electronic medium have also led to other forms of many-to-many human-computer interaction, including such collective online activities as virtual communities, on-line forums, and teleconferencing. >>



Douglas Engelbart at the Augmentation Research Center. Courtesy of Douglas Engelbart, Bootstrap Institute.

"The term 'intelligence amplification' seems applicable to our goal of augmenting the human intellect in that the entity to be produced will exhibit more of what can be called intelligence than an unaided human could; we will have amplified the intelligence of the human by organizing his intellectual capabilities into higher levels of synergistic structuring."

I. INTRODUCTION

A. General

By "augmenting human intellect" we mean increasing the capability of a man to approach a complex problem situation, to gain comprehension to suit his particular needs, and to derive solutions to problems. Increased capability in this respect is taken to mean a mixture of the following: more-rapid comprehension, better comprehension, the possibility of gaining a useful degree of comprehension in a situation that previously was too complex, speedier solutions, better solutions, and the possibility of finding solutions to problems that before seemed insoluble. And by "complex situations" we include the professional problems of diplomats, executives, social scientists, life scientists, physical scientists, attorneys, designers—whether the problem situation exists for twenty minutes or twenty years. We do not speak of isolated clever tricks that help in particular situations. We refer to a way of life in an integrated domain where hunches, cut-and-try, intangibles, and the human "feel for a situation" usefully co-exist with powerful concepts, streamlined terminology and notation, sophisticated methods, and high-powered electronic aids.

Man's population and gross product are increasing at a considerable rate, but the *complexity* of his problems grows still faster, and the *urgency* with which solutions must be found becomes steadily greater in response to the increased rate of activity and the increasingly global nature of that activity. Augmenting man's intellect, in the sense defined above, would warrant full pursuit by an enlightened society if there could be shown a reasonable approach and some plausible benefits.

This report covers the first phase of a program aimed at developing means to augment the human intellect. These "means" can include many things—all of which appear to be but extensions of means developed and used in the past to help man apply his native sensory, mental, and motor capabilities—and we consider the whole system of a human and his augmentation means as a proper field of search for practical possibilities. It is a very important system to our society, and like most systems its performance can best be improved by considering the whole as a set of interacting components rather than by considering the components in isolation.

This kind of system approach to human intellectual effectiveness does not

find a ready-made conceptual framework such as exists for established disciplines. Before a research program can be designed to pursue such an approach intelligently, so that practical benefits might be derived within a reasonable time while also producing results of long-range significance, a conceptual framework must be searched out—a framework that provides orientation as to the important factors of the system, the relationships among these factors, the types of change among the system factors that offer likely improvements in performance, and the sort of research goals and methodology that seem promising.¹

In the first (search) phase of our program we have developed a conceptual framework that seems satisfactory for the current needs of designing a research phase. Section II contains the essence of this framework as derived from several different ways of looking at the system made up of a human and his intellectual augmentation means.

The process of developing this conceptual framework brought out a number of significant realizations: that the intellectual effectiveness exercised today by a given human has little likelihood of being intelligence limited—that there are dozens of disciplines in engineering, mathematics, and the social, life, and physical sciences that can contribute improvements to the system of intellectual augmentation means; that any one such improvement can be expected to trigger a chain of coordinating improvements; that until every one of these disciplines comes to a standstill *and* we have exhausted all the improvement possibilities we could glean from it, we can expect to continue to develop improvements in this "human-intellect" system; that there is no particular reason not to expect gains in personal intellectual effectiveness from a concerted system-oriented approach that compare to those made in personal geographic mobility since horseback and sailboat days....

To give the reader an initial orientation about what sort of thing this computer-aided working system might be, we include below a short description of a possible system of this sort. This illustrative example is not to be considered a description of the actual system that will emerge from the program. It is given only to show the general direction of the work, and is clothed in fiction only to make it easier to visualize.

Let us consider an "augmented" architect at work. He sits at a working station that has a visual display screen some three feet on a side; this is his working surface, and is controlled by a computer (his "clerk") with which he can communicate by means of a small keyboard and various other devices.

He is designing a building. He has already dreamed up several basic layouts and structural forms, and is trying them out on the screen. The surveying data

tree like
thinking
a
rhizome

visually
displayed

for the layout he is working on now have already been entered, and he has just coaxed the "clerk" to show him a perspective view of the steep hillside building site with the roadway above, symbolic representations of the various trees that are to remain on the lot, and the service tie points for the different utilities. The view occupies the left two-thirds of the screen. With a "pointer," he indicates two points of interest, moves his left hand rapidly over the keyboard, and the distance and elevation between the points indicated appear on the right-hand third of the screen.

Now he enters a reference line with his "pointer" and the keyboard. Gradually the screen begins to show the work he is doing—a neat excavation appears in the hillside, revises itself slightly, and revises itself again. After a moment, the architect changes the scene on the screen to an overhead plan view of the site, still showing the excavation. A few minutes of study, and he enters on the keyboard a list of items, checking each one as it appears on the screen, to be studied later.

Ignoring the representation on the display, the architect next begins to enter a series of specifications and data—a six-inch slab floor, twelve-inch concrete walls eight feet high within the excavation, and so on. When he has finished, the revised scene appears on the screen. A structure is taking shape. He examines it, adjusts it, pauses long enough to ask for handbook or catalog information from the "clerk" at various points, and readjusts accordingly. He often recalls from the "clerk" his working lists of specifications and considerations to refer to them, modify them, or add to them. These lists grow into an ever-more-detailed, interlinked structure, which represents the maturing thought behind the actual design.

Prescribing different planes here and there, curved surfaces occasionally, and moving the whole structure about five feet, he finally has the rough external form of the building balanced nicely with the setting and he is assured that this form is basically compatible with the materials to be used as well as with the function of the building.

Now he begins to enter detailed information about the interior. Here the capability of the "clerk" to show him any view he wants to examine (a slice of the interior, or how the structure would look from the roadway above) is important. He enters particular fixture designs, and examines them in a particular room. He checks to make sure that sun glare from the windows will not blind a driver on the roadway, and the "clerk" computes the information that one window will reflect strongly onto the roadway between 6 and 6:30 on midsummer mornings.

Next he begins a functional analysis. He has a list of the people who will occupy this building, and the daily sequences of their activities. The "clerk" allows

him to follow each in turn, examining how doors swing, where special lighting might be needed. Finally he has the "clerk" combine all of these sequences of activity to indicate spots where traffic is heavy in the building, or where congestion might occur, and to determine what the severest drain on the utilities is likely to be.

All of this information (the building design and its associated "thought structure") can be stored on a tape to represent the "design manual" for the building. Loading this tape into his own "clerk," another architect, a builder, or the client can maneuver within this "design manual" to pursue whatever details or insights are of interest to him—and can append special notes that are integrated into the "design manual" for his own or someone else's later benefit.

In such a future working relationship between human problem-solver and computer "clerk," the capability of the computer for executing mathematical processes would be used whenever it was needed. However, the computer has many other capabilities for manipulating and displaying information that can be of significant benefit to the human in nonmathematical processes of planning, organizing, studying, etc. Every person who does his thinking with symbolized concepts (whether in the form of the English language, pictographs, formal logic, or mathematics) should be able to benefit significantly.

Pre
Artec
Culture
Diagrammatic
Framework

B. Objective of the Study

The objective of this study is to develop a conceptual framework within which could grow a coordinated research and development program whose goals would be the following: (1) to find the factors that limit the effectiveness of the individual's basic information-handling capabilities in meeting the various needs of society for problem solving in its most general sense; and (2) to develop new techniques, procedures, and systems that will better match these basic capabilities to the needs, problems, and progress of society. We have placed the following specifications on this framework:

1. That it provide perspective for both long-range basic research and research that will yield practical results soon.
2. That it indicate what this augmentation will actually involve in the way of changes in working environment, in thinking, in skills, and in methods of working.
3. That it be a basis for evaluating the possible relevance of work and knowledge from existing fields and for assimilating whatever is relevant.

4. That it reveal areas where research is possible and ways to assess the research, be a basis for choosing starting points, and indicate how to develop appropriate methodologies for the needed research.

Two points need emphasis here. First, although a conceptual framework has been constructed, it is still rudimentary. Further search, and actual research, are needed for the evolution of the framework. Second, even if our conceptual framework did provide an accurate and complete basic analysis of the system from which stems a human's intellectual effectiveness, the explicit nature of future improved systems would be highly affected by (expected) changes in our technology or in our understanding of the human being.

II. CONCEPTUAL FRAMEWORK

A. General

The conceptual framework we seek must orient us toward the real possibilities and problems associated with using modern technology to give direct aid to an individual in comprehending complex situations, isolating the significant factors, and solving problems. To gain this orientation, we examine how individuals achieve their present level of effectiveness, and expect that this examination will reveal possibilities for improvement.

The entire effect of an individual on the world stems essentially from what he can transmit to the world through his limited motor channels. This in turn is based on information received from the outside world through limited sensory channels; on information, drives, and needs generated within him; and on his processing of that information. His processing is of two kinds: that which he is generally conscious of (recognizing patterns, remembering, visualizing, abstracting, deducing, inducing, etc.), and that involving the unconscious processing and mediating of received and self-generated information, and the unconscious mediating of conscious processing itself.

The individual does not use this information and this processing to grapple directly with the sort of complex situation in which we seek to give him help. He uses his innate capabilities in a rather more indirect fashion, since the situation is generally too complex to yield directly to his motor actions, and always too complex to yield comprehensions and solutions from direct sensory inspection and use of basic cognitive capabilities. For instance, an aborigine who possesses

all of our *basic* sensory-mental-motor capabilities, but does not possess our background of indirect knowledge and procedure, cannot organize the proper direct actions necessary to drive a car through traffic, request a book from the library, call a committee meeting to discuss a tentative plan, call someone on the telephone, or compose a letter on the typewriter.

Our culture has evolved means for us to organize the little things we can do with our basic capabilities so that we can derive comprehension from truly complex situations, and accomplish the processes of deriving and implementing problem solutions. The ways in which human capabilities are thus extended are here called *augmentation means*, and we define four basic classes of them:

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

The system we want to improve can thus be visualized as a trained human being together with his artifacts, language, and methodology. The explicit new system we contemplate will involve as artifacts computers, and computer-controlled information-storage, information-handling, and information-display devices. The aspects of the conceptual framework that are discussed here are primarily those relating to the human being's ability to make significant use of such equipment in an integrated system.

Pervading all of the augmentation means is a particular structure or organization. While an untrained aborigine cannot drive a car through traffic, because he cannot leap the gap between his cultural background and the kind of world that contains cars and traffic, it is possible to move step by step through an organized training program that will enable him to drive effectively and safely. In other words, the human mind neither learns nor acts by large leaps, but by steps organized or structured so that each one depends upon previous steps.

The importance of a good education

mental network

nodes of knowledge

Although the size of the step a human being can take in comprehension, innovation, or execution is small in comparison to the over-all size of the step needed to solve a complex problem, human beings nevertheless do solve complex problems. It is the augmentation means that serve to break down a large problem in such a way that the human being can walk through it with his little steps, and it is the structure or organization of these little steps or actions that we discuss as *process hierarchies*.

Every process of thought or action is made up of sub-processes. Let us consider such examples as making a pencil stroke, writing a letter of the alphabet, or making a plan. Quite a few discrete muscle movements are organized into the making of a pencil stroke; similarly, making particular pencil strokes and making a plan for a letter are complex processes in themselves that become sub-processes to the over-all writing of an alphabetic character.

Although every sub-process is a process in its own right, in that it consists of further sub-processes, there seems to be no point here in looking for the ultimate "bottom" of the process-hierarchical structure. There seems to be no way of telling whether or not the apparent "bottoms" (processes that cannot be further subdivided) exist in the physical world or in the limitations of human understanding.

In any case, it is not necessary to begin from the "bottom" in discussing particular process hierarchies. No person uses a process that is completely unique every time he tackles something new. Instead, he begins from a group of basic sensory-mental-motor process capabilities, and adds to these certain of the process capabilities of his artifacts. There are only a finite number of such basic human and artifact capabilities from which to draw. Furthermore, even quite different higher-order processes may have in common relatively high-order sub-processes.

When a man writes prose text (a reasonably high-order process), he makes use of many processes as sub-processes that are common to other high-order processes. For example, he makes use of planning, composing, dictating. The process of writing is utilized as a sub-process within many different processes of a still higher order, such as organizing a committee, changing a policy, and so on.

What happens, then, is that each individual develops a certain repertoire of process capabilities from which he selects and adapts those that will compose the processes that he executes. This repertoire is like a tool kit, and just as the mechanic must know what his tools can do and how to use them, so the intellectual worker must know the capabilities of his tools and have good methods, strategies, and rules of thumb for making use of them. All of the process capabilities in the

individual's repertoire rest ultimately upon basic capabilities within him or his artifacts, and the entire repertoire represents an inter-knit, hierarchical structure (which we often call the *repertoire hierarchy*).

We find three general categories of process capabilities within a typical individual's repertoire. There are those that are executed completely within the human integument, which we call *explicit-human* process capabilities; there are those possessed by artifacts for executing processes without human intervention, which we call *explicit-artifact* process capabilities; and there are what we call the *composite* process capabilities, which are derived from hierarchies containing both of the other kinds.

We assume that it is our H-LAM/T system (Human using Language, Artifacts, Methodology, in which he is Trained) that has the capability and that performs the process in any instance of use of this repertoire. Let us look within the process structure for the LAM/T ingredients, to get a better "feel" for our models. Consider the process of writing an important memo. There is a particular concept associated with this process—that of putting information into a formal package and distributing it to a set of people for a certain kind of consideration—and the type of information package associated with this concept has been given the special name of *memorandum*. Already the system language shows the effect of this process—i.e., a concept and its name.

The memo-writing process may be executed by using a set of process capabilities (in intermixed or repetitive form) such as the following: planning, developing subject matter, composing text, producing hard copy, and distributing. There is a definite way in which these sub-processes will be organized that represents part of the system methodology. Each of these sub-processes represents a functional concept that must be a part of the system language if it is to be organized effectively into the human's way of doing things, and the symbolic portrayal of each concept must be such that the human can work with it and remember it.

If the memo is simple, a paragraph or so in length, then the first three processes may well be of the explicit-human type (i.e., it may be planned, developed, and composed within the mind) and the last two of the composite type. If it is a complex memo, involving a good deal of careful planning and development, then all of the sub-processes might well be of the composite type (e.g., at least including the use of pencil and paper artifacts), and there might be many different applications of some of the process capabilities within the total process (i.e., successive drafts, revised plans).

The set of sub-process capabilities discussed so far, if called upon in proper

occasion and sequence, would indeed enable the execution of the memo-writing process. However, the very process of organizing and supervising the utilization of these sub-process capabilities is itself a most important sub-process of the memo-writing process. Hence, the sub-process capabilities as listed would not be complete without the addition of a seventh capability—what we call the *executive* capability. This is the capability stemming from habit, strategy, rules of thumb, prejudice, learned method, intuition, unconscious dictates, or combinations thereof, to call upon the appropriate sub-process capabilities with a particular sequence and timing. An executive process (i.e., the exercise of an executive capability) involves such sub-processes as planning, selecting, and supervising, and it is really the executive processes that embody all of the methodology in the H-LAM/T system.

To illustrate the capability-hierarchy features of our conceptual framework, let us consider an artifact innovation appearing directly within the relatively low-order capability for composing and modifying written text, and see how this can affect a (or, for instance, your) hierarchy of capabilities. Suppose you had a new writing machine—think of it as a high-speed electric typewriter with some special features. You could operate its keyboard to cause it to write text much as you could use a conventional typewriter. But the printing mechanism is more complicated; besides printing a visible character at every stroke, it adds special encoding features by means of invisible selective components in the ink and special shaping of the character.

As an auxiliary device, there is a gadget that is held like a pencil and, instead of a point, has a special sensing mechanism that you can pass over a line of the special printing from your writing machine (or one like it). The signals which this reading stylus sends through the flexible connecting wire to the writing machine are used to determine which characters are being sensed and thus to cause the automatic typing of a duplicate string of characters. An information-storage mechanism in the writing machine permits you to sweep the reading stylus over the characters much faster than the writer can type; the writer will catch up with you when you stop to think about what word or string of words should be duplicated next, or while you reposition the straight-edge guide along which you run the stylus.

This writing machine would permit you to use a new process of composing text. For instance, trial drafts could rapidly be composed from re-arranged excerpts of old drafts, together with new words or passages which you stop to type in. Your first draft could represent a free outpouring of thoughts in any order, with the inspection of foregoing thoughts continuously stimulating new considera-

tions and ideas to be entered. If the tangle of thoughts represented by the draft became too complex, you would compile a reordered draft quickly. It would be practical for you to accommodate more complexity in the trails of thought you might build in search of the path that suits your needs.

You can integrate your new ideas more easily, and thus harness your creativity more continuously, if you can quickly and flexibly change your working record. If it is easier to update any part of your working record to accommodate new developments in thought or circumstance, you will find it easier to incorporate more complex procedures in your way of doing things. This will probably allow you to accommodate the extra burden associated with, for instance, keeping and using special files whose contents are both contributed to and utilized by any current work in a flexible manner—which in turn enables you to devise and use even more complex procedures to better harness your talents in your particular working situation.

The important thing to appreciate here is that a direct new innovation in one particular capability can have far-reaching effects throughout the rest of your capability hierarchy. A change can propagate *up* through the capability hierarchy; higher-order capabilities that can utilize the initially changed capability can now reorganize to take special advantage of this change and of the intermediate higher-capability changes. A change can propagate *down* through the hierarchy as a result of new capabilities at the high level and modification possibilities latent in lower levels. These latent capabilities may previously have been unusable in the hierarchy and become usable because of the new capability at the higher level.

The writing machine and its flexible copying capability would occupy you for a long time if you tried to exhaust the reverberating chain of associated possibilities for making useful innovations within your capability hierarchy. This one innovation could trigger a rather extensive redesign of this hierarchy; your way of accomplishing many of your tasks would change considerably. Indeed, this process characterizes the sort of evolution that our intellect-augmentation means have been undergoing since the first human brain appeared.

To our objective of deriving orientation about possibilities for actively pursuing an increase in human intellectual effectiveness, it is important to realize that we must be prepared to pursue such new-possibility chains throughout the *entire* capability hierarchy (calling for a "system" approach). It is also important to realize that we must be oriented to the *synthesis* of new capabilities from reorganization of other capabilities, both old and new, that exist throughout the hierarchy (calling for a "system-engineering" approach).

B. The Basic Perspective

Individuals who operate effectively in our culture have already been considerably "augmented." Basic human capabilities for sensing stimuli, performing numerous mental operations, and for communicating with the outside world, are put to work in our society within a system—an H-LAM/T system—the individual augmented by the language, artifacts, and methodology in which he is trained. Furthermore, we suspect that improving the effectiveness of the individual as he operates in our society should be approached as a system-engineering problem—that is, the H-LAM/T system should be studied as an interacting whole from a synthesis-oriented approach.

This view of the system as an interacting whole is strongly bolstered by considering the repertoire hierarchy of process capabilities that is structured from the basic ingredients within the H-LAM/T system. The realization that any potential change in language, artifact, or methodology has importance only relative to its use within a process, and that a new process capability appearing anywhere within that hierarchy can make practical a new consideration of latent change possibilities in many other parts of the hierarchy—possibilities in either language, artifacts, or methodology—brings out the strong interrelationship of these three augmentation means.

Increasing the effectiveness of the individual's use of his basic capabilities is a problem in redesigning the changeable parts of a system. The system is actively engaged in the continuous processes (among others) of developing comprehension within the individual and of solving problems; both processes are subject to human motivation, purpose, and will. To redesign the system's capability for performing these processes means redesigning all or part of the repertoire hierarchy. To redesign a structure, we must learn as much as we can of what is known about the basic materials and components as they are utilized within the structure; beyond that, we must learn how to view, to measure, to analyze, and to evaluate in terms of the functional whole and its purpose. In this particular case, no existing analytic theory is by itself adequate for the purpose of analyzing and evaluating over-all system performance; pursuit of an improved system thus demands the use of *experimental* methods.

It need not be just the very sophisticated or formal process capabilities that are added or modified in this redesign. Essentially any of the processes utilized by a representative human today—the processes that he thinks of when he looks ahead to his day's work—are composite processes of the sort that involve external composing and manipulating of symbols (text, sketches, diagrams, lists, etc.).

Many of the external composing and manipulating (modifying, rearranging) processes serve such characteristically "human" activities as playing with forms and relationships to see what develops, cut-and-try multiple-pass development of an idea, or listing items to reflect on and then rearranging and extending them as thoughts develop.

Existing, or near-future, technology could certainly provide our professional problem-solvers with the artifacts they need to have for duplicating and rearranging text before their eyes, quickly and with a minimum of human effort. Even so apparently minor an advance could yield total changes in an individual's repertoire hierarchy that would represent a great increase in over-all effectiveness. Normally the necessary equipment would enter the market slowly; changes from the expected would be small, people would change their ways of doing things a little at a time, and only gradually would their accumulated changes create markets for more radical versions of the equipment. Such an evolutionary process has been typical of the way our repertoire hierarchies have grown and formed.

But an active research effort, aimed at exploring and evaluating possible integrated changes throughout the repertoire hierarchy, could greatly accelerate this evolutionary process. The research effort could guide the product development of new artifacts toward taking long-range meaningful steps; simultaneously, comparatively minded individuals who would respond to demonstrated methods for achieving greater personal effectiveness would create a market for the more radical equipment innovations. The guided evolutionary process could be expected to be considerably more rapid than the traditional one.

The category of "more radical innovations" includes the digital computer as a tool for the personal use of an individual. Here there is not only promise of great flexibility in the composing and rearranging of text and diagrams before the individual's eyes, but also promise of many other process capabilities that can be integrated into the H-LAM/T system's repertoire hierarchy.

C. Detailed Discussion of the H-LAM/T System

1. THE SOURCE OF INTELLIGENCE When one looks at a computer system that is doing a very complex job, he sees on the surface a machine that can execute some extremely sophisticated processes. If he is a layman, his concept of what provides this sophisticated capability may endow the machine with a mysterious power to sweep information through perceptive and intelligent synthetic thinking devices. Actually, this sophisticated capability results from a very clever

Getting yourself in the right frame of mind for what

Dictionary, Second Edition) the "... cooperative action of discrete agencies such that the total effect is greater than the sum of the two effects taken independently..." This term seems directly applicable here, where we could say that synergism is our most likely candidate for representing the actual source of intelligence.

Actually, each of the social, life, or physical phenomena we observe about us would seem to derive from a supporting hierarchy of organized functions (or processes), in which the synergistic principle gives increased phenomenological sophistication to each succeeding higher level of organization. In particular, the intelligence of a human being, derived ultimately from the characteristics of individual nerve cells, undoubtedly results from synergism.

2. INTELLIGENCE AMPLIFICATION It has been jokingly suggested several times during the course of this study that what we are seeking is an "intelligence amplifier." (The term is attributed originally to W. Ross Ashby.² At first this term was rejected on the grounds that in our view one's only hope was to make a better match between existing human intelligence and the problems to be tackled, rather than in making man more intelligent. But deriving the concepts brought out in the preceding section has shown us that indeed this term does seem applicable to our objective.)

Accepting the term "intelligence amplification" does not imply any attempt to increase native human intelligence. The term "intelligence amplification" seems applicable to our goal of augmenting the human intellect in that the entity to be produced will exhibit more of what can be called intelligence than an unaided human could; we will have amplified the intelligence of the human by organizing his intellectual capabilities into higher levels of synergistic structuring. What possesses the amplified intelligence is the resulting H-LAM/T system, in which the LAM/T augmentation means represent the amplifier of the human's intelligence.

In amplifying our intelligence, we are applying the principle of synergistic structuring that was followed by natural evolution in developing the basic human capabilities. What we have done in the development of our augmentation means is to construct a superstructure that is a synthetic extension of the natural structure upon which it is built. In a very real sense, as represented by the steady evolution of our augmentation means, the development of "artificial intelligence" has been going on for centuries.

3. TWO-DOMAIN SYSTEM The human and the artifacts are the only physical components in the H-LAM/T system. It is upon their capabilities that the ultimate

organizational hierarchy, so that pursuit of the source of intelligence within this system would take one down through layers of functional and physical organization that become successively more primitive. *to machine language*

To be more specific, we can begin at the top and list the major levels down through which we would pass if we successively decomposed the functional elements of each level, in search of the "source of intelligence." A programmer could take us down through perhaps three levels (depending upon the sophistication of the total process being executed by the computer) perhaps depicting the organization at each level with a flow chart. The first level down would organize functions corresponding to statements in a problem-oriented language (e.g., ALGOL or COBOL), to achieve the desired over-all process. The second level down would organize lesser functions into the processes represented by first-level statements. The third level would perhaps show how the basic machine commands (or rather the processes which they represent) were organized to achieve each of the functions of the second level.

Then a machine designer could take over, and with a block diagram of the computer's organization he could show us (Level 4) how the different hardware units (e.g., random-access storage, arithmetic registers, adder, arithmetic control) are organized to provide the capability of executing sequences of the commands used in Level 3. The logic designer could then give us a tour of Level 5, also using block diagrams, to show us how such hardware elements as pulse gates, flip-flops, and AND, OR, and NOT circuits can be organized into networks giving the functions utilized at Level 4. For Level 6 a circuit engineer could show us diagrams revealing how components such as transistors, resistors, capacitors, and diodes can be organized into modular networks that provide the functions needed for the elements of Level 5.

Device engineers and physicists of different kinds could take us down through more layers. But rather soon we have crossed the boundary between what is man-organized and what is nature-organized, and are ultimately discussing the way in which a given physical phenomenon is derived from the intrinsic organization of sub-atomic particles, with our ability to explain succeeding layers blocked by the exhaustion of our present human comprehension.

If we then ask ourselves where that intelligence is embodied, we are forced to concede that it is elusively distributed throughout a hierarchy of functional processes—a hierarchy whose foundation extends down into natural processes below the depth of our comprehension. If there is any one thing upon which this "intelligence" depends, it would seem to be *organization*. The biologists and physiologists use a term "synergism" to designate (from Webster's *Unabridged*

organization
synergism
level

mate capability of the system will depend. This was implied in the earlier statement that every composite process of the system decomposes ultimately into explicit-human and explicit-artifact processes. There are thus two separate domains of activity within the H-LAM/T system: that represented by the human, in which all explicit-human processes occur; and that represented by the artifacts, in which all explicit-artifact processes occur. In any composite process, there is cooperative interaction between the two domains, requiring interchange of energy (much of it for information exchange purposes only). Figure 1 depicts this two domain concept and embodies other concepts discussed below.

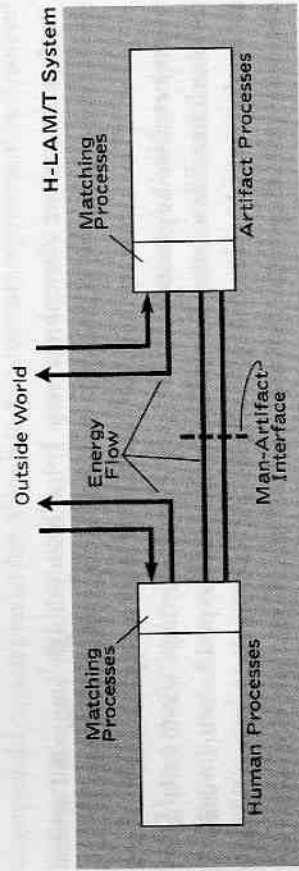


FIGURE 1. Portrayal of the Two Active Domains within the H-LAM/T System.

Where a complex machine represents the principal artifact with which a human being cooperates, the term "man-machine interface" has been used for some years to represent the boundary across which energy is exchanged between the two domains. However, the "man-artifact interface" has existed for centuries, ever since humans began using artifacts and executing composite processes.

Exchange across this "interface" occurs when an explicit-human process is coupled to an explicit-artifact process. Quite often these coupled processes are designed for just this exchange purpose, to provide a functional match between other explicit-human and explicit-artifact processes buried within their respective domains that do the more significant things. For instance, the finger and hand motions (explicit-human processes) activate key-linkage motions in the typewriter (couple to explicit-artifact processes). But these are only part of the matching processes between the deeper human processes that direct a given word to be typed and the deeper artifact processes that actually imprint the ink marks on the paper.

The outside world interacts with our H-LAM/T system by the exchange of energy with either the individual or his artifact. Again, special processes are often designed to accommodate this exchange. However, the direct concern of our present study lies within the system, with the internal processes that are and can be significantly involved in the effectiveness of the *system* in developing the human's comprehension and pursuing the human's goals. . . .

5. CAPABILITY REPERTOIRE HIERARCHY The concept of our H-LAM/T system possessing a repertoire of capabilities that is structured in the form of a hierarchy is most useful in our study. We shall use it in the following to tie together a number of considerations and concepts.

There are two points of focus in considering the design of new repertoire hierarchies: the materials with which we have to work, and the principles by which new capability is constructed from these basic materials.

a. Basic Capabilities

Materials in this context are those capabilities in the human and in the artifact domains from which all other capabilities in the repertoire hierarchy must be constructed. Each such basic capability represents a type of functional component with which the system can be built, and a thorough job of redesigning the system calls for making an inventory of the basic capabilities available. Because we are exploring for perspective, and not yet recommending research activities, we are free to discuss and define in more detail what we mean by "basic capability" without regard to the amount of research involved in making an actual inventory.

The two domains, human and artifact, can be explored separately for their basic capabilities. In each we can isolate two classes of basic capability; these classes are distinguished according to whether or not the capability has been put to use within out augmentation means. The first class (those in use) can be found in a methodical manner by analyzing present capability hierarchies. For example, select a given capability, at any level in the hierarchy, and ask yourself if it can be usefully changed by any means that can be given consideration in the augmentation research contemplated. If it can, then it is not basic but it can be decomposed into an eventual set of basic capabilities. As you proceed down through the hierarchy, you will begin to encounter capabilities that cannot be usefully changed, and these will make up your inventory of basic capabilities. Ultimately, every such recursive decomposition of a given capability in the hierarchy will find every one of its branching paths terminated by basic capabilities. Be-

ginning such decomposition search with different capabilities in the hierarchy will eventually uncover all of those basic capabilities used within that hierarchy or augmentation system. Many of the branching paths in the decomposition of a given higher-order capability will terminate in the same basic capability, since a given basic capability will often be used within many different higher-order capabilities.

Determining the class of basic capabilities not already utilized within existing augmentation systems requires a different exploration method. Examples of this method occur in technological research, where analytically oriented researchers search for new understandings of phenomena that can add to the research engineer's list of things to be used in the synthesis of better artifacts.

Before this inventorying task can be pursued in any specific instance, some criteria must be established as to what possible changes within the H-LAM/T system can be given serious consideration. For instance, some research situations might have to disallow changes which require extensive retraining, or which require undignified behavior by the human. Other situations might admit changes requiring years of special training, very expensive equipment, or the use of special drugs.

The capability for performing a certain finger action, for example, may not be basic in our sense of the word. Being able to extend the finger a certain distance would be basic, but the strength and speed of a particular finger motion and its coordination with higher actions generally are usefully changeable and therefore do not represent basic capabilities. What would be basic in this case would perhaps be the processes whereby strength could be increased and coordinated movement patterns learned, as well as the basic movement range established by the mechanical-limit loci of the muscle-tendon-bone system. Similar capability breakdowns will occur for sensory and cognitive capabilities.

b. Structure Types

1) *General* The fundamental principle used in building sophisticated capabilities from the basic capabilities is structuring—the special type of structuring (which we have termed *synergetic*) in which the organization of a group of elements produces an effect greater than the mere addition of their individual effects. Perhaps “purposeful” structuring (or organization) would serve us as well, but since we aren't sure yet how the structuring concept must mature for our needs, we shall tentatively stick with the special modifier, “synergetic.” We are developing a growing awareness of the significant and pervasive nature of such struc-

ture within every physical and conceptual thing we inspect, where the hierarchical form seems almost universally present as stemming from successive levels of such organization.

The fundamental entities that are being structured in each and every case seems to be what we could call processes, where the most basic of physical processes (involving fields, charges, and momenta associated with the dynamics of fundamental particles) appear to be the hierarchical base. There are dynamic electro-optical-mechanical processes associated with the function of our artifacts, as well as metabolic, sensory, motor, and cognitive processes of the human, which we find to be relatively fundamental components within the structure of our H-LAM/T system—and each of these seems truly to be ultimately based (to our degree of understanding) upon the above mentioned basic physical processes. The elements that are organized to give fixed structural form to our physical objects—e.g., the “element” of tensile strength of a material—are also derived from what we could call synergetic structuring of the most basic physical processes.

But at the level of the capability hierarchy where we wish to work, it seems useful to us to distinguish several different types of structuring—even though each type is fundamentally a structuring of the basic physical processes. Tentatively we have isolated five such types—although we are not sure how many we shall ultimately want to use in considering the problem of augmenting the human intellect, nor how we might divide and subdivide these different manifestations of physical-process structuring. We use the terms “mental structuring,” “concept structuring,” “symbol structuring,” “process structuring,” and “physical structuring.”

2) *Mental Structuring* Mental structuring is what we call the internal organization of conscious and unconscious mental images, associations, or concepts (or whatever it is that is organized within the human mind) that somehow manages to provide the human with understanding and the basis for such as judgment, intuition, inference, and meaningful action with respect to his environment. There is a term used in psychology, “cognitive structure,” which so far seems to represent just what we want for our concept of mental structure, but we will not adopt it until we become more sure of what the accepted psychological meaning is and of what we want for our conceptual framework.

For our present purpose, it is irrelevant to worry over what the fundamental mental “things” being structured are, or what mechanisms are accomplishing the structuring or making use of what has been structured. We feel

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reasonably safe in assuming that learning involves some kind of meaningful organization within the brain, and that whatever is so organized or structured represents the operating model of the individual's universe to the mental mechanisms that derive his behavior. And further, our assumption is that when the human in our H-LAM/T system makes the key decision or action that leads to the solution of a complex problem, it will stem from the state of his mental structure at that time. In this view, then, the basic purpose of the system's activity on that problem up to that point has been to develop his mental structure to the state from which the mental mechanisms could derive the key action.

Our school systems attest that there are specific experiences that can be given to a human that will result in development of his mental structure to the point where the behavior derived therefrom by his mental mechanisms shows us that he has gained new comprehension—in other words, we can do a certain amount from outside the human toward developing his mental structure. Independent students and researchers also attest that internally directed behavior on the part of an individual can directly aid his structure-building process.

We don't know whether a mental structure is developed in a manner analogous to (a) development of a garden, where one provides a good environment, plants the seeds, keeps competing weeds and injurious pests out, but otherwise has to let natural processes take their course, or to (b) development of a basketball team, where much exercise of skills, patterns, and strategies must be provided so that natural processes can slowly knit together an integration, or to (c) development of a machine, where carefully formed elements are assembled in a precise, planned manner so that natural phenomena can immediately yield planned function. We don't know the processes, but we can and have developed empirical relationships between the experiences given a human and the associated manifestations of developing comprehension and capability, and we see the near-future course of the research toward augmenting the human's intellect as depending entirely upon empirical findings (past and future) for the development of better means to serve the development and use of mental structuring in the human.

We don't mean to imply by this that we renounce theories of mental processes. What we mean to emphasize is that pursuit of our objective need not wait upon the understanding of the mental processes that accomplish (what we call) mental structuring and that derive behavior therefrom. It would be to ignore the emphases of our own conceptual framework not to make fullest use of any theory that provided a working explanation for a group of empirical data. What's

more, our entire conceptual framework represents the first pass at a "theoretical" model with which to organize our thinking and action.

3) *Concept Structuring* Within our framework we have developed the working assumption that the manner in which we seem to be able to provide experiences that favor the development of our mental structures is based upon concepts as a "medium of exchange." We view a concept as a tool that can be grasped and used by the mental mechanisms, that can be composed, interpreted, and handling done the natural mental substances and processes. The grasping and handling done by these mechanisms can often be facilitated if the concept is given an explicit "handle" in the form of a representative symbol. Somehow the mental mechanisms can learn to manipulate images (or something) of symbols in a meaningful way and remain calmly confident that the associated conceptual manipulations are within call.

Concepts seem to be structurable, in that a new concept can be composed of an organization of established concepts. For present purposes, we can view a *concept structure* as something which we might try to develop on paper for ourselves or work with by conscious thought processes, or as something which we try to communicate to one another in serious discussion. We assume that, for a given unit of comprehension to be imparted, there is a concept structure (which can be consciously developed and displayed) that can be presented to an individual in such a way that it is mapped into a corresponding mental structure which provides the basis for that individual's "comprehending" behavior. Our working assumption also considers that some concept structures would be better for this purpose than others, in that they would be more easily mapped by the individual into workable mental structures, or in that the resulting mental structures enable a higher degree of comprehension and better solutions to problems, or both.

A concept structure often grows as part of a cultural evolution—either on a large scale within a large segment of society, or on a small scale within the activity domain of an individual. But it is also something that can be directly designed or modified, and a basic hypothesis of our study is that better concept structures can be developed—structures that when mapped into a human's mental structure will significantly improve his capability to comprehend and to find solutions within his complex-problem situations.

A natural language provides its user with a ready-made structure of concepts that establishes a basic mental structure, and that allows relatively flexible, general-purpose concept structuring. Our concept of "language" as one of the

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basic means for augmenting the human intellect embraces all of the concept structuring which the human may make use of.

4) *Symbol Structuring* The other important part of our "language" is the way in which concepts are represented—the symbols and *symbol structures*. Words structured into phrases, sentences, paragraphs, monographs—charts, lists, diagrams, tables, etc. A given structure of concepts can be represented by any of an infinite number of different symbol structures, some of which would be much better than others for enabling the human perceptual and cognitive apparatus to search out and comprehend the conceptual matter of significance and/or interest to the human. For instance, a concept structure involving many numerical data would generally be much better represented with Arabic rather than Roman numerals and quite likely a graphic structure would be better than a tabular structure.

But it is not only the *form* of a symbol structure that is important. A problem solver is involved in a stream of conceptual activity whose course serves his mental needs of the moment. The sequence and nature of these needs are quite variable, and yet for each need he may benefit significantly from a form of symbol structuring that is uniquely efficient for that need.

Therefore, besides the forms of symbol structures that can be constructed and portrayed, we are very much concerned with the speed and flexibility with which one form can be transformed into another, and with which new material can be located and portrayed.

We are generally used to thinking of our symbol structures as a pattern of marks on a sheet of paper. When we want a different symbol-structure view, we think of shifting our point of attention on the sheet, or moving a new sheet into position. But another kind of view might be obtained by extracting and ordering all statements in the local text that bear upon Consideration A of the argument—or by replacing all occurrences of specified esoteric words by one's own definitions. This sort of "view generation" becomes quite feasible with a computer-controlled display system, and represents a very significant capability to build upon.

With a computer manipulating our symbols and generating their portrayals to us on a display, we no longer need think of our looking at *the* symbol structure which is stored—as we think of looking at *the* symbol structures stored in notebooks, memos, and books. What the computer actually stores need be none of our concern, assuming that it can portray symbol structures to us that are consistent with the form in which we think our information is structured.

A given concept structure can be represented with a symbol structure that is completely compatible with the computer's internal way of handling symbols, with all sorts of characteristics and relationships given explicit identifications that the user may never directly see. In fact, this structuring has immensely greater potential for accurately mapping a complex concept structure than does a structure an individual would find it practical to construct or use on paper.

The computer can transform back and forth between the two-dimensional portrayal on the screen, of some limited view of the total structure, and the aspect of the n-dimensional internal image that represents this "view." If the human adds to or modifies such a "view," the computer integrates the change into the internal-image symbol structure (in terms of the computer's favored symbols and structuring) and thereby automatically detects a certain proportion of his possible conceptual inconsistencies.

Thus, inside this instrument (the computer) there is an internal-image, computer-symbol structure whose convolutions and multi-dimensionality we can learn to shape to represent to hitherto unattainable accuracy the concept structure we might be building or working with. This internal structure may have a form that is nearly incomprehensible to the direct inspection of a human (except in minute chunks).

But let the human specify to the instrument his particular conceptual need of the moment, relative to this internal image. Without disrupting its own internal reference structure in the slightest, the computer will effectively stretch, bend, fold, extract, and cut as it may need in order to assemble an internal substructure that is its response, structured in its own internal way. With the set of standard translation rules appropriate to the situation, it portrays to the human via its display a symbol structure designed for *his* quick and accurate perception and comprehension of the conceptual matter pertinent to this internally composed substructure.

No longer does the human work on stiff and limited symbol structures, where much of the conceptual content can only be implicitly designated in an indirect and distributed fashion. These new ways of working are basically available with today's technology—we have but to free ourselves from some of our limiting views and begin experimenting with compatible sets of structure forms and processes for human concepts, human symbols, and machine symbols.

5) *Process Structuring* Essentially everything that goes on within the H-LAM/T system and that is of direct interest here involves the manipulation of concept and symbol structures in service to the mental structure. Therefore, the processes

may be tougher than the problem he faced in the role of direct-contributive worker. If the flexibility desired for the process hierarchies (to make room for human cut-and-try methods) is not to be degraded or abandoned, the executive activity will have to be provided with fast and flexible symbol-structuring techniques.

The means available to humans today for developing and manipulating these symbol structures are both laborious and inflexible. It is hard enough to develop an initial structure of diagrams and text, but the amount of effort required to make changes is often prohibitively great; one settles for inflexibility. Also, the kind of generous flexibility that would be truly helpful calls for added symbol structuring just to keep track of the trials, branches, and reasoning thereto that are involved in the development of the subject structure; our present symbol-manipulation means would very soon bog down completely among the complexities that are involved in being more than just a little bit flexible.

We find that the humans in our H-LAM/T systems are essentially working continuously within a symbol structure of some sort, shifting their attention from one structure to another as they guide and execute the processes that ultimately provide them with the comprehension and the problem solutions that they seek. This view increases our respect for the essential importance of the basic capability of composing and modifying efficient symbol structures. Such a capability depends heavily upon the particular concepts that are isolated and manipulated as entities, upon the symbology used to represent them, upon the artifacts that help to manipulate and display the symbols, and upon the methodology for developing and using symbol structures. In other words, this capability depends heavily upon proper language, artifacts, and methodology, our basic augmentation means. a pattern language

When the course of action must respond to new comprehension, new insights and new intuitive flashes of possible explanations or solutions, it will not be an orderly process. Existing means of composing and working with symbol structures penalize disorderly processes very heavily, and it is part of the real promise in the automated H-LAM/T systems of tomorrow that the human can have the freedom and power of disorderly processes. . . .

VI. CONCLUSIONS

Three principal conclusions may be drawn concerning the significance and implications of the ideas that have been presented.

First, any possibility for improving the effective utilization of the intellectual

within the H-LAM/T system that we are most interested in developing are those that provide for the manipulation of all three types of structure. This brings us to the fourth category of structuring, *process structuring*.

As we are currently using it, the term *process structuring* includes the organization, study, modification, and execution of processes and process structures. Whereas concept structuring and symbol structuring together represent the language component of our augmentation means, process structuring represents the methodology component (plus a little more, actually). There has been enough previous discussion of process structures that we need not describe the notion here, beyond perhaps an example or two. The individual processes (or actions) of my hands and fingers have to be cooperatively organized if the typewriter is to do my bidding. My successive actions throughout my working day are meant to cooperate toward a certain over-all professional goal.

Many of the process structures are applied to the task of organizing, executing, supervising, and evaluating other process structures. Many of them are applied to the formation and manipulation of symbol structures (the purpose of which will often be to support the conceptual labor involved in process structuring).

6) *Physical Structuring* Physical structuring, the last of the five types which we currently use in our conceptual framework, is nearly self-explanatory. It pretty well represents the artifact component of our augmentation means, insofar as their actual physical construction is concerned. . . .

e. Flexibility in the Executive Role

[T]here is finite human capability which must be divided between executive and direct-contributive activities [in the H-LAM/T system]. An important aspect of the multi-role activity of the human in the system is the development and manipulation of the symbol structures associated with *both* his direct-contributive roles and his executive roles.

When the system encounters a complex situation in which comprehension and problem solutions are being pursued, the direct-contributive roles require the development of symbol structures that portray the concepts involved within the situation. But executive roles in a complex problem situation also require conceptual activity—e.g., comprehension, selection, supervision—that can benefit from well-designed symbol structures and fast, flexible means for manipulating and displaying them. For complex processes, the executive problem posed to the human (of gaining the necessary comprehension and making a good plan)

power of society's problem solvers warrants the most serious consideration. This is because man's problem-solving capability represents possibly the most important resource possessed by a society. The other contenders for first importance are all critically dependent for their development and use upon this resource. Any possibility for evolving an art or science that can couple directly and significantly to the continued development of that resource should warrant doubly serious consideration.

Second, the ideas presented are to be considered in both of the above senses: the direct-development sense and the "art of development" sense. To be sure, the possibilities have long-term implications, but their pursuit and initial rewards await us now. By our view, we do not have to wait until we learn how the human mental processes work, we do not have to wait until we learn how to make computers more intelligent or bigger or faster; we can begin developing powerful and economically feasible augmentation systems on the basis of what we now know and have. Pursuit of further basic knowledge and improved machines will continue into the unlimited future, and will want to be integrated into the "art" and its improved augmentation systems—but getting started now will provide not only orientation and stimulation for these pursuits, but will give us improved problem-solving effectiveness with which to carry out the pursuits.

Third, it becomes increasingly clear that there should be action now—the sooner the better—action in a number of research communities and on an aggressive scale. We offer a conceptual framework and a plan for action, and we recommend that these be considered carefully as a basis for action. If they be considered but found unacceptable, then at least serious and continued effort should be made toward developing a more acceptable conceptual framework within which to view the overall approach, toward developing a more acceptable plan of action, or both.

This is an open plea to researchers and to those who ultimately motivate, finance, or direct them, to turn serious attention toward the possibility of evolving a dynamic discipline that can treat the problem of improving intellectual effectiveness in a total sense. This discipline should aim at producing a continuous cycle of improvements—increased understanding of the problem, improved means for developing new augmentation systems, and improved augmentation systems that can serve the world's problem solvers in general and this discipline's workers in particular. After all, we spend great sums for disciplines aimed at understanding and harnessing nuclear power. Why not consider developing a discipline aimed at understanding and harnessing "neural power"? In the long run, the power of the human intellect is really much the more important of the two.

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