MASSACHUSETTS INSTITUTE OF TECHNOLOGY

A. I. LABORATORY

Artificial Intelligence
Memo No. 496

September 1978
LOGO Memo No. 51

INFORMATION PROSTHETICS FOR THE HANDICAPPED

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Abstract

In this proposal we describe a technological step towards the realization of INFORMATION PROSTHETICS. Our primary focus is on using rather than making the technology.

Specifically, our goal is to tranpose for the use of cerebral-palsied children a computer-based learning environment we have developed, and to study in this environment a series of issues in developmental psychology, in the psychology of learning, in psycho-diagnostic techniques and in methods of instruction.

The work proposed in this paper is being supported by the Board of Education of the Handicapped (BEH) under grant number CFDA 13-443. The views and conclusions contained in this paper are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the BEH or the United States Government.

ABSTRACT

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Specifically, our goal is to transpose for the use of cerebral-palsied children a computer-based learning environment we have developed, and to study in this environment a series of issues in developmental psychology, in the psychology of learning, in psycho-diagnostic techniques and in methods of instruction.

The work involved entails a close collaboration between several groups at M.I.T.: the Division for Study and Research in Education, the Mechanical Engineering Department, the Artificial Intelligence Laboratory, and the Center for Advanced Rehabilitation Engineering, Draper Laboratory.

INFORMATION PROSTHETICS FOR THE HANDICAPPED

1. STATEMENT OF NEEDS

This proposal addresses the problem of how to increase the possibility for action of individuals grossly disabled by cerebral palsy i.e. so impaired that there is an almost total lack of overt activity. To put the work we propose here in perspective it is useful to make a distinction between three periods of development of communication aids for the cerebral palsied:

> Period 1: Mechanical Aids, typically headstick and word board. Here communication is slow and limited to a person actually present.
>
> Period 2: Electronic Communicators, typically operating a text-producing device by mechanical or electro-mechanical switches. Text can be produced to be read by someone not present at the time.
>
> Period 3: Information Prosthesis. When the communication is with a computer, the system goes beyond the concept of "communicator". The computer can become an extension of the operator who can now do "anything a computer can do" such as draw, compose music, gain access to information libraries, put text on permanent file and so on. In particular the computer enables someone who has never manipulated concrete objects to manipulate abstract (or "AS-IF") objects drawn electronically on a T.V. screen in a simulated but physically and geometrically veridicial world.

Our laboratory has been exploring several aspects of the last mentioned category i.e. information prosthesis. In this proposal we describe a technological step in this direction; however our focus is on USING rather on MAKING technology. We are concerned primarily with the implications of information prosthetics for learning. In this initial phase of our work we shall focus on two aspects of learning, chosen because of their central practical and theoretical importance. These are:

(1) Spatial thinking in subjects with almost no capacity for the overt manipulation of objects in physical space.

(2) Linguistic structures in individuals who have developed comprehension competence with almost no experience in production of structured speech.

Both of these areas touch on issues of central importance to contemporary cognitive theory. Indeed the very existence of spatial thinking in such subjects challenges widely accepted theories which ascribe a determining role in the developmental process to the exercise of sensori-motor schemata. Our own interest in this connection goes in two directions: we believe that an understanding of these handicapped subjects will illuminate deep controversies in theoretical psychology and we believe that understanding these controversial issues will inform the design of effective educational procedures for the handicapped.

2. A LEARNING ENVIRONMENT FOR CEREBRAL PALSY

2.1 Activities

What we require is a learning environment which provides an opportunity:

A. for interesting activity to motivate our subjects
B. for revealing activity to find out what they already know
C. for challenging activity to find out what they can achieve.

An important sense in which our proposal breaks new ground, we feel, rests on exploiting particular properties of a computer-based learning laboratory which we have developed. A crucial feature of the lives of severely handicapped person is that they cannot indulge in ordinary motor activity, to form the basis of their learning, i.e. of the acquisition of cognitive structures. This means that there is no explicit confrontation between actions performed and the consequences of such action in the physical world. We suggest that such a confrontation can occur in the interactive-graphics learning situation of our LOGO laboratory (see Appendix A), because it provides the opportunity for manipulating an object on the screen. In our AS-IF world a person with only the most rudimentary motor ability can try his hand at puzzles as well as art and can acquire some of the strategic skills of ball games. This is the setting, then, in which we suggest that the requirements for interesting, revealing and challenging activity can be met.

A. Interesting Activity

In addition to sharing with other researchers in the field, a concern to build on the strengths of handicapped person rather than concentrating on their disabilities (White, HEW, 1976), we focus on the quality of the learning environment to be used. We need to give handicapped individuals the facility to have interesting exciting and creative things to communicate about. We have for the past 10 years been developing a computer-based learning environment --LOGO laboratory-- whose main features are:

---a concentration of initiative and control in the hands of the user;

---a flexible and open-ended, yet structured environment based on the interactive graphics system, for doing computer programming, mathematics, animation, music, physics, and for producing and editing text. (Papert, 1973).

Pilot studies with cerebral palsy adolescents (Goldenberg, 1977) have shown that individuals previously uninterested in using a prosthesis which had been contructed specially for them e.g. a headstick for typing, responded with unexpected and impressive zeal and excitement when given a chance to use that same headstick to interact with the LOGO system (see Appendix B).

We hope to show that existing prostheses can be used to greater effect in a LOGO Learning Environment.

B. Revealing Activity

The same pilot study showed that children previously judged to be mentally defective could be seen to engage in intelligent cognitive tasks when given access to the LOGO system. The critical education problem for physically handicapped persons is the restriction in their expressive power, so that such mental activity as does go on is trapped within the individual's own head. Indeed in the HEW project quoted above, it was found by "extensive and innovative testing.... that 12% of the handicapped children who were studied were gifted, roughly three times as many as in the general school population" (White, HEW, 1976).

We envisage our setting as especially well placed to reveal previously covert "thinking" on the part of our subjects, given the success we and others working in a LOGO environment have had with normal fifth graders, (Papert, 1973; Howe and O'Shea, 1976) with children with learning difficulties (Howe and O'Shea, 1976; O'Brien, 1977) and with an autistic child (Weir and Emanuel, 1976). Indeed the possibility arises of carrying out a whole battery of AS-IF manipulation test tasks with such individuals, e.g. could we get them to do an AS-IF seriation?

We suggest the use of our system as a diagnostic tool to be used in the ascertainment of mental abilities in the population of physically handicapped persons.

C. Challenging Activity

To offer a disabled person the possibility of communicating with a computer immediately extends the range of task complexity which becomes possible. We include in Appendix A an extended account of the kinds of problem-solving activities available in the LOGO Laboratory.

We hope our system will lead its users to increasing levels of intellectual achievement.

2.2 Technical Issues

Detecting and harnessing of signals from a severely disabled person has received a great deal of attention (see Proceedings of Conference on Systems and Devices for the Disabled, 1976; Proceedings of Fourth Annual Conference on Systems and Devices for the Disabled, 1977). Any of the methods used in these reports to mediate verbal communication can be transposed to achieve communication with a computer. For example, in our pilot study, we used the device already familiar to the subject, in some cases a headstick, in some cases a switch used to start and stop a cursor in the style of the TIC (Foulds, 1976). In the present study we shall begin our exploration in the same style, thus allowing our subjects to make the simplest possible transition to using the computer and allowing us a more modular work plan. For the later phase of our work we shall introduce more sophisticated methods of detecting signals. These are discussed in section 3.2.4.

2.3 Theoretical Issues

The implications of this work for our understanding of cognitive development are profound. The question arises as to the role of particular sense modalities in shaping conceptual structures e.g. how will the notion of a "cube" in the head of an individual who has never touched a brick -- who has never played with building blocks -- differ from the way cubes are represented by persons with full motor power. The LOGO laboratory is a place where concepts of physical space and shape are extensively explored and the child's programming activity in relation to these ideas provides a window into his thinking about these ideas. To illustrate the point, consider the subject Jay (described in Appendix B), whose degree of cerebral palsy is so severe as to exclude not only all effective, controlled, manipulation of objects, but even all regularity in the response of his own body to sensory stimuli or to volitional schemata. Now, if one keeps Jay in mind in re-reading Piaget's account of the developmental role of sensori-motor activity (Piaget 1952) one cannot help being struck by a rather powerful discordance. We are not suggesting that Piaget's theories would be refuted by the discovery that Jay's intelligence, including his representation of space, followed the same pattern as we see in normal subjects. Such a suggestion could only come from a rather simple-minded (though unfortunately widespread) interpretation of Piaget. But we do strongly suggest that the development of Jay's considerable intelligence, and especially his spatial intelligence, does force a re-thinking and re-definition of many Piagetian concepts.

> Piaget is, of course, not the only theorist whose ideas might have to be refined in the light of data about subjects like Jay. A very striking example is the work of our M.I.T. colleague R. Held on the role of motor activity in the development of visual perception in kittens (Held and Hein). It will be recalled that in Held's experiment two groups of kittens were exposed to the same visual environment, one group "actively" by walking through it the other "passively" by being carried through it in a basket. The analogy with Jay's experience of being "carried" through his world in a wheel-chair is obvious. Yet Jay seems to have developed where the kittens did not. It is easy to invent explanations of the difference between Jay and the passive kittens. So Held's conclusion is certainly not refuted by Jay's existence any more than is Piaget's. But the parallel already makes us think more carefully about how to interpret and generalize Held's results. More data would undoubtedly go further in this direction.

Our pilot studies provided us with very limited and impressionistic data. However we were able to make one rather precise observation by taking Jay through a learning experience, namely the elements of Turtle Geometry, which several hundred normal subjects of various ages have had in our experimental classes. Jay's rate of learning showed no impairment which could be attributed to weakness of spatial representation. On the contrary, in some respects he was unusually quick! Our interpretation of this is that his limited capacity to operate on the actual physical object had forced him to develop greater than normal facility in "working in his head". It is much harder, on the basis of such limited data, to evaluate his pattern of learning (eg. which aspects he found more difficult than others, what kinds of errors did he fall into most easily).

The proposed research then offers an opportunity of observing individuals who have been deprived of experiences usually regarded as centrally important in the development of certain concepts and of observing such individuals behave in an environment which is specially and explicitly designed to promote an exploration of such concepts.

The research is expected to yield insights into mechanisms of the acquisition and representation of knowledge.

2.4 Social Issues

If our arguments are sound and if our preliminary findings generalise, then what we are talking about is a very fundamental change in the lives of such individuals. For as well as operating independently, a grossly disabled person equipped in the way we describe in section 3.2.4 can be put in contact with other persons and institutions similarly connected to a computer. Being a member of this computer society will open possibilities for such an individual in education, entertainment, frendship, hobbies and even in employment.

We foresee a future in which a disabled person previously in contact with almost noone, can become a participant in many worlds.

3. WHAT WE PROPOSE TO DO

3.1 Overview

3.1.1 Steps in the Study Seen from a Psychological Perspective

(a) We propose to work with a small population (8 children) of severely cerebral palsied children of ages 6-14 years old.

(b) The first stage with all subjects will be to establish communication with a computer equipped with graphic capabilities. Pilot studies suggest that within two weeks most subjects have acquired some degree of ability to draw and to manipulate AS-IF objects on the computer screen.

(c) Concurrent with (b) the subjects will go through a series of activities designed to give insights into their capability in spatial reasoning. These will include graded Piagetian tasks as described in section 3.2.1.

(d) Over a longer period, some of the subjects will undergo a mathematical learning experience parallel to a LOGO-based experiment now being studied in Brookline Public Schools.

(e) While (d) is in progress, we will gradually introduce work with language to a subset of that group. This will involve learning to write and edit text on the computer. We will document these experiences and compare them with the

Brookline group, focusing on evidence for linguistic structures.

3.1.2 Steps in the Study Seen from a Technological Perspective

(a) The first stage involves interfacing standard communicators with a computer. This means selecting individuals in the school/institution who are already equipped with a headstick, say, and introducing them to the computer, as we did in the pilot study. We will take our sample of 8 individuals, in two groups of 4 each, through the LOGO experience with concurrent testing on Piagetian tasks. Documentation for this phase will be based on the system of record-keeping being currently developed in the Brookline Public School experiment to facilitate comparison

(i) between the handicapped and the "normal" group and

(ii) between the handicapped group using different communication devices.

(b) In collaboration with our colleagues in the Artificial Intelligent Laboratory, Mechanical Engineering Department and Draper Laboratory, who have a long record of relevant experience in this area, we will interface an eye-tracking system with the LOGO system. Hardware tasks involve connecting the machines which support each system. On the software side, we will develop a system of coding the signals which provides the possibility of faster, more comfortable and more relaxed communication, suitable to support the sophisticated type of use we are proposing (see section 3.2.4). Our intention is to phase our students gradually out of the initial mechanical prostheses into this eye-tracking system. We are fortunate in that one of the subject at Westfield school is due to be introduced to the eye-tracking equipment we propose to use in the next few months.

We expect that this stage will take place during the second year of the study.

3.2 Detailed Exposition of Steps in the Study

3.2.1 AS-IF Version of Piagetian Tasks

Piagetian tests can be tranformed into multiple choise tests as opposed to a more active participation of the subject. Of necessity, only the former have been used in the past with subjects as severely afflicted as ours will be; initial work has led us to believe that the more involved, active situation we are creating will produce very significantly different diagnoses of mental capacity. We hope to be in a position to develop and carry out Piagetian tests in order to construct Piagetian profiles. The following tests lend themselves to our purposes:

(a) spatio-logical tests at the concrete-operational level e.g.:

classifications

seriations

projective geometry

(b) the Sinclair de Zwart linguistic tests at the concrete-operational level e.g.:

relation of linguistic forms to conservation

conflictual words order experiments

(c) formal operational level e.g.:

permutations

hypothesis formation

Piagetian Profile

Using AS-IF versions of Piagetian experiments, we shall map out a profile for each subject at the beginning of our study. Although the sample is small, we expect to be able to distinguish between certain extreme hypotheses.

Questions about the existence of standard patterns

The Piagetian theory of stages is based on the fact that certain abilities cluster together into patterns e.g. conservation and seriation at the concrete-operational level. Will these clusters be maintained in our subjects, or will we find a wider than usual range of discrepancies? In other words, will we recognise normal stages?

Questions about timing

(a) Even if the normal stages are recognisable, there is a further question about whether they are drastically retarded or not.

(b) One possible outcome is that children who are found to be retarded in some or all respects at the beginning of the study are found to make considerably more rapid progress than is seen in normal children.

Other work in this area

Detailed reports of this kind of information about the cognitive development of cerebral palsied children are scanty, as Goldenberg (1977) found, in a computer search through both the ERIC and EXCEPTIONAL CHILD databases. The Melcer and Peck (1967) study he quotes involved a modified Peabody Picture Vocabulary Test, so that each item contained both an object representation of the vocabulary item and an action representation e.g. a ball vs someone playing with a ball. These authors conclude that cerebral palsied children

> "do not develop concepts of action in the same ratio to object concepts as children who are not motorically handicapped" (Melcer and Peck, 1967)

They and we are concerned about the weakness of their test instruments. We feel there is clearly an urgent need for the study we are proposing.

3.2.2 Comparative Learning Study

We believe that the best source of in-depth data about the learning ability of an individual or group can be obtained by documenting a substantial learning experience of a few individuals i.e. the case study approach. We are already undertaking a study at this sort on the effect of exposing 16 sixth grade children to about 40 hours of work in a LOGO/Turtle environment. The progress of these children, including the difficulties they encounter and how they deal with them is being recorded in great detail . These records include: a detailed trace made by the computer of the total interaction of the child and the machine; observer notes kept by experienced evaluators; notes kept on a detailed basis by the teacher who works with a small enough group (4 at a time) to pay attention to what each is doing, including a checklist of the acquisition of particular items; interviews and a battery of pre-tests and post-tests. The sample of children covers the entire range of a "normal" urban school population. Several of the subjects are classified by the school as having learning disabilities, one as dyslexic. The sample contains one exceptionally gifted child and a cluster of children who appear as "average" according to school records.

We propose to give 8 cerebral palsied children an experience as close as is feasable to the one we are using in this LOGO evaluation study to provide the basis for a comparative study.

3.2.3 Language Learning

The goals of the linguistic aspect of the study parallel those of the spatio-mathematico-logical aspects:

(a) to understand as far as possible the linguistic competence of subjects who have acquired proficiency in understanding but have had virtually no experience in production of language.

(b) to understand the process of learning in such subjects when they are given the opportunity to use a "language prosthesis".

(c) to bring a selected subset of subjects to as high a level as possible of proficiency in the expressive use of English.

Facilities for text display, editing and filing are already available. Progress in this area will depend on a mastery of the system described in section 3.2.4 allowing for an input of a full range of alphanumeric characters, and should follow smoothly on from the LOGO/Turtle work, which will have used the same character set, and the same text-editor and filing conventions.

We are not in a position to predict what form our "language education" will take since this area will be an entirely new exploration. Our methodology will be to keep a computer record of all transactions and to evolve a "curriculum" on the basis of what transpires.

3.2.4 The Interface

We recall that the means of communication between the subjects and the computer is to be developed in two phases.

In phase one we use the traditional electro-mechanical communication aids to which the children are already accustomed. In phase two we shift gradually from this to the use of an eye-movement tracking device.

The first phase needs little further discussion under this heading. We know that standard devices can in general be easily connected to our computer.

In the second phase,

(a) Early contact of the student with the eye-tracking devices will be undemanding in precision and in speed of movements. Our collaborators at the Draper Laboratory have accumulated some experience with an analogous system which allows eyes movements to "paint" pictures on a television screen (Warren, 1977). The significant aspect is that there is no fixed goal except the subject's own sense of aesthetics; many different movements can produce pleasing effects so that the subjects find the situation rewarding even when their skill is still very low. In time skill in controlling one's own eye-movements builds up.

(b) When we move the subject into the use of discrete codes we will use a software system designed to allow for very flexible choice of code. Thus we can begin with "easy but slow" codes and shift later to more efficient and faster but more demanding ones. In case of exceptional problems we shall be able to custom-fit the code to the individual. Indeed, for some individuals we may resort to tracking a movement other than the eye such as a bright light source on the end of the headstick. The hardware and software of the tracking system is designed to be highly flexible.

(c) Preliminary turtle work

We will start with a small number of "eye gestures", one for each of the following commands: FORWARD, RIGHT-TURN, PENUP, PENDOWN, ERASE, DEFINE, SELECT-SUBPROCEDURE, HELP

These could be coded into eight directions of eye-movements:

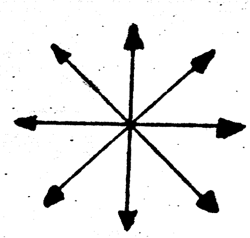

fig. 1

The tracking system has to recognize only which of the eight directions of movement was intended.

The absence of general alphanumeric symbols is compensated for by: default inputs for FORWARD (say 10) and RIGHT (say 15, because it divides 30 and 45) and an automatic assignment of eight direction symbols for user defined sub-procedures.

Only after this system is mastered, will we move to a full alphanumeric code. Our present preference is for a two-movement code using the same eight directional movements. It is convenient to think of a 3x3 array, each slot of which contains a 3x3 array of characters.

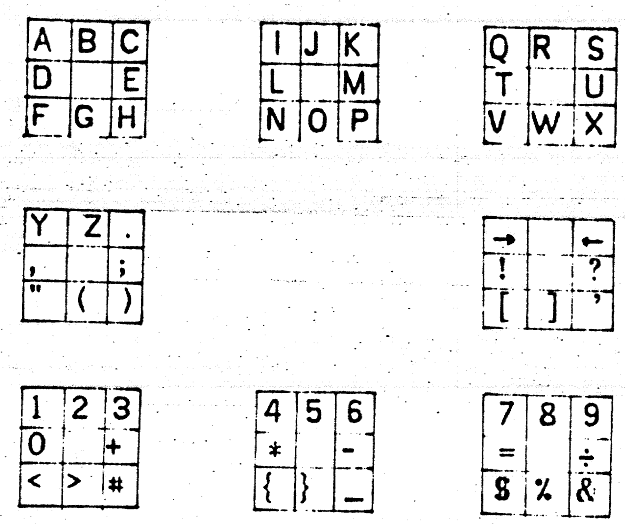

fig. 2

The entire array is present on the screen, lightly super-imposed on the drawing or text. The movement " ↖ ", i.e. looking at the upper left hand cell, causes this sub-array to be selected and to be blown-up to fill the entire screen. Making the same movement again will select the letter A (see fig. 2).

As the user becomes proficient, it will become unnecessary to display the arrays. Since he has command over the computer he can ask for them to be displayed or not as he chooses.

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APPENDIX A

LOGO Learning Laboratory - Basis for Curriculum

To provide a context for "learning by doing", we link up various devices to a computer so that a child can, via computer, "command" an output device to carry out an action. One device we have used is a mechanical "turtle" capable of moving forward or back in a particular direction (relative to itself) and of rotating about its central axis. It has retractible pen on its underside which can be in two states called PENUP and PENDOWN.

The mechanical turtle can be replaced by a Δ on a display screen, and this is made to "act" by typing commands. At any time the turtle is set at particular place and facing a particular direction.

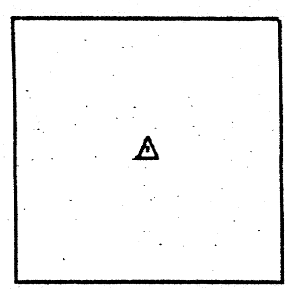


fig. 1

If the pen is down, then as the turtle moves around, it leaves a trace, and so arbitrarily complex patterns can be drawn.

e.g. the following commands will cause the turtle to draw fig. 2

PENDOWN

FORWARD 100

LEFT 120

FORWARD 100

LEFT 120

FORWARD 100

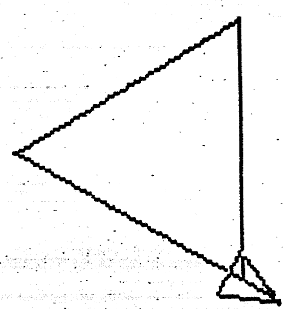
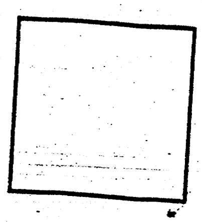


fig. 2

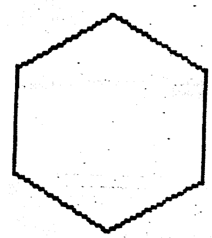
There are many paths to take from this point depending on the individual characteristics of the learner (and of the teacher). For example, the set of instructions required to draw a triangle can be wrapped up into a bundle as a PROCEDURE and given a NAME. Different sizes and orientation of triangle can be drawn by introducing a variable parameter for the procedure. This immediately leads to the <u>discovery</u> that other polygonal shapes can be drawn by selecting appropriate values for the input variables.

```
TO TRI :ANGLE  :SIDE
10 FORWARD  :SIDE
20 LEFT  :ANGLE
30 FORWARD  :SIDE
40 LEFT  :ANGLE
50 FORWARD  :SIDE
END
```

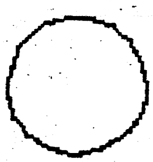
```
TO POLY :ANGLE :SIDE
10 FORWARD  :SIDE
20 LEFT  :ANGLE
30 POLY  :ANGLE :SIDE
END
```



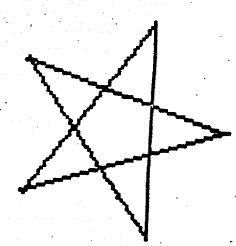
POLY 90 100



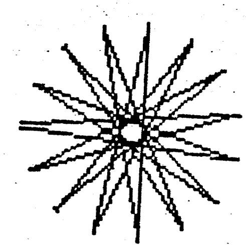
POLY 60 50



POLY 9 5



POLY 144 100

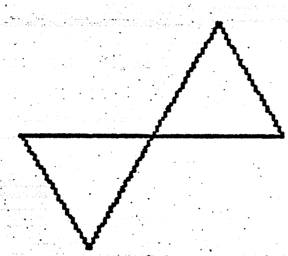


POLY 156 100

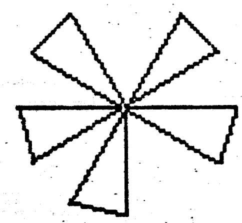
Notice that in addition to learning computer programming, the student is learning mathematical ideas - he is exploring the notion of ANGLE, POLYGONS, RECURSION and so on.

PROBLEM SOLVING

Repeated calls of the same triangle procedure were named by children currently doing LOGO in a school in the Brookline public school system as:



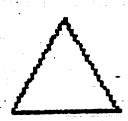
and



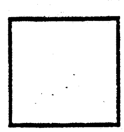
(a) butterfly (b) flower

This leads to an IMPORTANT IDEA: use what you have learned.

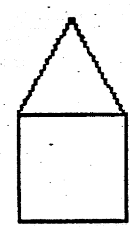
Complex patterns can be seen as consisting of familiar parts e.g. a house can be broken into:



triangle

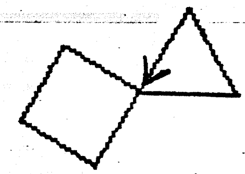


square



house

This introduces a basic PROBLEM-SOLVING heuristic i.e. break up a complex problem into its subparts. The HOUSE procedure can be built up out of a TRIANGLE sub-procedure and a SQUARE sub-procedures. Putting together these procedures produces an unexpected result.



This is because when the triangle was completed the turtle was left facing in the direction of the arrow. So this introduces the idea of a BUG, which can be easily fixed or DEBUGGED because it is so easy to follow what is happening -- the relation between the ACTION and its CONSEQUENCE is very EXPLICIT.

A glimpse of the wide range of activity possible using this LOGO language is given in the document "Twenty Things To Do With A Computer" which is appended.

APPENDIX B

Crotched Mountain Experience

Our initial experience in this field has involved bringing 4 cerebral palsied children from Crotched Mountain Center to MIT for three sections and later taking our equipment to their residential treatment center for a week.

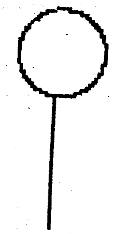
We worked with 9 cerebral palsied children, 7 deaf children and 6 children diagnosed as autistic. The following example is intended to give a flavour of what was achieved.

CASE

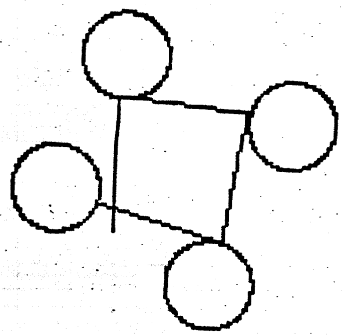
Jay is an 18 years old with no effective use of hands or legs or speech. He is experienced in the use of a headstick with which he can type, touch slowly and inaccurately, on an electric typewriter. Unfortunately he showed very little inclination to use this facility until he met a computer console. After approximatelly 3 hours on our systemn Jay's enthusiasm had become so great that he spent a full week back at the Center typing a long and elaborate letter home to his parents explaining what he had done with the computer. Then in the week we spent at the Center, he learned to draw some very elaborate and handsome pictures. The interest of these events is greatly increased by the fact that Jay's intelectual potential had previously been assumed to be extremely slow. Jay's experince with the computer demonstrated for the first time a high level of analytic and of spacial ability.

On the next pages we have samples of the computer programs which Jay wrote by himself during the first two days of his work with us at own laboratory. Note that the first procedure, which he named MOM, required a right turn in order to draw the circle, and that he adjusted that turn slightly, adding five degrees to it, which caused the next procedure, GOING, not to close. By using four MOM's in GOING and eight GOING's in DAD's, Jay was able to multiply the effect, producing a more intricate design. Jay began drawing a car, but did not have time to finish it or to make the changes needed to turn it right side up.

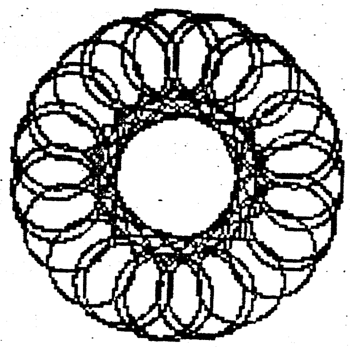
```
TO MOM
10 FORWARD 60
20 RIGHT 5
30 RIGHT 90
40 ARCL 360 20
END
```



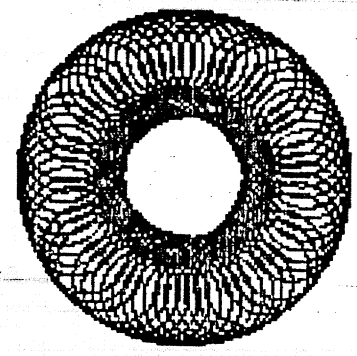
```
TO GOING
10 MOM
20 MOM
30 MOM
40 MOM
END
```



```
TO DADS
1 GOING
2 GOING
3 GOING
4 GOING
5 GOING
6 GOING
7 GOING
8 GOING
END
```



```
TO JAY
1 DADS
2 DADS
3 DADS
END
```



```
TO CAR
10 SQR 100
20 RIGHT 90
30 ARCL 360 15
40 LEFT 90
50 FORWARD 58
60 RIGHT 90
70 ARCL 360 15
END
```