The Mind's Eye and the CRT Terminal: Towards a Diagrammatic Interface

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The differences between humans and computers are drastic. The most significant for this discussion is the difference between the parallel processing of humans and the sequential processing of current machines. We can take advantage of parallel processing by combining the eye with the CRT. Computer memory is presented in a virtually simultaneous manner on the screen, and the image there presented is processed in parallel by the human visual system. The CRT is not only an input port to the eyes, but also a model of the mind. Renaissance practitioners of mnemonics appreciated the screen-like nature of human memory. This leads to a visual comparison between the Renaissance memory systems and the current trend toward windows on the CRT. It is appropriate to look at the sign process. We look at current interfaces in terms of Peirce's most used trichotomy, that between Icon, Index, and Symbol. Current interfaces involve mainly symbolic signs, with the recent addition of low-level iconic signs. Missing from the interfaces as a main component are the indexical signs and their realization through more sophisticated iconic representations.

> *A concept is the living influence upon us of a diagram, or icon, with whose several parts are connected in thought an equal number of feelings or ideas.* (Peirce 7.467)

The rapid spread of personal computers has stirred interest in making the computer easier to use. Since using a computer is essentially a process of handling signs, a look at the interface from the perspective of semiotics is revealing. This discussion concerns the visual aspect of the interface, calling on the nature of the visual system, the history of mnemonic techniques, the nature of the technology, and the nature of signs, in order to establish the significance of an interface emphasizing diagrams.

The Visual Realm

Given the specialized circuitry our minds possess, it is not surprising that we can imagine the world as well as see it (Figure 1). We can

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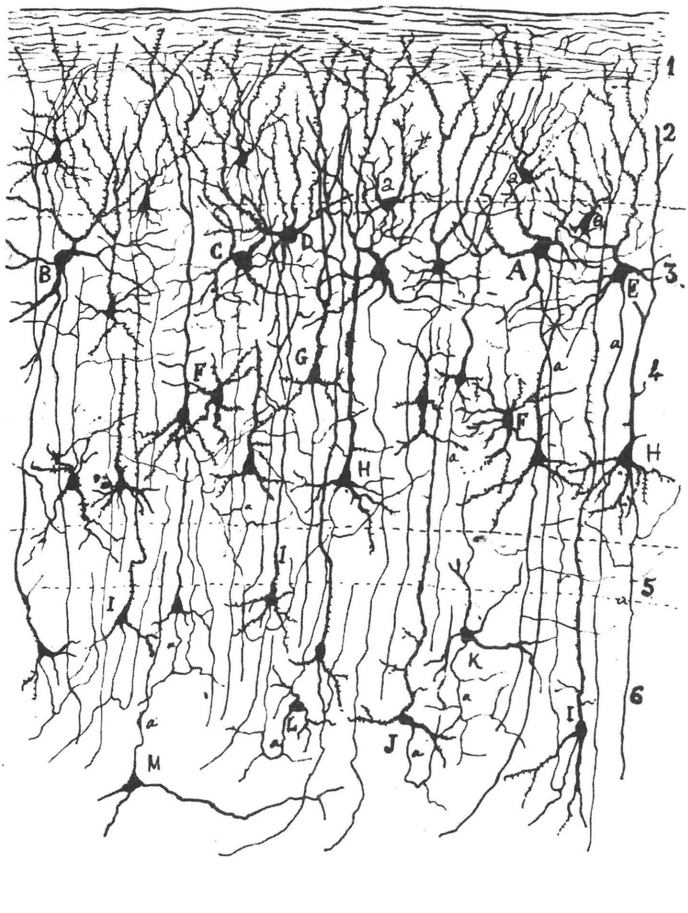
remember or construct images in our mind's eye, altering and examining them at will. Whether these inner images are intrinsic to thinking, or whether they are mere manifestations of some deeper structure is a question that has excited controversy (Kosslyn). Whatever the case, the imaging capabilities of the mind are not new, and the history of their recognition and use are instructive.

From the ancient Greeks up until this century, those studying rhetoric were exposed to mnemonic techniques for improving memory. These techniques involve linking pre-memorized spaces or images to other images that in some way represented the object in question (Figures 2a, 2b). A speaker would walk around a building, memorizing a certain direction of movement. In each room he would imagine an object corresponding to a concept he wished to discuss. A concept such as war that was to be discussed as a second topic might be represented by a sword placed mentally in the second room to be walked through (Yates).



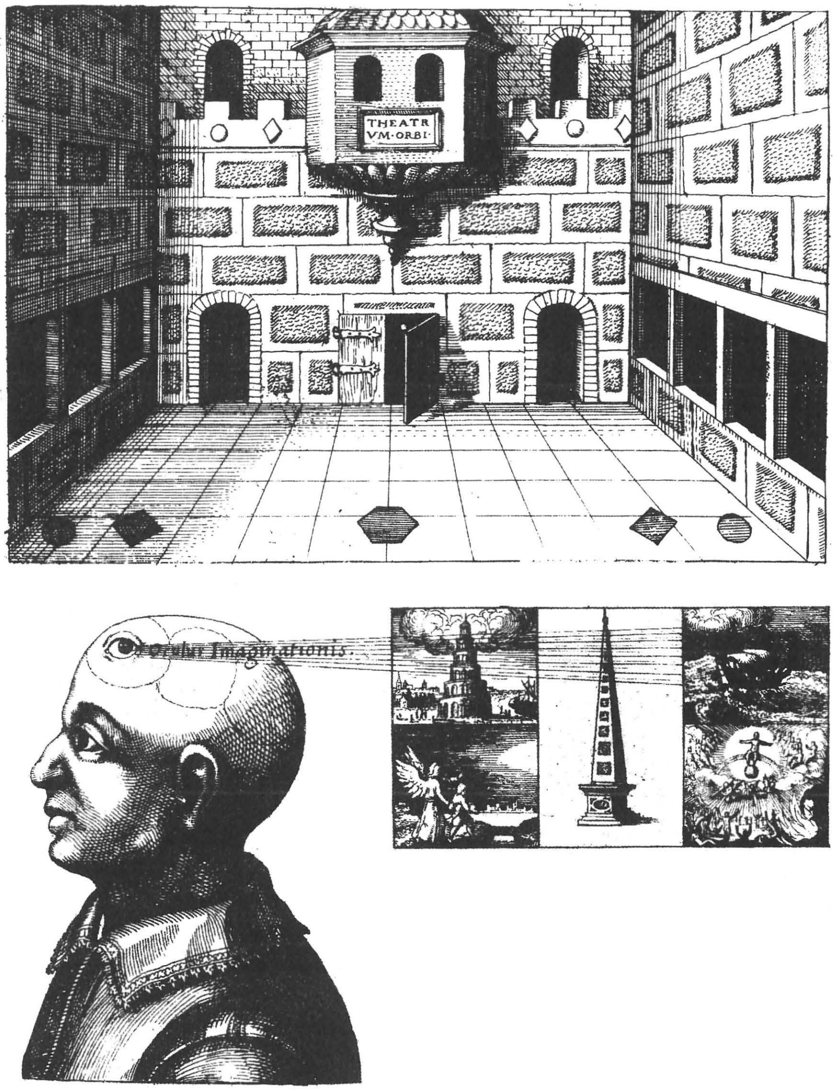


Figure 2a, 2b. The theatre memory system of Robert Fludd, circa 1625. The mnemonic practioner would pre-memorize the biblical images of 2b, which are arranged according to the windows of the stage-set 2a.

Figure 1. Visual cortex of a rat, drawn by Santiago Ramon y Cajal in 1888. The numbers identify cellular levels.

The more we find out about the psychology of the mind, the more the mnemonic techniques once taught as an integral part of rhetoric make sense. Research in cognitive psychology affirms what introspection tells us. The mind can remember images far easier than abstract concepts, hence the efficacy of representing the concept of war by a sword. The mind has a good spatial memory, so that the placing of objects in rooms or in windows of a facade take advantage of a psychological ability (Paivio).

From Simonedes to Leibnitz there were many famous practitioners of the art of memory. Cicero, Descartes, Lull, Bruno, and Leibnitz were familiar with the techniques. The practitioners of mnemonics, especially Bruno and Leibnitz, had high hopes for a universal language based on spatial, visual systems (Yates). We may realize their hopes through the displays of our computers, which will spread the conventions that make language possible.

The Computer Realm

The computer grew out of a need to automate the process of precise calculation. One of the earliest calculating devices, the abacus, would be described today as a dynamic memory device, with tactile input and graphic output. Embedded in the use of the abacus are the important concepts of the principle of position and the zero. The word algorithm for a period of time referred exclusively to positional numeration, before expanding into its current, more general usage (Dantzig). So this early device manifests a very important concept in a visual form that can be manipulated and changed. And this device was meant to be used in a strict manner that became an automatic program in the minds of those who used it extensively.

Mechanical devices were created to do the actual steps of addition and subtraction, but the harder tasks of multiplication and division were automated by Leibnitz. Leibnitz, in the earliest commentaries on user interface, said the computer should be used as a timesaver, to relieve good minds from the drudgery of calculation. He also suggested the machine would help in generating tables for curves, a foreshadowing of the eventual development of modern computers out of a need for ballistic calculations (Goldstine).

Peirce was the first to suggest the use of electricity for the computer (Burks). But it was Von Neumann and Turing who defined the electronic digital computer as we know it today. The model of a computer has changed little; it is still seen as a deterministic machine that reads and writes. Change has only taken place in the technological

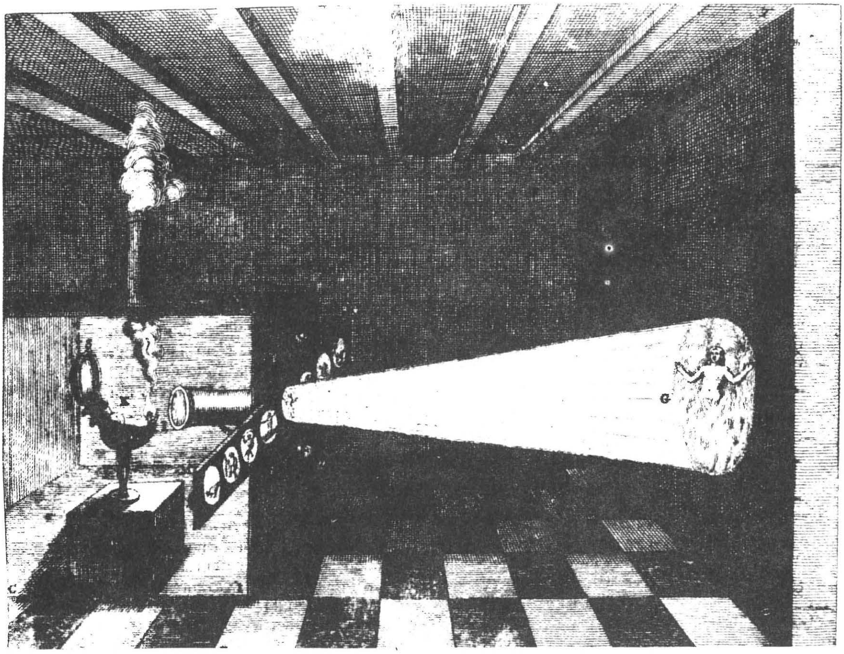


Figure 3. An illustration by Athanasius Kircher of the magic lantern, 17th century.

methods of reading and writing, change resulting in the present CRT terminal.

The modern CRT functions as a bitmapped graphic screen, in effect a visible array of computer memory. Each cell is given a light intensity value; the eye synthesizes these memory cells into an image, whether the image be a diagram or a page of text. In this way the CRT functions as an output device from the computer. Input to the computer can be made through a mouse, a pointing instrument that rolls across a flat desk area. The mouse allows the user to make choices directly off a CRT, speeding up and spatializing the interface.

The CRT has already been championed as a new model for the mind (Kosslyn). For a period, the mind was compared to mechanical devices: wheel-spinning, gear-meshing, hand-ticking machines. And internal images have been described as shadows on the wall, theater, paintings, photographs, and cinema, which all stress the dream-like, passive side of thought (Figure 3). Now the computer in conjunction with the CRT terminal forms the current model of the mind. It is an external object that is much closer to our conscious imaginings. Elements of both clockwork and cinema are involved, with the addition of the interactive qualities of the computer.

Signs

Interaction, whether it be between two people or a person and a machine, occurs by means of signs. We shall look at the visual realm in reference to Peirce's most fundamental division of signs, that between Icon, Index, and Symbol. This trichotomy explains the relationship of signs to the exterior (dynamic) objects that determine them. We concentrate on the Iconic and Indexical signs in order to point out the possibilities of the visual computer interface.

A *Iconic Signs*

An Iconic sign is a sign that represents its object through similarity. Peirce describes a further breakdown of iconic signs into images, diagrams, and metaphors:

> Those which partake of simple qualities, or First Firstnesses, are images; those which represent the relations, mainly dyadic, or so regarded, of the parts of one thing by analogous relations in their own parts are diagrams; those which represent the representative character of a representamen by representing a parallelism in something else, are metaphors. (Peirce 2.277)

A1 *Images*

Images are the lowest level icons. They are mainly mimetic, such as a drawing of an object (Figure 4). In current computer vernacular, the term icon refers only to these kind of signs, such as a line drawing of a file folder or an eraser. Such images have the advantage of being memory devices that can be used by non-readers, but also suffer from the possibility of misinterpretation. As soon as the object they represent is frozen by convention, they lose their iconic qualities and take on the role of symbols.

There is a current emphasis on this lowest level iconic sign, which is seen as an antidote for the over-symbolic nature of the older interfaces. The problem in the current interface is in the under-use of the really important visual signs, diagrams.

A2 *Diagrams*

A diagram is analogous to the object or process which it represents. The analogy is generally carried out by mapping a certain characteristic of the object onto a dimension of space. The diagram can appear analogous through its spatial connection (Figure 5). Peirce describes the diagram as being topological; the skeleton of set relationships.

The concept of projecting a characteristic onto a spatial dimension can be extended into projecting onto the time dimension. While on the

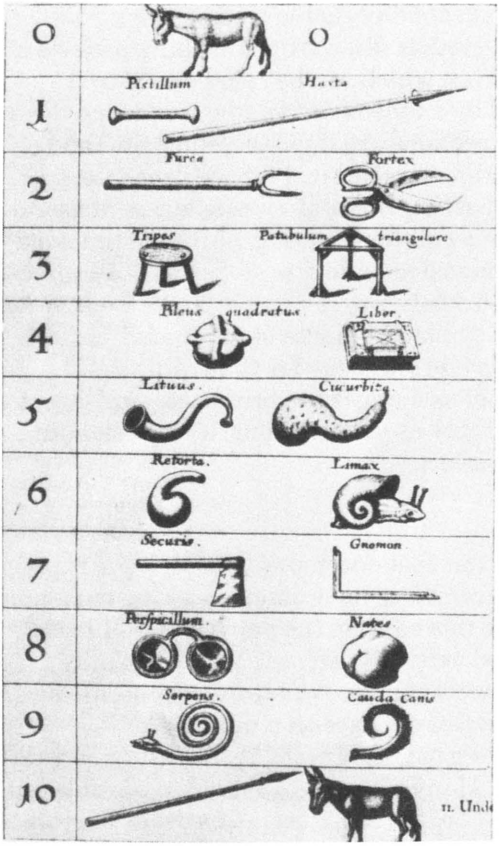
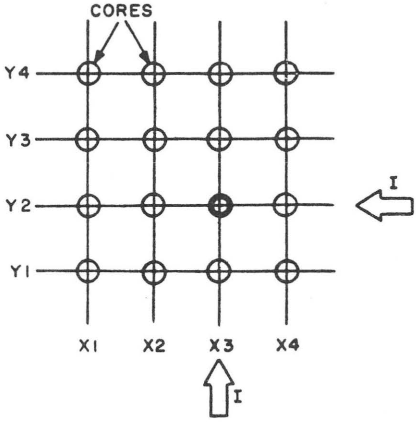


Figure 4. Robert Fludd's *Numerorum Descriptio,* 1617.

Figure 5. A diagram used to explain core memory. The topology of the lines is similar to the topology of the computer circuits.



printed page an arrow may indicate flow, using a computer a point may move across the screen. Another alternative mapping projects onto an auditory dimension. That which can be represented by a rising line can be represented by a tone of increasing frequency. These kinds of alternative projections are impossible in print, and a currently unused but potentially powerful tool for the user interface.

Pitts and McCulloch, in discussing the brain, write about "a useful general principle which we may call the exchangeability of time and space. This states that any dimension or degree of freedom of a manifold or group can be exchanged freely with as much delay in operation as corresponds to the number of distinct places along that dimension."

In the computer we have a crude analogue for the brain which allows us to perform the kind of exchanges the brain accomplishes. The time domain can be profitably used for the purpose of extending the dimensions of the user interface.

A3 *Metaphors*

A Metaphor is a general diagram that encompasses a series of mappings. Metaphors for the user interface have changed as the technology has improved. We have moved from the papyrus-scroll model, in which information streamed vertically off onto a roll of printer paper, to the current desktop metaphor, in which one is presented with an electronic version of series of pages on a desk.

This desktop metaphor is not a satisfying one; it suggests a certain kind of civil service drudgery. Many other metaphors are possible, all emphasizing a particular aspect of the interface. A model of the interface as that of a roomful of blackboards would suggest that not only text, but also diagrams might be scribbled on the board in the quest for the solution to a problem. A model based on the dashboard of a car would suggest a highly interactive, highly visual interface.

B *Indexical Component*

The above analogy between a dashboard and a computer screen brings forward the concept of an interface linked to the real world. Peirce sites a barometer or a weathervane as being diagrams that function as indexical signs. The list of such indicators can be extended to include speedometers, gas gauges, clocks, and all the other instrumentation we rely on to give us information about the world (Figure 6).

These instruments detect changes in the immediate environment, yet there exist broader, long term indexes, such as economic indicators. When one manipulates abstract lines on the computer terminal, one is playing in the realm of possibility. When one generates a chart from statistics supplied by the marketplace (Figure 7), one brings the diagram into the realm of actuality. The power of such indexical signs is obvious, if only from their extensive use in science and business. Yet the user interface has not taken advantage of the computer's ease in generating such signs.

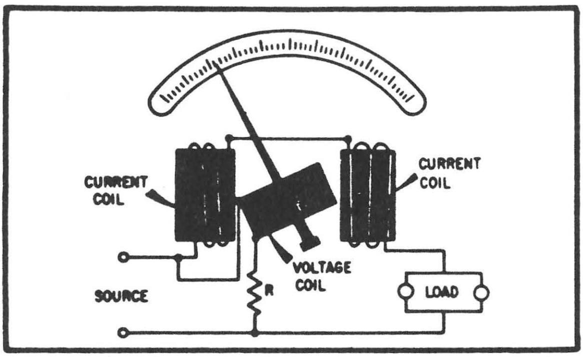
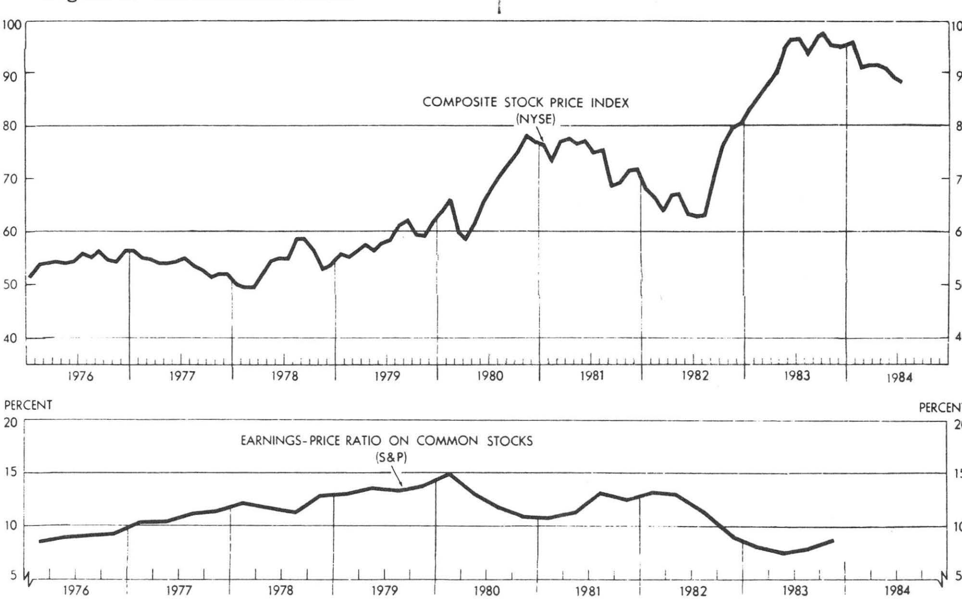


Figure 6. A wattmeter circuit, an example of an indexical sign generated electronically.

Figure 7. An economic index.



In a footnote about the indexical characteristics of language, Peirce writes:

> Once a logician had to construct a language de novo — which he actually has almost to do — he would naturally say, I shall need prepositions to express the temporal relations of before, after, and at the same time with, I shall need prepositions to express the spatial relations of adjoining, containing, touching, of in range with, of near to, far from, of to the right of, to the left of, above, below, before, behind, and I shall need prepositions to express motions into and out of these situations. For the rest, I can manage with metaphors. (2.290)

Peirce points out that prepositions are indexical in that they refer to a situation relative to the observer. This passage suggests a kind of visual language that links to the rest of the world through indices.

Significance

The diagram represents precise information in such a way that the human mind can determine the information's significance (Figure 8). Peirce writes:

> For a great distinguishing property of the icon is that by the direct observation of it other truths concerning its object can be discovered than those which suffice to determine its construction. Thus, by means of two photographs a map can be drawn, etc. Given a conventional or other general sign of an object, to deduce any other truth than that which it expicitly signifies, it is necessary, in all cases, to replace that sign by an icon. (2.279)

The importance of the icon is tied to the concept of similarity, which in turn is tied to the concept of continuity. Peirce saw the importance of this continuity, and more recent research in semiotics, mathematics, and computer science is affirming his concern (Nadin). In the field of neuroscience, the brain is being modeled as a continuous manifold of high dimensionality (McCullough, Anderson). Its nature is analogue, its algorithms statistical. In contrast, the computer is discrete, digital, sequential. If, as Peirce claims, discovery involves replacing symbols by diagrams, then the computer cannot discover anything. The computer can, however, display information in the form of diagrams that can be observed and manipulated by the human user. And the computer can compute statistics, which can provide the user with further refined information (Nadin).

Windows as Frames

The best way to represent statistics is through the diagram, and the best way to calculate them is often from different levels of globality, or different frames, or different degrees of resolution. The computer

x	$e^{-x^2}\int_0^x e^{t^2}dt$	x	$e^{-x^2}\int_0^x e^{t^2}dt$
0.00	0.00000 00000	1.00	0.53807 95069
0.02	0.01999 46675	1.02	0.53637 44359
0.04	0.03995 73606	1.04	0.53431 71471
0.06	0.05985 62071	1.06	0.53192 50787
0.08	0.07965 95389	1.08	0.52921 57454
0.10	0.09933 59924	1.10	0.52620 66800
0.12	0.11885 46083	1.12	0.52291 53777
0.14	0.13818 49287	1.14	0.51935 92435
0.16	0.15729 70920	1.16	0.51555 55409
0.18	0.17616 19254	1.18	0.51152 13448

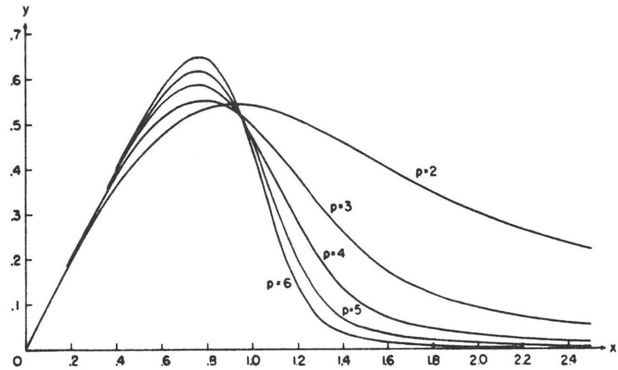


FIGURE 7.2. $y=e^{-x^p}\int_0^x e^{t^p}dt.$

$p=2(1)6$

Figure 8a, 8b. A table of values as it might be stored in computer memory, compared to a diagram of the same values as it might be displayed for a computer user.

should present its stored information and the results of its calculation in a form which will allow the mind to assess significance. Such a presentation takes advantage not just of the symbolic powers of language, but also of the continuous, parallel, multi-level nature of the mind. Peirce writes:

> All necessary reasoning without exception is diagrammatic. That is ,we construct an icon of our hypothetical state of things and proceed to observe it. This observation leads us to suspect that something is true, which we may or may not be able to formulate with precision, and we proceed to inquire whether it is true or not. For this purpose it is necessary to form a plan of investigation and this is the most difficult part of the whole operation.... But the greatest point of art consists in the introduction of suitable abstractions. By this I mean such a transformation of our diagrams that characters of one diagram may appear in another as things. A familiar example

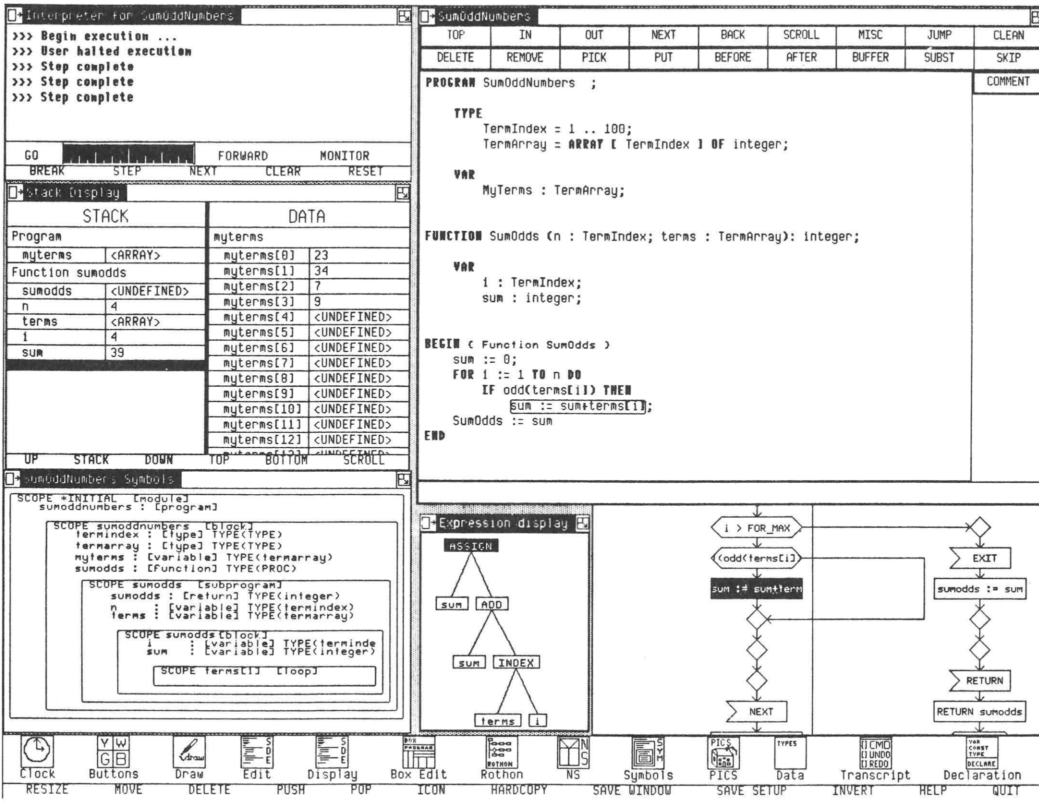


Figure 9. Steven P. Reiss's Programming Environment, illustrating the sophisticated use of windows with diagrams.

is where in analysis we treat operations as themselves the subject of operations. (5.162)

This passage suggests an interface in which a particular relationship, or diagram, is treated as an object, a node, in a higher level diagram. The human being is able to simultaneously keep both views in mind, the level and the meta-level, the details and the overview. Computers are notoriously bad at such tasks, but this process of framing is at the root of intelligence. Framing can be implemented in the interface with windows on the screen, simultaneously presenting the details and the overview, and allowing the user to steer through whatever level of detail is appropriate at a given point in time.

While windows exist in current interfaces, the software that uses them is still primitive. Outline processors are an attempt at a multi-level interface, but these programs must be moved from their verbal emphasis to a more visual perspective if full utility is going to be gained from presenting windows in parallel.

Windows in the interface allow for multiple viewpoints based not only on hierarchy, but also on other criteria such as the location of certain data on the machine. The end effect is virtual parallelism, in which windows correspond to processes, in which one feels like one has many simultaneous jobs going and many different options for giving input or receiving output (Figure 9).

The user has the ability to create his own environment, an environment that becomes a kind of personal memory system, an environment that allows him to spatialize the sequential and linear nature of the machine.

The user interface should be tailored to take advantage of the human mind's abilities. The computer has precision, but cannot assess significance. The best kind of interface allows the user to determine significance, and steer the machine to the next set of retrievals or calculations. Such an interface makes use of the diagram, a form of iconic sign that allows new information to be deduced from it. Such diagrams can be tied to the actual world through indexical signs in the form of labels, or they can be determined by indexical data in the same way the direction of a weathervane is determined by the wind. Finally, a user needs an interface that allows for attacking multiple problems simultaneously, and attacking individual problems from multiple perspectives.

REFERENCES

Burks, Arthur W. Logic, biology and automata—Some historical reflections. *International Journal of Man-Machine Studies,* Vol. 7, 1975.

Dantzig, Tobias. *Number, The Language of Science.* New York: Macmillan, 1954.

Goldstine, Herman H. *The Computer from Pascal to von Neumann.* Princeton: Princeton University Press, 1972.

Hinton, Geoffrey E., and James A. Anderson. *Parallel Models of Associative Memory.* Hillside, NJ: Lawrence Erlbaum Associates, 1981.

Kosslyn, Stephen M. *Image and Mind.* Cambridge: Harvard University Press, 1980.

Nadin, Mihai. The logic of vagueness and the category of synechism. *The Monist,* Vol. 63, No. 3, July 1980.

Paivio, Allan. *Imagery and Verbal Processes.* New York: Holt, Rinehart and Winston, 1971.

Peirce, Charles S. *Collected Papers.* Cambridge: Harvard University Press, 1958.

Pitts, Walter, and Warren S. McCulloch. How we know universals: the perception of auditory and visual forms. *Bulletin of Mathematical Biophysics,* 1947.

Reiss, Steven P. Graphical program development with PECAN development systems. *Proceedings of the ACM SIGSOFT/SIGPLAN Software Engineering Symposium,* Vol. 19, No. 5, April 1984.

Yates, Frances A. *The Art of Memory.* Chicago: University of Chicago Press, 1966.