A Personal Computer for Children of All Ages

Alan Kay

Alan Kay's initial description
of a "Dynabook" written at
Xerox PARC in 1972

VPRI Paper for Historical Context

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A Personal Computer for Children of All Ages

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Abstract

This note speculates about the emergence of personal, portable information manipulators and their effects when used by both children and adults. Although it should be read as science fiction, current trends in miniaturization and price reduction almost guarantee that many of the notions discussed will actually happen in the near future.

> "To know the world one must construct it."
> -Pavese

For many years it has been a tradition to attempt to cure our society's ills through technology: "You have slums? Let's build low-cost housing!" "You can't afford that TV? We'll build a cheaper one and you can buy it on time, even though it will break before you've finished paying for it!" "Your kids aren't learning and education is too expensive? We'll build you a teaching machine for less which will guarantee your kids will pass tests!"

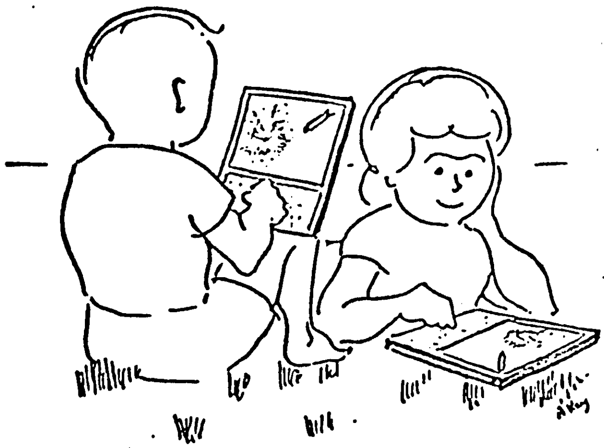
Unfortunately, most of these "cures" are no more than paint over rust; the sources of the initial problems still remain. Educational goals are even more obscured by the diverse models of the "end product" which exist: the society wants more members of the society (cultural genetics), the parents may want success, conformity, fame, or don't care; the kid is not asked (he may just want to plant beans and watch them come up). What about the teachers? They, of course, range from enlightened human beings (who have a good model of themselves, what it is that they are trying to communicate, and what the child's current model of the situation is), to those well-intentioned people who would like to teach (but lack talent), to those who take it as a job, or worse, drifted into it because "ed" was the easiest way through college and now begrudge their fate through their young charges.

Technologists point out that at least the bottom categories would be eliminated through a teaching machine. What they seldom understand is that what is delivered is a box which at best squarely fits the middle category: well intentioned but lacking talent! Can technology ever deliver a box with the attributes of the first category of teacher? Maybe. But first, it must decide that it is a <u>necessary</u> and desirable goal to do so.

What we would like to do in this brief note is to discuss some aspects of the learning process which we feel <u>can</u> be augmented through technological <u>media</u>. Most of the notions have at their root a number of theories about the child that lie much closer to Piaget than to Skinner. We feel that a child is a "verb" rather than a "noun", an actor rather than an object; he <u>is not</u> a scaled-up pigeon or rat; he <u>is</u> trying to acquire a model of his surrounding environment in order to deal with it; his theories are "practical" notions of how to get from idea A to idea B rather than "consistent" branches of formal logic, etc. We would like to hook into his current modes of thought in order to influence him rather than just trying to replace his model with one of our own.

We do not feel that technology is a <u>necessary</u> constituent for this process any more than is the book. It may, however, provide us with a better "book", one which is active (like the child) rather than passive. It may be something with the attention grabbing powers of TV, but controllable <u>by the child</u> rather than the networks. It can be like a piano: (a product of technology, yes), but one which can be a tool, a toy, a medium of expression, a source of unending pleasure and delight...and, as with most gadgets in unenlightened hands, a terrible drudge!!

This new medium will not "save the world" from disaster. Just as with the book, it brings a new set of horizons and a new set of problems. The book did, however, allow centuries of human knowledge to be encapsulated and transmitted to everybody; perhaps an active medium can also convey some of the excitement of thought and creation!



Zap! With a beautiful flash and appropriate noise, Jimmy's spaceship disintegrated; Beth had won Spacewar again. The nine-year-olds were lying on the grass of a park near their home, their DynaBooks hooked together to allow each of them a viewscreen into the space world where Beth's ship was now floating triumphantly alone.

"Y' wanna play again?" asked Jimmy.

"Naw," said Beth, "It's too easy."

"Well, in real space you'd be in orbit around the sun. Betcha couldn't win then!"

"Oh yeah?" Beth was piqued into action. "How could we do the sun?"

"Well, uh, let's see. When the ship's in space without a sun, it just keeps going 'cause there's nothing to stop it. Whenever we push the thrust button, your program adds speed in the direction the ship is pointing."

"Yeah. That's why you have to turn the ship and thrust back to get it to stop." She illustrated by maneuvering her ship with a few practiced button pushes on her DynaBook. "But the sun makes things fall into it...it's not the same."

"But look, Beth," Jimmy aimed her ship, "when you hold the thrust button down, it starts going faster and faster, just like Mr. Jacobsen said rocks and things do in gravity."

"Oh yeah. It's just like the rock had a jet on it pointed towards the earth. Hey, what about also adding speed to the ship that way?"

"Whadaya mean?" Jimmy was confused.

"Here look." Her fingers started to fly on the DynaBook's keyboard, altering the program she had written several weeks before after she and the rest of her school group had "accidently" been exposed to Spacewar by Mr. Jacobsen. "You just act as though the ship is pointed towards the sun and add speed!" As she spoke her ship started to fall, but not towards the sun. "Oh no! It's going all over the place!"

Jimmy saw what was wrong. "You need to add speed in the direction of the sun no matter where your ship is."

"But how do we do that? Cripes!"

"Let's go and ask Mr. Jacobsen!" They picked up their DynaBooks and raced across the grass to their teacher who was helping other members of their group to find out what they wanted to know.

Mr. Jacobsen's eyes twinkled at their impatience to know things. They were still as eager as two-year-olds. He and others like him would do their best to sustain the curiosity and desire to create that are the birthright of every human being.

From what Beth and Jimmy blurted at him, he was able to see that the kids had rediscovered an important idea intuitively and needed only a hint in order to add the sun to their private cosmos. He was enthusiastic, but a bit noncommittal:

"That's great! I'll bet you the Library has just about what you need." At that, Jimmy connected his DynaBook to his class's LIBLINK and became heir to the thought and knowledge of ages past, all perusable through the screen of his DB. It was like taking an endless voyage through a space that knew no bounds. As always he had a little trouble remembering what his original purpose was. Each time he came to something interesting, he caused a copy to be send into his DynaBook, so he could look at it later. Finally, Beth poked him in the ribs, and he started looking more seriously for what they needed. He composed a simple filter for his DynaBook to aid their search...

At the same time that Beth and Jimmy were earnestly trying to discover the notion of a coordinate system, Beth's dad was sitting on a plane preparing for an important meeting. He was perusing pertinent background facts which he had abstracted into his DynaBook that morning from his business' Masterfile, every once in a while pausing to enter a voice comment. He knew it was somewhat anachronistic of him not to type in his comments (Miss Jones would still have to do that), and he wished ardently for the long-promised speech recognition capability to be added to his DynaBook. On the ground his eye was attracted by a lurid poster on one of the airport's StoryVends. He connected his DB to the StoryVend "just to see" if the heroine was truly that "inventive". She was, and as he pushed the Copy Key on his DynaBook (Alice would never know), he was chagrined to be reminded by the StoryVend that he had neglected to pay for the copy.

He got into the taxi in a somewhat more businesslike frame of mind and decided to check the opposition's estimates. As he scanned the information with his DB, he reflected that this was something that he just wouldn't have done five years before; it was too much of a hassle to do it by hand or to pass it on to someone else. And besides he had just thought of a new way to look at their figures while on the plane.

By then, Beth had discovered that her problem was ridiculously easy if the sun was placed at "zero", and she simply subtracted a little bit from the "horizontal" and "vertical" speeds of her craft according to where the ship was located. All of the drawing and animations she and the other kids had done previously were accomplished by using relative notions which coincided with the scope of their abilities at the time. She was now ready to hold several independent ideas in her mind. The intuitive feeling for linear and nonlinear motion that the children gained would be an asset for later understanding of some of the great generalizations of science.

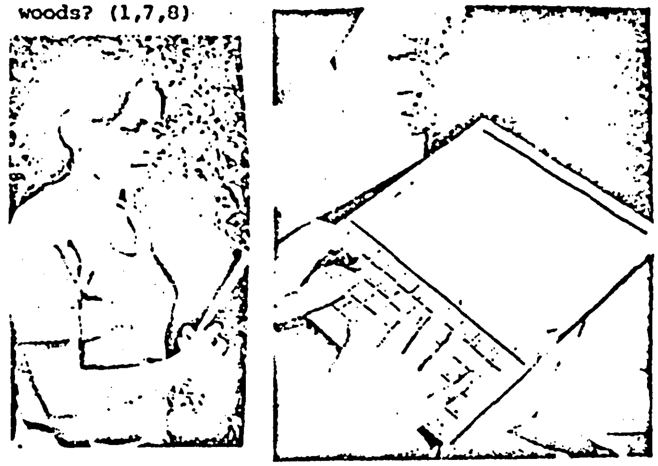
After getting her spaceship to perform, she found Jimmy, hooked to his DynaBook, and then soundly trounced him until she became bored. While he went off to find a less formidable foe, she retrieved a poem she had been writing on her DynaBook and edited a few lines to improve it...

....

It is now within the reach of current technology to give all the Beths and their dads a "DynaBook" to use anytime, anywhere as they may wish. Although it can be used to communicate with others through the "knowledge utilities" of the future such as a school "library" (or business information system), we think that a large fraction of its use will involve reflexive communication of the owner with himself through this personal medium, much as paper and notebooks are currently used.

A tool is something that aids manipulation of a medium and man is cliched as the "tool building animal". The computer is also regarded as a tool by many. Clearly, though, the book is much more than a tool, and man is much more than a tool builder...he is an inventor of universes. From the moment he learns to see and to use language, each new universe serves as a medium (and constraint) of expression in which imagined structures can be embedded, usually with the aid of tools. What about computers? They are clearly more than a tool also, though in typical McLuhanesque fashion, much of their content has been adopted from previous media, and their own attributes are just beginning to be discovered.

What then is a personal computer? One would hope that it would be both a medium for containing and expressing arbitrary symbolic notions, and also a collection of useful tools for manipulating these structures, with ways to add new tools to the repertoire. Another rarely invoked constraint is that it be superior to books and printing in at least some ways without being markedly inferior in others. (The previous remark seems to disallow known commercial display devices from consideration.) "Personal" also means owned by its user (needs to cost no more than a TV) and portable (which to me means that the user can easily carry the device <u>and other things</u> at the same time). Need we add that it be usable in the woods? (1,7,8)



The "DynaBook" and Education

> "One must learn to think well before learning to think. Afterward it proves too difficult."
> -A. France

It has recently become fashionable for researchers in artificial intelligence and (to a certain extent) in education to examine the way children gain their models of the world. (It was once thought that a simulation of intelligent behavior could be obtained through nonanthropomorphic means.) Following the lead of Newell and Simon, Papert and Minsky, Moore and Andersen, many are now interested in what little is known about the acquisition and manipulation of human knowledge by both children and adults. Of particular interest are theories of early development and model building epitomized by Piaget, Bruner, Hunt, Kagan, among others who study what a child does at various stages of development.

There is another closely related group that is interested in discovering just what children are really capable of at various levels of maturity. We must mention Montessori, who was one of the first to decide that children were much more adept at learning during early years (2-5) than was generally supposed.* O. K. Moore has shown, via a reactive environment, that even very young children can learn to read, write and abstract. Shinichi Suzuki has successfully taught thousands of children between 3 and 6 to play the violin. Work by Bruner and Kagan has demonstrated that children, even in their first year (or first

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*It is interesting how provable a sociological theory can be. There not only is ample evidence to support the idea that children are tremendously capable, but there also exists an equal body of evidence (gathered by more pessimistic souls) to show that children are really quite stupid and require endless repetition in order to learn. The obvious Hawthorn effect says that we should be as optimistic as possible and the children will save us every time.

month), are capable of visual discrimination and generalization far beyond what was previously supposed. (2)

The work and thoughts of O. K. Moore and Seymour Papert particularly influenced the notions which led to the DynaBook. Both men feel that the child is an active agent, a creator and explorer, and is far more capable intellectually than is generally supposed.

A number of the principles which led to Moore's "talking typewriter" are worth examination. He feels that it is not so much that children lack a long attention span, but that they have difficulty remaining in the same role with respect to an idea or activity. The role of "patient listener" to an idea can quickly lead to boredom and lack of attention, unless other roles can also be assumed such as "active agent", "judge" or "game player", etc. An environment which allows many perspectives to be taken is very much in tune with the differentiating, abstracting and integrative activities of the child.

A "safe and covert" environment, where the child can assume almost any role without social or physical hurt is an important part of the day. Although it is necessary that skills and knowledge be occasionally put to serious test before peers and adults, there must also be times of absolute safety for "winging it" without reproach. A "productive" environment, in Moore's terms, is one in which things that are learned can be used as part of (and for further learning of) new ideas. Finally, an environment which is immediately responsive to the child's activities and allows him to gain a model of himself is tremendously important.

The "talking typewriter" was a crystallization of these ideas into a device (initially simulated by a graduate student behind a wall) which led to many beautiful insights into the abilities and inclinations of the young child. (3)

> "Should the computer program the kid, or should the kid program the computer?"
> —S. Papert

Papert's work in "teaching kids thinking" through giving them an environment in which they can write programs for their own ends (animations, games, etc.) is strikingly similar in spirit to Moore's, although the philosophical background is that of AI and Piaget. (4,5,6)

The language LOGO is used (via a timesharing system) through terminals which allow text, graphics, music and a lumbering mechanical "turtle" to be under control of a child's programs. Papert's LOGO efforts are "CAI" only if the acronym stands for Computer Aided Intuition (or Inspiration) rather than Instruction. Much of current computer-related education, however, is based on Programmed Learning which was largely derived from Behavioralists' experiments with rats and pigeons. Papert's view, on the other hand, was highly influenced by contact with Piaget and his work which (oddly enough...) was drawn mostly from studies of actual children and how they think about the world.

Our project is very sympathetic to the latter view. Where some people measure progress in answers-right/test or tests-passed/year, we are more interested in "Sistine-Chapel-Ceilings/Lifetime. This is not to say that skill achievement is de-emphasized. "Sistine-Chapel-Ceilings are not gotten without healthy application of both dreaming and great skill at painting those dreams. As bystander L. d.Vinci remarked, "Where the spirit does not work with the hand, there is no art". Papert has pointed out that people will willingly and joyfully spend thousands of hours of highly physical and mental effort in order to perfect a sport (such as skiing) that they are involved in. Obviously school and learning have not been made interesting to children, nor has a way to get immediate enjoyment from practicing intellectual skills generally appeared.

With Dewey, Piaget and Papert, we believe that children "learn by doing" and that much of the alienation in modern education comes from the great philosophical distance between the kinds of things children can "do" and much of 20-century adult behavior. Unlike the African child whose play with bow and arrow INVOLVES him in future adult activity, the American child can either indulge in irrelevant imitation (the child in a nurse's uniform taking care of a doll) or is forced to participate in activities which will not bear fruit for many years and will leave him alienated (mathematics: "multiplication is GOOD for you - see, you can solve problems in books; "music: "practice your violin, in three years we might tell you about music;" etc.).

If we want children to learn any particular area, then it is clearly up to us to provide them with something real and enjoyable to "do" on their way to perfection of both the art and the skill. Painting can be frustrating, yet practice is fun because a finished picture is a subgoal which can be accomplished without needing total mastery of the subject.

Playing musical instruments and gaining musical thinking is unfortunately much further removed. Most modern keyboard and orchestral instruments do not provide subgoals which are satisfying to the child or adult for many months, nor do they really give any insight into what music is or how to "do" it on one's own. It is usually much more analogous to "drill and skill" in painting a billboard "by the numbers", and not even getting to use your own numbers or paint!

The study of arithmetic and mathematics is, in general, an even worse situation. What can a child "do" with multiplication? The usual answer is work problems in the math book! A typical establishment reaction to this is that "some things just have to be learned by drill". (Fortunately kids don't have to learn their native tongue under those circumstances.) Papert's kids need to use multiplication to make the size of their computer-drawn animations change. They have something to "do" with it.

"Genetic Epistemology"

The life work of Jean Piaget is both wide and deep enough to defy any cursory summation. Since there exist summaries and critiques (e.g. Furth: Piaget and Knowledge: Theoretical Foundations), a more eclective strategy is in order.

Two of Piaget's fundamental notions are attractive from a computer scientist's point of view.

The first is that knowledge, particularly in the young child, is retained as a series of operational models, each of which is somewhat ad hoc and need not be logically consistent with the others. (They are essentially algorithms and strategies rather than logical axioms, predicates and theorems.) It is much later in development that logic is used and even then through extralogical strategies.

The second notion is that development proceeds in a sequence of stages (which seem to be independent of cultural environment), each one building on the past, yet showing dramatic differences in ability to apprehend, generalize and predict casual relations. Although the age at which a stage is attained may vary from child to child, the apparent dependency of a stage on previous stages seem to be invariant. Another point which will be important later on is that language does not seem to be the mistress of thought but rather the handmaiden, in that there is considerable evidence by Piaget and others that much thinking is nonverbal and iconic.

a. Stages

Both Piaget and Bruner have coined names for the stages of development. Bruner's are a bit more descriptive so they are included here also.

Age	Piaget	Bruner	Properties
0	Sensorimotor	Enactive	Reflexive REVERSIBILITY Discrepancy/ Novelty Object Conservation
1½	Preoperational		Speech starts Mass: Not Length: Conserved
4	Concrete Operational	Iconic	Length Conservation Negation (Inversion) $f(x) = y$ $f'(y) = x$ Reciprocity
8	Formal	Symbolic	Multi v. Conservation Hypotheses/ Deductions

If the stage dependency is real, it may be worse than useless to try cramming context from upstream stages down children's throats until they are ready. For instance, it is now fashionable to teach children (in "new math") point set topology on a 2-dimensional cartesian coordinate system at the earliest possible age. The wisdom of this is contradicated by a series of Piaget's experiments which show that children in the operational stage simply do not grasp the notion of a coordinate system until later on. However, they do have very sophisticated notions of topology, connection, enclosure and grouping - all RELATIVE concepts. These facts were used by Papert and Goldstein to teach geometry and topology without reference to a global coordinate system - a much more satisfying state of affairs.

If we believe in the veracity of "operational" (semantic) rather than "predicative" (logical, syntactic) models, a quarrel has to be made with the very syntactic notions currently in favor in "New Math". For example, in natural numbers:

"3 + 5"

"4 + 4"

"16 - 8"

"4 * 2

"8"

are said to be "numerals" for the number eight.

This concept is not only misleading and nonsemantic, it is also wrong. (What number is "8/3" a "numeral" for?)

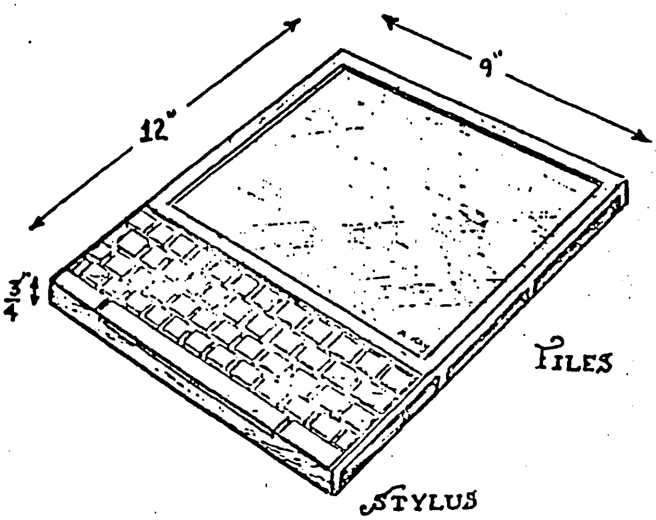
Minsky has noted: "The trouble with new math is that you have to understand it everytime you use it". (20)

Piaget's and others' work on the bases and forms of children's thought is a fairly convincing argument for believing that computers are an almost ideal medium for the expression of a child's epistemology. What is an "operational model" if not an algorithm, a procedure for accomplishing a goal? Algorithms are fairly informal and not necessarily logically consistent (as anyone who has ever spent a few hours debugging a program well knows). This fits in well with the child's viewpoint which is global and interested in structure rather than strict implication of "truths". On the other hand, the computer also aids in the formation of skills concerning "thinking": strategies and tactics, planning, observation of causal chains, debugging and refinement, etc. Rarely does a child have a chance to practice these skills in an environment that is patient, covert and fun!

:: The DynaBook

"I wish to God these calculations were executed by steam!"
Charles Babbage (age 19)
ca. 1803

"The Analytical Engine weaves algebraic patterns, just as the Jacquard Loom weaves patterns in silk."
-Ada Augusta
Countess of Lovelace



We now have some reasons for wanting the DynaBook to exist. Can it be fabricated from currently invented technology in quantities large enough to bring a selling (or renting) price within reach of millions of potential users? The set of considerations which pertain to the more practical aspects of the device such as size, cost, capability, etc.) are just as important as the more abstruse philosophy which prompted us in the first place. The next few pages discuss some of the tradeoffs involved, and will attempt to convince the reader that a target price of $500 is not totally outrageous. The current cost trends and size of the various components do offer considerable hope that the target can be reached. The analogy to color TVs which can be sold for under $500 is also important to keep in mind. Now, what should the DynaBook be?

The size should be no larger than a notebook; weight less than 4 lbs.; the visual display should be able to present at least 4000 printing quality characters with contrast ratios approaching that of a book; dynamic graphics of reasonable quality should be possible; there should be removable local file storage of at least one million characters (about 500 ordinary book pages) traded off against several hours of audio (voice/music) files.

The active interface should be a language which uses linguistic concepts not far removed from the owner of the device. The owner will be able to maintain and edit his own files of text and programs when and where he chooses. He can use his DynaBook as a terminal when at work (or as a connection to the library system when in school). When he is done perusing and has discovered information that he wishes to abstract and take with him, it can rapidly be transferred to his local file storage. The umbilical connection will supply not only information but also extra power for any motors the device might have, allowing high bandwidth transmission of about 300K bits/sec to the file storage, or 1 500-page-book in 1/2 minute. The batteries will also be automatically recharging during this connection.

"Books" can now be "instantiated" instead of bought or checked out. One can imagine vending machines which will allow perusal of information (ranging from encyclopedias to the latest adventures of wayward women), but will prevent file abstraction until the fee has been paid. The ability to make copies easily and to "own" one's information will probably not debilitate existing markets, just as easy xerography has enhanced publishing (rather than hurting it as some predicted), and as tapes have not damaged the LP record business but have provided a way to organize one's own music. Most people are not interested in acting as a source or bootlegger; rather, they like to permute and play with what they own.

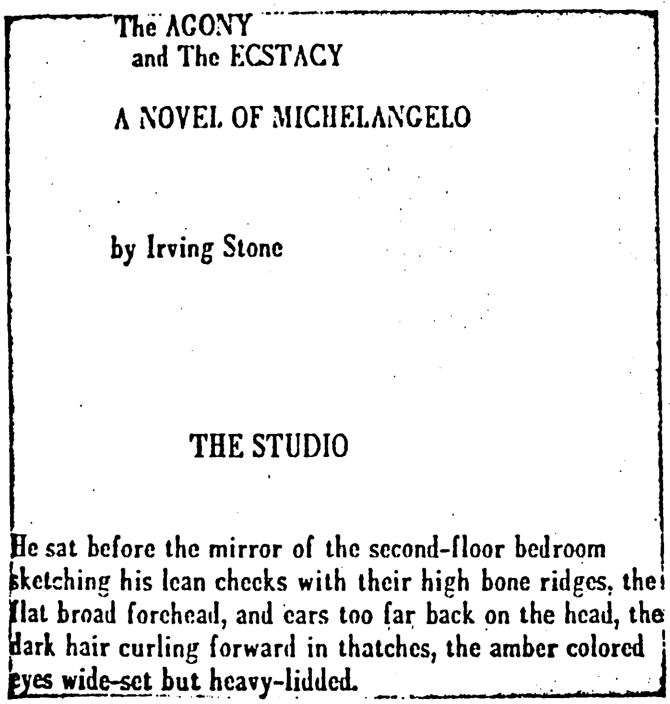
A combination of this "carry anywhere" device and a global information utility such as the ARPA network or two-way cable TV, will bring the libraries and schools (not to mention stores and billboards) of the world to the home. One can imagine one of the first programs an owner will write is a filter to eliminate advertising!

Input will be via keyboard (most people now learn how to type) or via secretary-cum-keyboard in the traditional manner. Or by voice. The file system of the device can easily allow audio files (with digital headers); however, they would have to be transcribed before any editing could be done. Although "interactive graphics" will be limited because of capacity, sketches can be retained and edited as facsimile files.

The Display

Either a flat panel display, such as the plasma panel, or a connection to an external CRT is dictated by the size requirement. The power specs disallow the plasma panel (it can draw 5 amps when fully lit), and the need to use it anywhere eliminates the almost (but not quite) ubiquitous CRT. What then is left? We clearly would like a technology that requires power only for state changing, not for viewing - i.e. can be read in ambient light. Phase Transition Liquid Crystal (16) can be x-y addressed and will obligingly turn opaque under the influence of a low-power electric field. Further, the display will maintain itself with very little additional power, the electrode widths can be as small as 1 mil, and the state of the entire 512x512 panel can be changed for less than 1/2 watt. (Note: This is a current technology even though no one has yet built a 512x512 panel.)

In order to put up book quality characters at normal viewing distance, we need to have a good intuitive model of the eye and to make use of some recent discoveries at our lab in the art of character generation (15). In order to build an in-house research terminal system with printing quality CRT display, an experimental "loadable font" character generator was designed and constructed. Any 128 character font which can be defined in terms of up to 32x32 bit matrices can be dynamically loaded into a fast bipolar memory to allow real-time scan conversion of ASCII text. Frills such as size, intensity, overlay characters (underlines, etc.) are also provided. All photos are of the actual screen (at 875 scan rate) and are unretouched.


The AGONY
and The ECSTACY

A NOVEL OF MICHELANGELO

by Irving Stone

THE STUDIO

He sat before the mirror of the second-floor bedroom sketching his lean cheeks with their high bone ridges, the flat broad forehead, and ears too far back on the head, the dark hair curling forward in thatches, the amber colored eyes wide-set but heavy-lidded.

Fig. 1. "Bodoni-Like" Font (19)

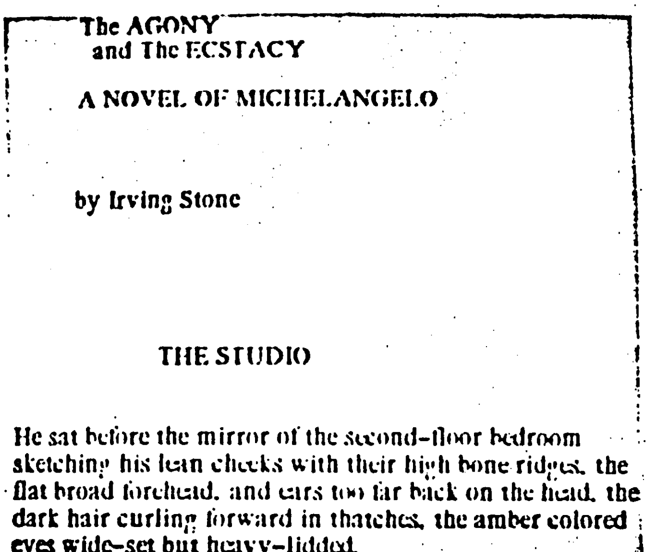

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Fig. 2. "Times Roman-Like" Font (19)

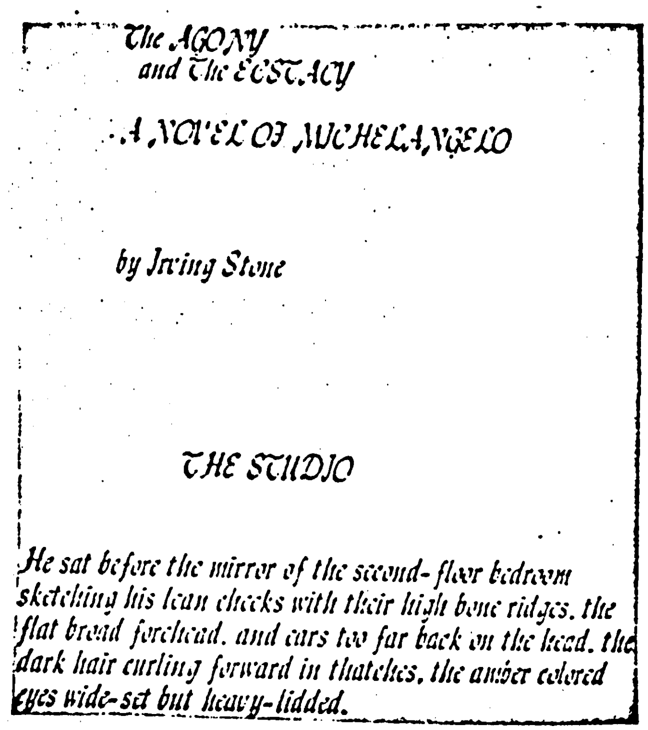
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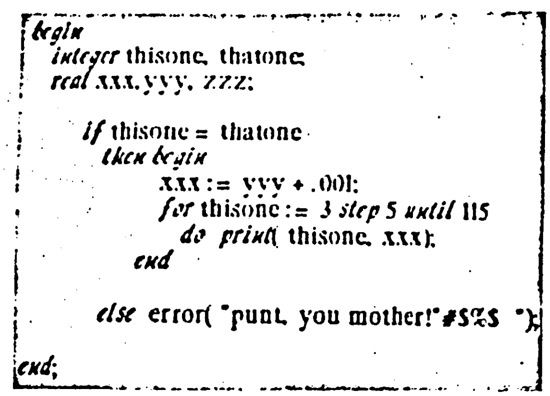
Fig. 3. "Lydian Cursive-Like" Font (19)


```
begin
  integer thisone, thatone;
  real xxx, yyy, zzz;

    if thisone = thatone
      then begin
            xxx := yyy + .001;
            for thisone := 3 step 5 until 115
              do print( thisone, xxx);
         end

      else error( "punt, you mother!"#$%$ ");

end;
```

Fig. 4. Spurious Algol in "Times Roman-Like" Font

The first interesting discovery was that the display looked much better than it "should", i.e. the characters seemed much more round than the quantization level seemed to indicate, yet, when they were blown up larger in size, they quickly became ugly. The intuitive reason for this has to do with the inherent noise reducing filter function of the optic tract that, essentially, first averages the signal (using an averaging window of about .02° of arc) which turns small corners into fuzz, then differentiates over a larger area to tweak the scene back into a sharp image. The effect of this filter is to remove small isolated glitches and, luckily for us, to allow matrix defined characters to look beautiful when the matrix is small. It also partially explains why 875 line TV seems to be subjectively more than twice as good as 525 at 22" viewing distance. The scan lines and their spaces are too large to be filtered for 525 since they are about 1/50" high.

Small characters are tough since the definition matrix is limited, yet more can be done than might be apparent. Two tricks that work are to change the aspect ratio of the characters (height: width ~2:1, thus making 45° angles into 60°) and to use multiple width strokes for a bold face effect even on absolutely tiny characters (this tricks the eyes' filter into trying to enhance the character rather than to remove it as noise).

To sum up. The display surface should probably be liquid crystal having at least 80 - 100 raster points/inch, an aspect ratio of about 2 points horizontally for each point vertically and a total raster of ~1024x1024.

Keyboard

Of course the keyboard should be as thin as possible. It may have no moving parts at all but be sensitive to pressure, feeding back a click through the loudspeaker when a successful press has taken place. Keyboards of this kind have been available for several years.

Once one has gotten used to the idea of no moving parts, he is ready for the idea of no keyboard at all!

Suppose the display panel covers the full extent of the notebook surface. Any keyboard arrangement one might wish can then be displayed anywhere on the surface. Four strain gauges mounted under the corners of the panel will register the position of any touch to within 3/16" which is close enough. The bottom portion of the display panel can be textured in various ways to permit touch typing. This arrangement allows the font in which one is typing to be shown on the keys, special characters can be windowed, and user identifiers can be selected with one touch.

File Storage

The only technology that currently exists which can handle the modest, though important, demand for a writable file storage is magnetic oxide on plastic in the form of tape cassette or floppy disk. Until recently, tape handling typically required a conglomeration of pinch rollers, capstans, solenoids and motors. Now the problems of constant tape tension and differential drive have been solved by a number of companies, the most elegant being the cassette by 3M which uses a "magic" driveband which contacts the outside of the tape takeup reels and requires only one motor for read, write, search and rewind. Four tracks of tape at a bit density of 1600 bpi allows 6400 bits/inch to be stored and retrieved. Our requirement for 8M bits thus demands 1250 inches (or 105 feet) of tape in the cassette. Of course there will be gaps, etc., so to play safe, our fantasy cassette will have 50% more tape or 150 feet.

The file directory will be placed in the middle of the tape (as in the LINC) so that only 1/4 the tape traversal time on the average is required to access it. From there, the average distance of any file is also just 1/4 the length of tape producing a total average random access time of 1/2 tape traversal time. The search speed depends almost entirely on the desired battery drain rate and the capacity of the motor. Cassettes of the 3M type can be positioned at 180 in/sec; 100 feet of tape can be traversed in about 7 seconds so the average latency to a file is about 4 seconds. This is very respectable. However, these speeds require far too many watts when using the batteries alone. A more reasonable rate for search on batteries would be 60 in/sec giving a latency of about 10 seconds for access to a file.

The floppy disk requires two motors (one a stepping motor for positioning the head) and is usually run continuously. The latter would not be possible for battery operation, and the device would have to be started and stopped. The one great advantage of the floppy disk is that swapping can be done on one track while still allowing decent access time to files. (The notion and utility of swapping storage will be discussed in the section on the processor.)

Processor and Storage

These two categories represent, respectively, the least expensive and the most expensive components in our fantasy machine. They are presented together because of the great influence the processor has on the amount of primary memory needed.

What follows is an attempt to show that both the performance and the packaging requirements are not necessarily incompatible with today's technologies (although a hand will occasionally have to be waved). Just as in the HP-35 pocket electronic "slide rule", the main savior of our dreams is cheap LSI components. The HP-35 uses five LSI chips with an equivalent of 30,000 transistors, for an average density of 6000 transistors/chip. Even better packaging densities are now being accomplished. The price of a packaged LSI chip seems to approach $12.00 asymtotically over a two-year period, then may dip suddenly to about $5.00.

Complete CPUs are now available on single chips. The challenge now lies more in determining what characteristics the processor should have rather than using just anything that will package nicely.

LSI Random Access Memory is now routinely available in 1024*1 bit chips (700 ns cycle time) for 1¢/bit packaged. A 4096*1 chip has now been announced and looks as though it can be packaged for .35¢/bit. An 8K*16 memory would thus cost about $460 (still too much, but encouraging).

The rechargeable-battery state-of-the-art has been considerably advanced by the advent of portable shavers, tape recorders, toothbrushes, TV, etc. We may expect even higher performance/charge in the future.

Since ~20 ICs is the current estimate of the number of chips needed in the DynaBook, we can be reasonably sure that the electronics part of the device will package quite nicely.

The processor is envisioned as being implemented as 1, or at most 2, LSI chips. Such devices already exist for less than $100 with a projected price of less than $15. They typically contain the equivalent of several thousand transistors; have registers for a program counter, arithmetic operations, an instruction return stack, etc.; and even may use a carry-lookahead arithmetic unit. A standalone "smart terminal" that uses one of these chips for a processor (and includes memory, a keyboard, a display and two cassettes) is now on the market for about $6000 (Datapoint 2200).

Since the DynaBook is an attempt to be much more than a terminal, for much less cost, a great deal of careful thought needs to be expended on the processor-memory design. We would obviously like to maximize the use of the expensive core replacement RAM; this can be done by:

1. Efficiently encoding the operators for maximum instruction density/bit.

2. Encoding the basic logical data element (the ordered set) to minimize space requirements.

3. Removing any systems routines from the RAM (including the interpreter) so that all of the space can be utilized by the user.

4. Mapping the virtual address space onto the file device, so that the RAM serves as a cache for most recently used portions of memory. (Doubting Thomases, who feel this would be worthless on a tape machine, are advised to consult the LINC literature (17,18) for a description of a similar scheme which has been successfully used for years by thousands of users.)

5. Eliminating the need for a resident "system" per se by merging the concept of files with user variables, by permitting the user to converse directly with the interpreter, and by using the multiple control path evaluator to allow interrupts, etc., to be handled within the system. (7,8)

> "The thought of the Middle Ages was not limited, but perhaps its vocabulary was."
> —Williams

In what fashion should any one of a potentially wide variety of users communicate with himself through his machine? A language containing features that supply "all things to all people" is clearly not possible. Neither is an "extensible language" in the usual sense. With these two tempting sinkholes removed from consideration (by definition, as it were), what remains is a chance to present to a user a very simpleminded language (which reveals the true state of programming semantics) that, nonetheless, is capable of a wide variety of expression. Well, just what is it that computers have over other message systems? For one thing, they can delay a message indefinitely (memory), they can transduce the message into other messages (processing), and they can represent transductions themselves as messages (procedures).

The use of this language is essentially divided into two activities: 1. giving names to objects and classes (memory association), and 2. retrieving objects and classes by supplying the name under which they had been previously stored. A process consists of these (activities) and is terminated when there are no longer any names under scrutiny. Although all of such a language can be easily derived from just these two notions, a few names would have an *a priori* meaning in order to allow interesting things to be done right away.

The following principles should be used in the design of the DynaBook language.

1. We need a uniform notion as to what objects are, how they may be referred to, and how they can manipulate other objects.

2. If each object can have its own control path, then there must be a concise way to coordinate and "control" these paths when more than one is active.

3. The evaluation of a control path should follow simple rules which show how objects are passed messages and return results.

4. Every object in a system should be redefinable in terms of other objects.

The basic idea is to exploit the duality between functions and tables (or processes and memory). English has nouns which refer to "objects", and verbs which refer to "actors" and "relators". This is a Newtonian epistemology. Modern physics and philosophy tend towards the idea that both "objects" and "actors" are just different aspects of the notion of process. A process has state (a set of relations having only to do with it) which changes as time (defined as interactions with other objects) passes. Using this view "data" is a process which changes "slowly", "function" is a process which changes more rapidly. Each process has the logical attributes of a complete "micro" computer: they can have inputs, give back outputs, act as a memory on file system, perform computations, be interrupted, etc. Since a "computer" can simulate all other computers (modulo time and space), having the notion of a process in a language allows useful ideas such as arrays, records, recursive procedures, etc., to be added to the repertoire at any time.

The techniques for evaluating such a language directly by hardware are well known and are within reach of a single chip processor. (7)

The notion of multiple control paths allows the separate notions of "files", "operating system", "monitor", etc., to be replaced by the single idea that the user is also a process (and thus has state which consists of variables and bindings, etc.). When he leaves the machine, his process is passivated until the next time he rejoins his DynaBook. His state (which is now activated) constituted "files" while he was away. The control of the evaluation of various programs is also accomplished without any additional mechanism through direct execution of user input (the "direct" mode of JOSS, LISP, etc.). Since multiple control paths are allowed, many processes can be in various stages of evaluation and debugging. (1,8,9,10,11,12,13,14)

Sizes and Costs

Previous experience with evaluators of the kind we have been discussing indicates that on the order of 8000 bits of control memory is needed to realize it in hardware. This memory at present would require 1 ROM LSI chip and the processor another. It is not too far out to assume that both can be combined in one package without straining the current state-of-the-art. The price of LSI packages tends to approach $12-14/package because most of the cost to the manufacturer comes from testing, substrating, padding, etc., all rather independent of device complexity (providing yield is reasonable).

Intelligent encoding of "data" and "code" allows a better than 3-fold reduction in memory needed to hold equivalent structures in a somewhat similar language such as BBN-LISP. That means that 8K 16 bit words of RAM are approximately equivalent to 12K 36-bit words for BBN-LISP on the PDP-10.

The DynaBook computer can now be postulated as a single bus machine consisting of

1 processor chip
16 (8K*1) RAM memory chips
4 IO controllers (also processor chips - why not?)
21 chips @$14 ~$294.00 for electronics.

This price has very little credibility because of science fiction and handwaving. However, some brave readers might decide that it is ridiculously high rather than just ridiculous!

Conclusion

Speculation and fantasy were promised and most readers will probably agree by now that the preceding pages delivered just that (along with some gas and maybe even a slight tinge of credibility?...).

We do feel that the pedagogical merits of teaching algorithmic thinking, having easy editing, etc. (all wrapped up in an environment which can go anywhere and can belong to everybody), are undeniable. Considerations of packaging, power and weight requirements were derived from current technology as were the electronics and are probably true. The software knowledge, language design philosophy, and user interface ideas are at least 5 years old. The three main handwaves are the flat screen low power display (which does not currently exist but seems possible), the guess about how much can be done "standalone" on an 8K machine (it has not yet been simulated), and the price.

Suppose the DynaBook could be sold for $500 (ridiculously low compared to current mini's, ridiculously high compared to current TV technology); where is the money to allow most children (and adults) to have one? The average yearly amount expended/child for all his education is only $850. One reason that some care was taken with very high quality character generation is that about $90-95/year of the student money goes for the purchase, maintenance, etc. of school books. If the DynaBook could assume this function over its useful life (at least 40 months) then about $300 is made available. Perhaps the device itself should be given away as with a looseleaf notebook, and only the content (cassettes, files, etc.) be sold. This would be similar in spirit to the way packaged TV or music is now distributed.

We have purposely made no quarrel with those people who feel life can best be served through sharing resources. The analogy with the book still holds: libraries are very useful, yet one neither wants to put up with their schedules nor locations (or content) 100% of the time. What about terminals say, through radio, as Larry Roberts has suggested? (21) Well, OK, for inverting large matrices, but not for graphics animation or any other high bandwidth output. Enough said.

Let's just do it!

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