N72-26166

STUDY TO DEVELOP TECHNIQUES FOR A SELF-ORGANIZING COMPUTER

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Third Quarterly Progress Report

Contract No. NASW-2276

Covering the period

1 January 1972 - 31 March 1972

Prepared by

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for

National Aeronautics and Space Administration

1 - FACTUAL INFORMATION

1.1 The work during this quarterly period has been essentially as anticipated in the second Quarterly Report. A description is given in section 2, subdivided in tasks as defined in the previous Quarterly Report.

In section 3 the work planned for the next period is described.

1.2 Meetings, attendance, papers

A paper "Structure of a Communication Network and Its Control Computers" with I. Cappetti has been prepared for presentation to the Symposium on Computer-Communication networks and teletraffic of the Polytechnic Institute of Brooklyn.

A paper "Abstract Models as a Programing Language" has been written and submitted for presentation.

During this quarter, attendance has been made to the IEEE International Convention and to the Conference on Information Sciences and Systems of Princeton University.

1.3 Personnel

The personnel active on this contract during the third quarter are:

Prof. Norman A. Phillips, Project Supervisor - Advisory Capacity	
Mario R Schaffner	2.2 months
Programmer	10 hours
Drafting, clerical and technical assistance	90 hours

Dr. Pauline M. Austin and Spiros G. Geotis of the Weather Radar Research Project at M.I.T. are also participating in consulting and advisory capacity for the applications to weather radar.

2. SUMMARY OF THE WORK PERFORMED IN THE THIRD QUARTER

The work under this contract has been subdivided into tasks labelled according to the chapters in a tentative table of contents for the Final Report; this table is here repeated and updated.

During the previous quarterly periods, attention was given to tasks 1, 2, and 3 and an account of the development reached was given in the corresponding sections of the second Quarterly Report. In this report, the main points of those tasks, with some additional comments, are repeated (Sections 2.1, 2.2, and 2.3) as a background to the task developed during the period referred to in the present report.

During the past three months the main emphasis has been on the language, and a first draft of the corresponding chapter of the Final Report is given here (Section 2.5).

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2.1 Task 1 - Motivation for a new approach

The activities and the inconveniences related to the use of computers were depicted symbolically by Fig. 1.

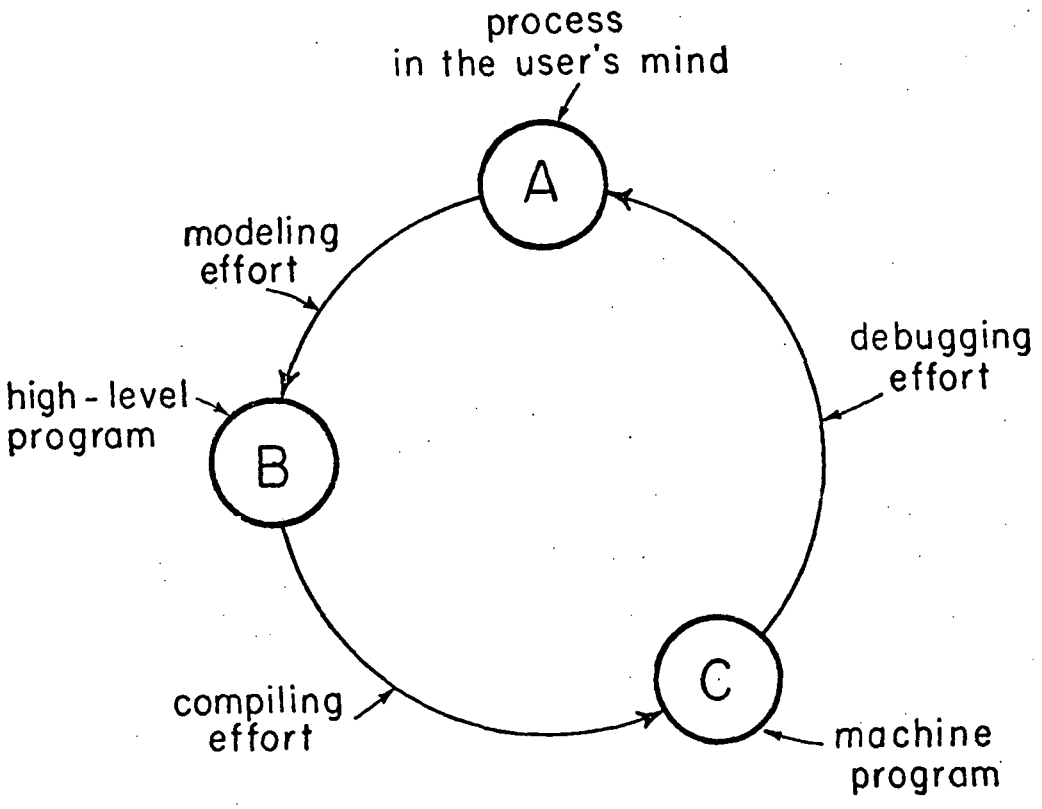

Fig. 1 - Process transformations in the use of a computer

It was pointed out that if a mode could be found to shorten the arrows of Fig. 1, in fact the efforts which they represent, the inconveniences would be lessened. The method which is proposed to accomplish this was stated as follows:

Given an activity A to be produced, described in whatever form,

rather than developing an algorith L, executable by a real machine B (or alternatively translatable by a compiler C of B) such that B (or C + B) produces A,

develop an abstract machine M such that M produces A as its natural response; then describe M in a form m acceptable by a given loose real system S, in order for S to become a real machine equivalent to M.

A loose system S can be thought of as an ensemble of operating and storage elements that can be organized to form desired operational networks. From automata theory viewpoint, it can be regarded as a giant, unmanageable, finite-state machine with a very large number of states and input signals. The state diagram of such a machine, which we call the total state diagram, is practically undescribable. Now, the input signals are divided into two categories which we call problem inputs and p inputs. For each set of values of the p inputs, a particular "component" of the total state diagram is selected, while all the rest disappear (Cfr. Minsky, 1967, sections 2.4 and 2.5). Such a component can be regarded as a specific computation. In dealing with this component, the user needs to be concerned only with the few problem inputs and the few states of that component.

The description m (that we can see as the program for the loose system S) consists of the management of those p inputs. The key point is that in this approach the p inputs are not prepared in terms of a

given real machine that has to simulate the desired activity A; the management of the inputs p results, almost completely, from the process of modeling the activity A in the form of an abstract machine M. The words "almost completely" account for the difference between M and m, due to possible limitations of the system S. In other words, the user is concerned only with the problem he is dealing with, in the terms he finds more appropriate for that specific problem. At the end of the construction of the abstract machine M, the management of the p inputs results almost completely established, without need for the user to think of any given computer.

2.2 Task 2 - Why Abstract Machines?

The justification for having chosen abstract machines was accounted in the Second Quarterly Report (Section 2.2). Further discussion is presented here from a viewpoint of interest for the issue of the language to be considered in Section 2.5.

In past decades there was strong interest in comparing the working of biological neural systems and of computers, at that time in their first emerging. McCulloch and Pitts (1943) made the first well known work. Then von Neumann worked increasingly in analyzing similarities and diversities between brain and computers (1948, 1958, 1966). Clearly, he was expecting to develop a general theory of automata that could be a useful model both of the brain and computer functioning.

Today, on the one hand, new specific technologies have been developed for the implementation of computers. Computers themselves have become a new discipline with its specialists, theories, and jargons. On the other

hand, continuous work in neurology has increased the realization of the complexity and multifacets of the neural system. As the two fields developed separately, there has been a decreased interest in comparing approaches and techniques used by the biological system with those appropriate for the man-made systems.

As a matter of fact we do not need a system compatibility between biological organisms and computers. We do not envision, for computer use, the application of electrodes to people for establishing direct communication with man-made devices. The communication we seek is through modes of expression with which human beings are normally familiar, e.g., languages and visual images.

In the last decades, automata theory has become of interest to other human fields besides neurology, namely, psychology and linguistics. In theory of thinking, developmental structures constitute new powerful models. (Cfr. Mandler, 1964: Piaget, 1950; Flavell, 1963; Miller, 1964). These models, of completely independent formation, find interesting parallelisms in automata theory. In linguistics, automata models give new possibilities for analyzing languages (Blumenthal, 1970; Chomsky, 1957, 1965).

It appears of interest now to compare the working of computers with the models used in psychology and linguistics. The aim is to reach a better compatibility of expression and communication between human users and computers.

2.3 - Task3 : FSM model and CPL automaton

The basic abstract machine - called FSM - to be used for modeling the processes is repeated in Fig. 2.

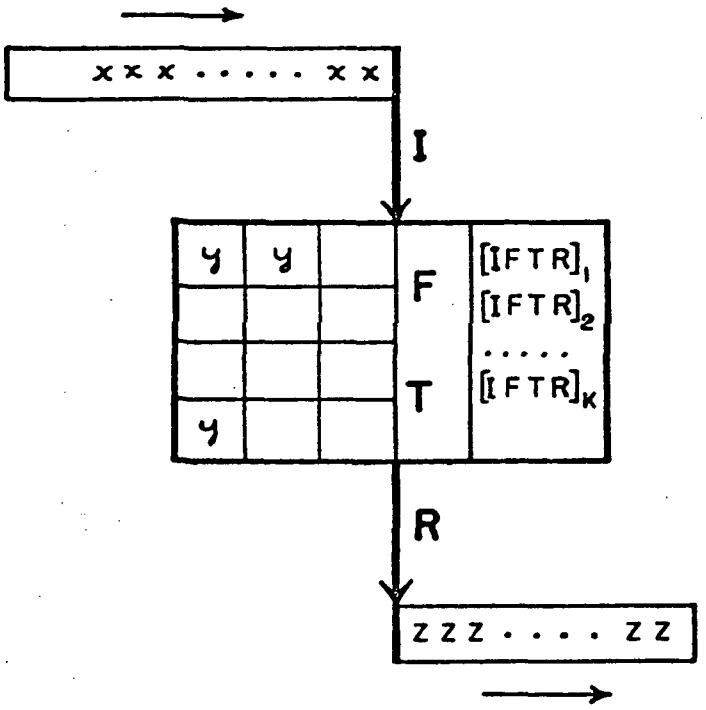

Fig. 2 - The basic automaton

A read-only tape contains a finite string of input symbols x, from an alphabet A. A "blackbox" contains a finite set Y of symbols y (internal variables) from A and is capable of assuming a finite set S of internal configurations (networks of logical elements capable of reading the symbols of A in some coding) called the states of the automaton. A state s is defined as a quadruplet (I, F, T, R), where I (input prescription function) is a mapping that makes available to the

black box a subset X of the symbols x in the input tape: F (data transformation function) is a mapping of X Y into a new set Y; T (transition function) is a mapping of X Y into the next state in S; and R (routing function) is a mapping of a subset of Y into a string of output symbols z in a write-only output tape.

The time is quantized in discrete moments i. The process is modeled by means of the two recursive functions (1) and the related state diagram.

$$Y(i+1) = F[Y(i), X(i)]$$
$$s(i+1) = T[Y(i+1), X(i)] \qquad (1)$$

The work of the automaton can be visualized in Fig. 2 as an activation of one of the k quadruplets at each moment i.

Turing showed the power of an infinite tape added to a finite-state machine. But engineers, unlike mathematicians, are unable to handle infinity. Therefore our automaton, called the CPL automaton, has a structure as shown in Fig. 3: the black box is the basic automaton shown in Fig. 2: the Q memory, a finite First-Input-First-Output storage, plays a role analogous to the tape in the Turing machine, and the connections with the environment allow us to extend the memory capacity as needed.

In the CPL automaton several FSMs are circulating through the black box and the Q memory, either independently or concurrently exchanging data through the storage H. Each FSM is active only when it is in the black box. Therefore for the user dealing with each FSM, all the data stay in the array shown in Fig. 2. As a consequence, a random access memory, with all the apparatus of addresses, is not needed. To relate different FSMs, and devices and storages in the environment, variables pertinent to the processes are used.

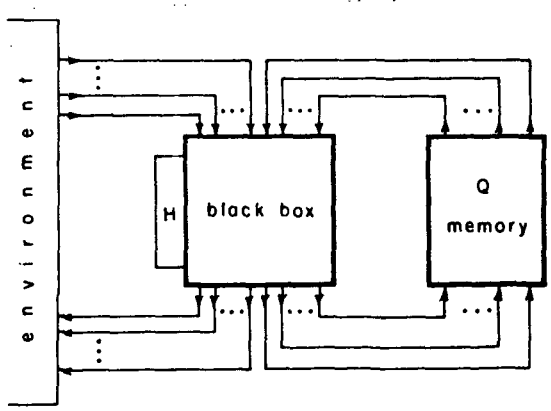

Fig. 3 - The CPL automaton

2.4 Task 4 - An implementable system

The description of a realizable CPL automaton, called CPL system, will be the work of the next quarterly period. Here an anticipation is given in so far as it is necessary for the discussion of the language. Such a system is composed of (Fig.4):

(a) A programable network including an array of registers imbedded in a loose ensemble of operating elements that can assume specialized configuration C, in response to digital words F and T.

(b) An assembler that, receiving a page of data from the memory and new data from the environment in response to digital words I, prepares in an array of registers Ω_a all the necessary data for a cycle of operations of the operating unit.

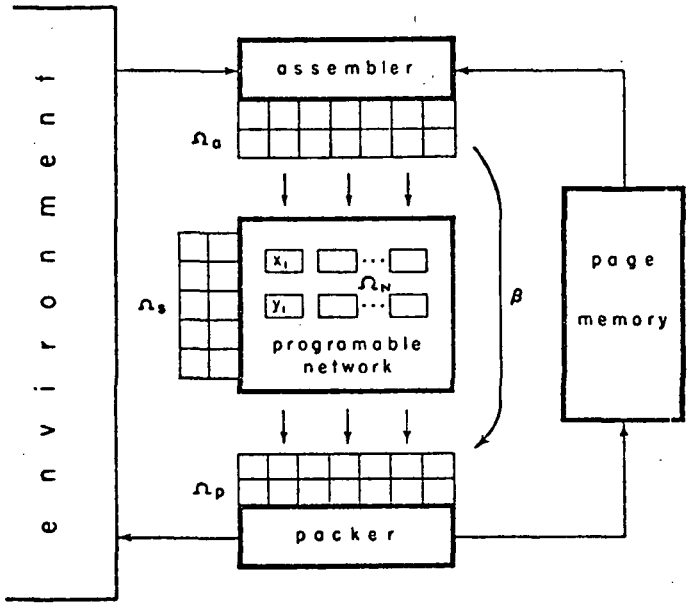

Fig. 4 - The CPL system

(c) A packer that, receiving a page of data into a register array Ω_s, at the end of each cycle of the operating unit, routes some data to the environment in response to digital words R, and some to the memory.

(d) A memory with a loose structure capable of holding a large number of pages. The memory receives one page at a time from the packer when requested, and furnishes one page at a time to the assembler again when requested.

A process to be performed is described as an FSM. The FSM description is stored in the form of a page of digital data. As the page circulates through the assembler, operating unit, packer, and page memory, the process is executed.

Main features of the system are:

(i) A mapping is implemented between functions F and configurations C, in accordance with the correspondance between logical behaviors and logical networks discussed in the Second Quarterly Report.

(ii) A loose structure similar to that of written pages is used for organizing in an independent manageable set of symbols all the information necessary for the performance of an FSM.

2.5 Task 5 - The language

2.5.1 The role of the language

As symbolized in Fig. 1, typically, three languages are involved in the use of computers: (1) a spoken language, typically mixed with expressions of mathematical languages, for describing a process originated by some human mind; (2) a high-level language for modeling that processes in a rigorous form acceptable by the available computing system (hardware plus software); and (3) a machine-language for actually instructing the computer to execute the process.

These three languages are independent. The process originator, during the description of his process, does not think of the other two languages. Even if the originator himself later programs the computer, he does not use, say, Fortran statements or machine instructions in delineating the process. He may have continuously in mind constraints and possibilities of the computer he is going to use, but he does not use computer languages in conceiving and clarifying the process he is dealing with. Several are the reasons for this. The elements of computer languages are too rigid for coping with the flexible, loose, self-adapting ways of human minds in search of a solution for a problem. Any expression of computer language requires that all the details be already established; clearly this is not the situation when one is constructing a process. All these points are highly relevant to our study and will be recalled repeatedly in the following.

The high-level language is used by the programer and, once chosen, does not have any relation either with the originator language or with the machine language. Each high-level language is developed independently, with the intention to be practical for particular types of processes, or of users.

The machine-language is used by the computer, and it does not have any connection with the other two languages. Each computer has its own machine language as a consequence of its design.

It is legitimate to wonder if three languages, foreign among themselves, are really necessary to communicate with a computer. As it can be seen in Sammet (1969), or in the most recent panel discussion on the subject (IEEE, 1972), the present trend is to accept this situation and to develop a set of the most appropriate high-level languages and to look for some standardization in the machine languages. The optimists hope that in so doing, each user will find a high-level language particularly efficient for his problem, while all these different languages will tend to have similarities in their structure. It is not clear if this hope is feasible or there is a contradiction. The pessimists simply worry about the proliferation of languages.

Let us consider the opposite approach: to search for possible universals in the expressions of the process originators in order to form a single high-level language appropriate for the different problems and users. In other words, rather than to follow the different jargons proliferating for the different problems, let us come back to the roots, if such there are, common to all, or majority of problems and users.

There are justifications for considering such an approach. An elementary part of mathematics, the arithmetic operations, are used, like universal notions, in all applied fields. We are all trained to that, in the elementary schools of all the world. As a matter of fact,

the universality of general purpose computers is based on their capability to execute the arithmetic operations. But the monstrosity into which software has grown shows that those universals alone are not capable of implementing our aim.

In philosophy also the perennial aim has been to seek universals in nature and human thoughts. More recently the same aim is exhibited by psychology and linguistics. This suggests that our search should not be confined to mathematics and engineering, but should share also the efforts made in other disciplines.

The language which is being developed is based on the premise that abstract machines constitute a language common to users and computers (see discussion in the second Quarterly Report). More precisely, that abstract machines play the role of machine languages, high-level languages, and be closely related to the process image in the user's mind. It has already been shown (Schaffner, 1971) that a form of abstract machine suitable to be a high-level model of processes can at the same time be an actual machine program for a particular type of computer. The experience gained with a first computer of this type confirms the practicality of the approach. More insight is needed on the claimed closeness between abstract machines and process image in the user's mind.

2.5.2. Psycholinguistic considerations

If a programing language is intended for use by nonspecialists, its psychological aspects have to be considered no less that its formal aspects. Spoken languages, which developed as a result of human needs

and characteristics, are undoubtedly compatible with these characteristics. Conversely, artificial languages need conscious attention in order to be appropriate to the psychological characteristics of the users. The first programing languages completely concentrated on making possible the use of existing computers, and few concessions could be made to psychological considerations. The present level of technology should allow much higher priority to the user's dispositions.

Two fields of psychology are highly relevant to a programing language, structures of thinking and of languages. A survey from a psychological viewpoint of the studies of thinking, from Aristotle's images to the present is given in Mandler (1964); mathematical modeling is discussed in Miller (1964); and a modern view of developmental structures can be found in Flavel (1963). A historical review of psychological studies of language can be found in Blumenthal (1970), and a modern approach of generative grammar is given by Chomsky (1957, 1965).

In the second Quartely Report (Section 2.2), similarities between abstract machines and models of the brain work were noted. Now we find analogies with models used in psychology and linguistic.

We can not escape pointing out that the developmental structures of modern psychology and the syntactic structures of modern linguistics are types of self-adapting finite state machines, while similar models are suggested in our work for programing computers. Functions F and T of our modeling, in a sense, have a similarity with the grouping of mental operations of Piaget (1950). One may be tempted to conjecture that the greater insight achieved in psychology by using developmental structures rather than association schemes might have a parallel in a

greater efficiency that could be obtained in computer programing by using abstract machine models rather than conventional command languages.

Even without becoming involved in thought theory, it is clearly recognizable that a process can be represented more easily by means of the multidimensional structure of an abstract machine than by means of an array of symbols as in conventional programing languages. It is common experience that a sketch is more easily understood than a set of formal phrased sentences. Therefore it seems likely that a nonprofessional user will need less effort to describe and read a process in the form of an abstract machine than in the form of formal sentence description. It is interesting to observe that before any development of automata theory, in mathematics, Turing (1936) needed an abstract machine in order to ascertain the computability of functions, and in engineering, Kutti (1928) used abstract machines to work on the operation of complex telephonic systems. Referring to the processing capability of the human brain, von Neumann (1948) argued that such a function as the recognition of visual analogies perhaps could not be described in sentences, while it is actually performed by the finite neural machine. Then he suggested (1966) that for complex automata their description should be simpler than a symbolic description of their behaviour. He was referring to mathematical complexity; here we are interested in the subjective complexity as felt by a user. While it is reasonable to think that a mathematical complexity has a counterpart in the subjective complexity, we do not have a basis for the reverse. The approach taken here on this subject will be discussed under task 6, and consists of comparing (under certain criteria) test processes described (1) by means of conventional procedural

programing-languages, and (2) by means of the description of abstract automata modeling the process.

Echoing Whorf's (1956) hypothesis that the structure of the language influences the manner in which humans understand reality and behave, one can simply mention the possible influence on those who use computers of changing from a command language to that of abstract machines. At least, when programing in the form of abstract machines, the user will not feel himself to be a slave of the computer since he will have designed its characteristics.

2.5.3. An experiment toward applying modes of thinking to computer programing

A first experiment has been undertaken on determining computer characteristics in accordance with natural inclinations of general users. A specific computer feature has been chosen, one which we feel is of such a general nature that it can be considered, a priori, related to a natural feature of our thinking: the transition between states. Undoubtedly, the notion of transition between items, times, actions, situations, places, etc., is familiar and "natural" for everyone, independently of the training, specialization and professional activity. A variety of people of different activity and age are being interviewed in order to collect patterns, usages, frames in the notion of transition, and the results have been considered for defining the modes in which transitions can be organized in a CPL system.

2.5.3.1. The interview

The form of Fig. 5 is used to facilitate the extraction of the wanted information from the interviewed people. In order to bring the interviewee to the issue, transition is presented first as physical

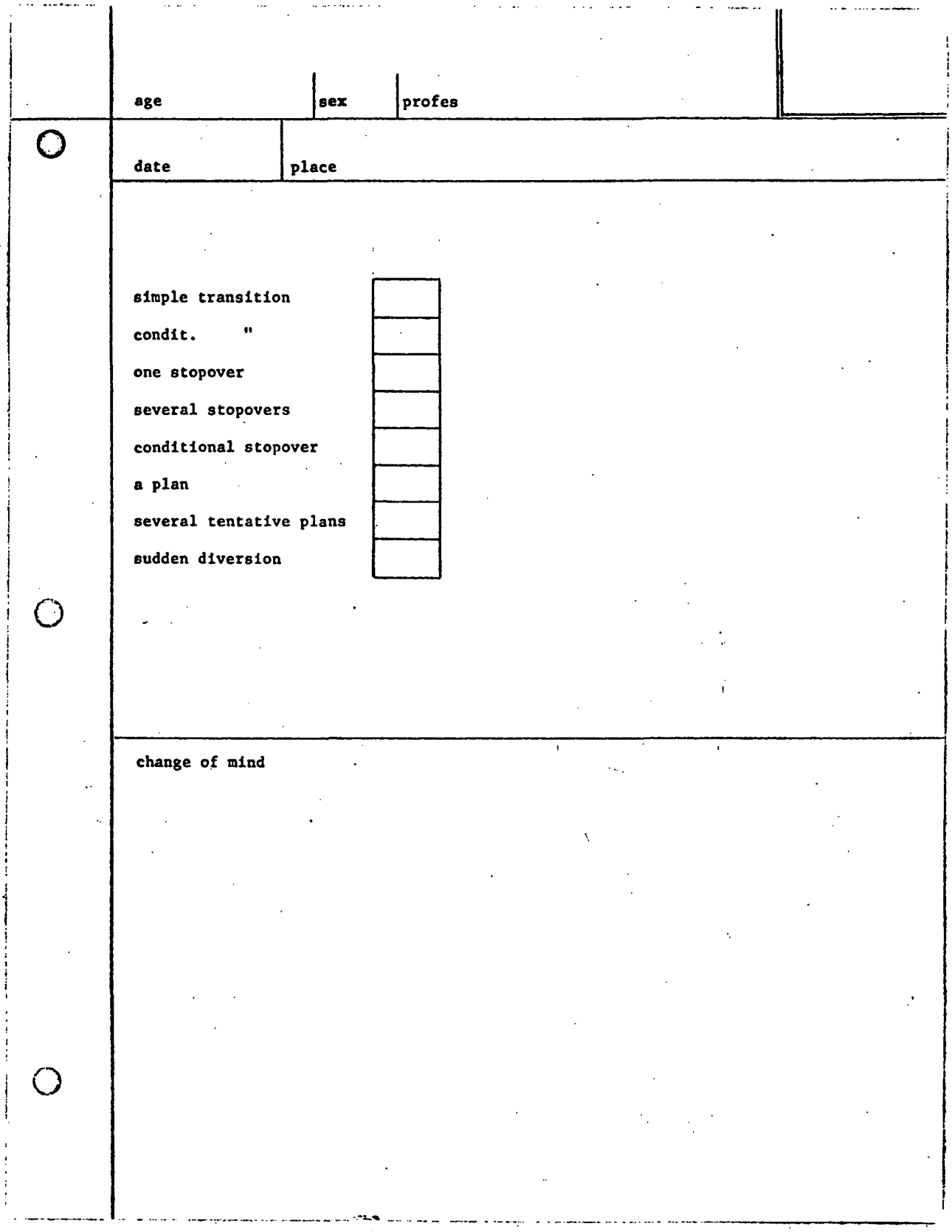

Fig. 5 - Form used for the interview

transfer from one place to another. Eight modes (upper part of the form) are presented as applicable to planning a trip, for business or pleasure. The relative applicability of these modes is asked and results recorded as ordered numbers in the form. At this time the person being interviewed is already "in" the notion of transition, and sometimes is able to mention some other ways of looking at it, ways that are transcribed if different from the eight examples given.

Then the notion of transition is presented in the sense of "changing mind", "changing situation", "changing status". The different ways of reacting and sayings of the interviewed are interpreted and if an interesting pattern of the transition appears it is noted in the second half of the form.

The population interviewed includes students, professionals in different fields, and people in a variety of occupations; their ages range from 11 years to mature age. Some distributions of the different viewpoints will be derived from the data. The following is a sample of some interesting expressions obtained.

T A B L E 1

1. I will go there, and then I will see.
2. I will go to C, and I might stop in B.
3. I will stop there for a certain time.
4. Temporary block.
5. Several plans performed sequentially.
6. Cancelling the plan, and making another.
7. Discuss this, before you forget.
8. If I think many things at a time, the efficiency decreases.

2.5.3.2. Features of the transition function.

From the material gathered with the interviews, and from the experience of programing the CPL 1 processor, features for the transition between states have been defined. Some of these have already been implemented in the CPL 1 processor, some were already planned, some are new extensions of the previous ones, and some are new forms of transitions in an FSM.

The effectiveness of the transition function T in describing a complex process in a simple form had already been recognized. The work done in connection with the reported interview has further confirmed that effectiveness, and demonstrated, at least for this case, the possibility and the convenience of modeling computer features after common features of people thinking.

Selected feature for the transition are described in Table 2, and corresponding graphical symbols that have been chosen are shown in Fig. 6. The usefulness of these features in modeling complex processes will be apparent in some of the programs that will be discussed under task 6, and in the example given in Section 2.5.7 .

Sentence 3 of table 1 suggested that stopover transition can be generalized to include general loops. In this case we do not need to occupy an operating register of the programable network for counting an index, and also the work of programing will be simplified. In accordance, features for the function T has been introduced by which we can prescribe loops of a given length or referring to any variable as index. Their graphical representation is shown in Fig. 6 (f), (g), (i).

The emphasis expressed by people on the conditionality of stopping over and in changing plans suggests a feature for specifying priority or

T A B L E 2 - Selected Transitions

(a). No prescription of any sort for T function means that the machine remains in the present state (until some action from the outside of that FSM occurs). In the state diagram, this case is represented by absence of any arrow emerging from the circle representing that state, Fig. 6 (a).

(b). Unconditional transition to the state with the next label (in the natural numerical order). Note that this is the simplest coded transition, no state labels need to be indicated. The adopted graphical representation consists of drawing adjacent the circles representing the states, Fig. 6 (b).

(c). Unconditional transition to state h. This prescription needs simply the state label h. Its graphical representation consists of an arrow pointing to state h, Fig. 6 (c). (Each specific example in Fig. 6 is shown in heavier lines).

(d). Transition to different states depending on conditions. The T function and the related state labels need to be prescribed. The graphical representation consists of several oriented arrows emerging from the state, Fig. 6 (d).

(e). Forced transition (produced as a consequence of actions by part of some other FSM). No prescription is made in this FSM. The graphical representation consists of a dashed arrow, Fig. 6 (e). This symbol is usually used also to indicate the starting state.

(f). Go to state h and stay there for n cycles (then the transition prescribed in state h will act). The prescription needs a code, the label h and the value n. The graphical representation consists of an arrow with open head where the value of n is written, Fig. 6 (f).

(g). Stay in the present state for n cycles (then the other prescriptions will act). The prescription needs a code and the value n. The graphical representation consists of an arrow looping into the state with the value of n written inside, Fig. 6 (g).

(h). Go to state h stopping over sates l, m, . . . (stopover transition). The prescription consists of the multiplicity of state labels in an established order. The graphical representation consists of a jagged arrow with notches pointing to the states where stop is made, Fig. 6 (h).

(i). As in h, but staying in the stopover states for assigned numbers of cycles. The prescription is as in h with added number of cycles. The graphical representation is as in h, with the number of cycles written in the notches , Fig. 6 (i).

(cont.)

(j). Priority is assigned to one or more transition branches. Priority means that that branch (if chosen by the function T) will occur first, regardless of other conventions. The prescription consists of a code added to the description of that branch. The graphical representation consists of a dot superimposed to the arrow representing that branch, Fig. 6 (j).

(k). Transfer of page. This feature is used when the page movement is controlled by function T, rather than following the automatic circulation. The prescription consists of a code added to the description of the branches for which the page remains in operation. The graphical representation consists of a square added to those branches, Fig. 6 (k).

(l). End of page. This transition produces the disappearing of the page. It is described as a special state label. It is represented graphically by a triangle, Fig. 6 (l).

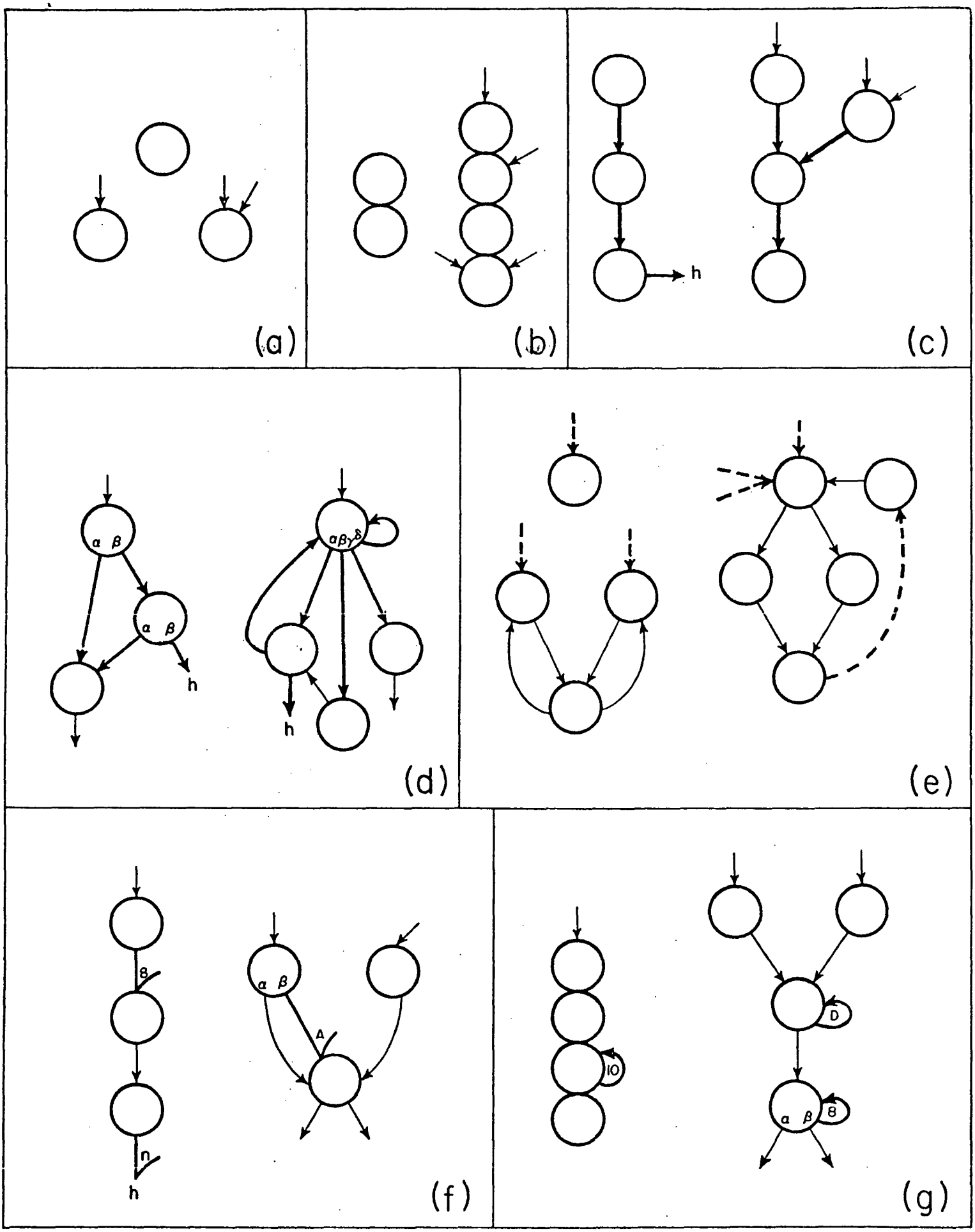

Fig. 6 - Symbols for transitions (cont.)

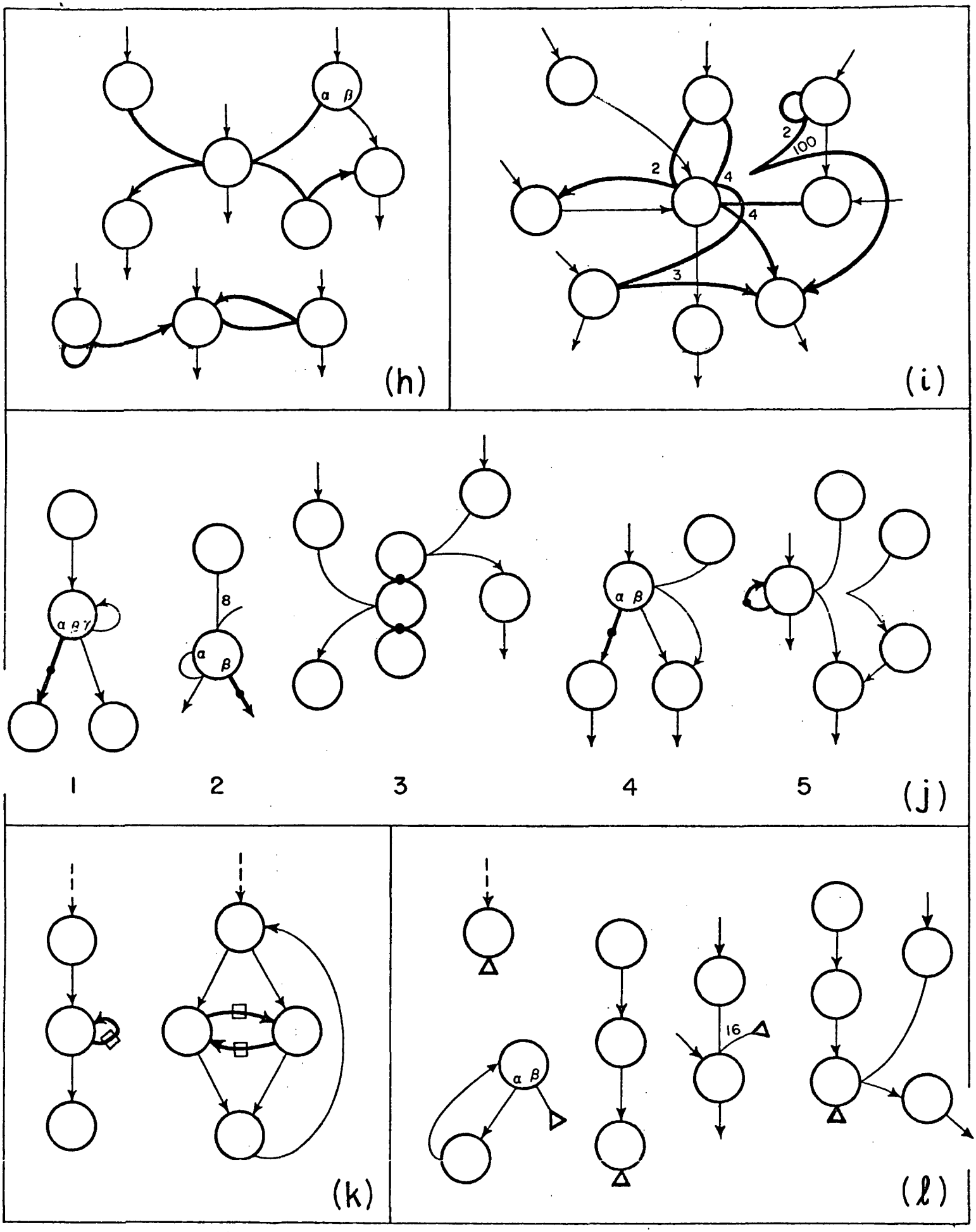

Fig. 6 - (cont.) Symbols for transitions

conditions on several options for a transition. In accordance, simple hardware features have been devised by which these possibilities can be prescribed as forms of the function T. Corresponding symbols for the state diagrams are in Fig. 6 (j) .

The feature of the priority allows the mechanization of a variety of rules. The following, that will be used often, refers to the stop-over transitions. When the states connected with priority transition are adjacent (in the state-label order), the next destination of a stopover transition will be reached at the end of the priority transitions, as in the example 3 of Fig. 6 (j). When the states connected with priority transition are not adjacent, the occurrence of that transition cancels every previous stopover prescription.(ex. 4 of Fig. 6 j).

Transitions f and g of Table 2 and transition h in the second example given in Fig. 6 (h) produce the same thing. But this redundancy is in fact a flexibility which eases the programing. In the case of transition g, the prescription of staying is made once and it holds for all the transits through that state. In the case of transitions f the stay can be different for different arrivals to that state. In the case of transition h, the stay can be different in accordance with events occurring in that state.

Note that two symbols of forced transition are used, Fig. 6 (e): a dashed arrow connecting two states, if the forced transition is supposed to occur when the machine is in that indicated state; a notched arrow, if the forced transition may occur when the machine is in any one of several different states.

2.5.4 - Abstract machine as a formal language

Formal language theory defines a language as a set of strings of symbols over a finite alphabet. Such a broad definition covers natural languages, programing languages, and certain mathematical systems studied in automata theory. The approach taken in formal languages also clarifies how a language makes it possible to express infinite information (the enumerable infinite set of strings) with finite means (the finite alphabet and grammar).

Our abstract machines as a language are multi-dimensional entities (as opposed to the linear strings of symbols), with a grammar left open (in a sense) to the imagination of the user. While it is expected that such a language, used as a programing language, can be brought under said definition of formal languages, there is not yet an available theoretical treatment. This fact does not limit the use of our language. In fact, we are using a very simple type of abstract machines, that is readily translatable in a normal string of symbols.

As an example, an actual program, referred to under task 6, is shown in Fig. 7 in its state diagram form. Five FSMs can be distinguished, all engaged concurrently on the same task. The constituent elements of such a program are: states, transitions, I, F. T, R's and data.

The program of Fig. 7 can be transformed into the string of symbols, (2), by very simple rules. The items constituting the FSMs are indicated sequentially, each state is delimited with square brackets, the states are ordered following their label number, the items of a state are

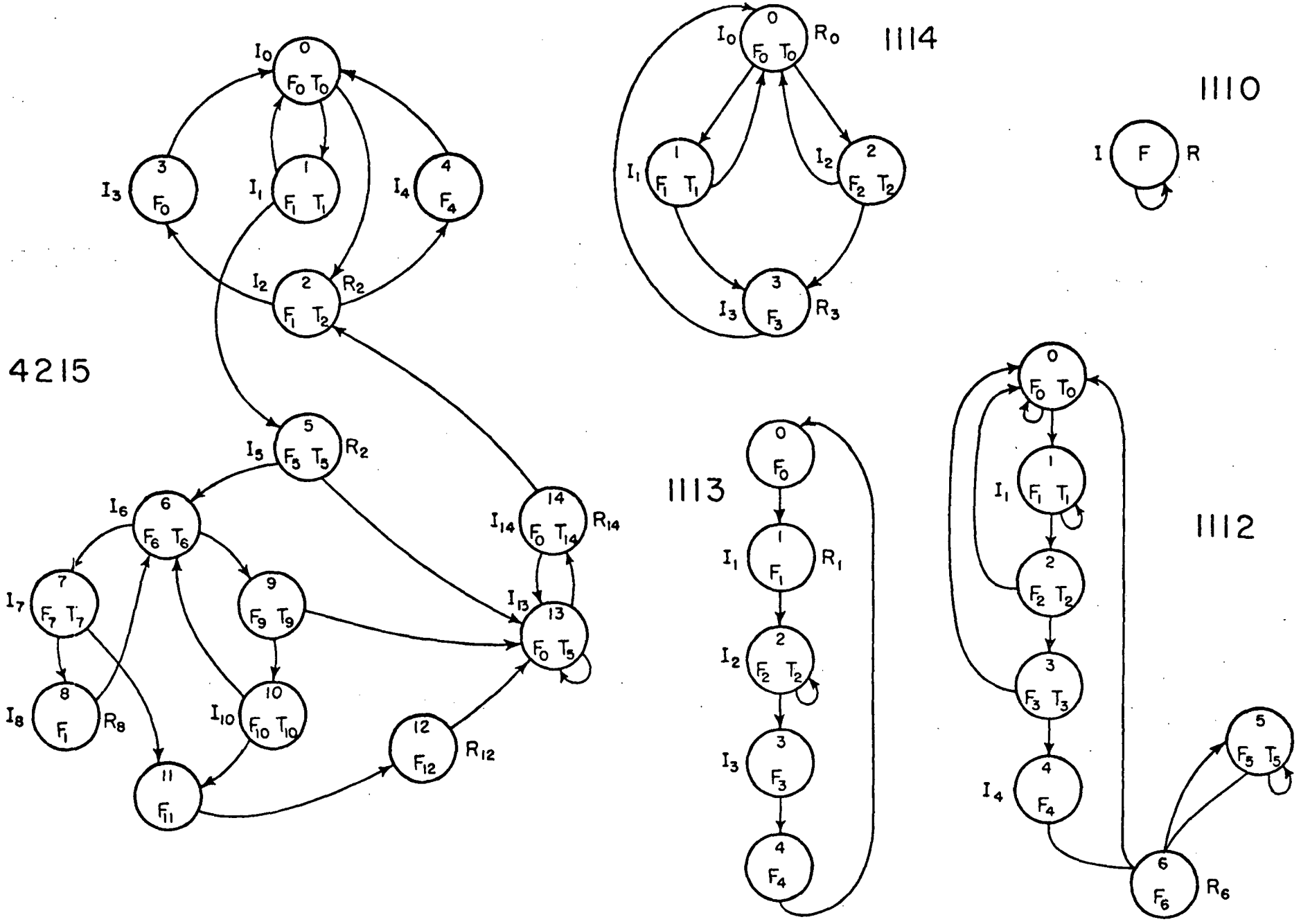

Fig. 7 - State diagram of a program

recognized by an established sequential order, and the symbol ; is used for missing items.

$$
\begin{aligned}
&\#4215[I_oF_oT_o(1,2)][I_1F_1T_1(0,5)][I_2F_1T_2(3,4)R_2][I_3F_o(0)][I_4F_4(0)]\\
&\quad[I_5F_5T_5(6,13)R_2][I_6F_6T_6(7,9)][I_7F_7T_7(8,11)][I_8F_1(6)R_8]\\
&\quad[;F_9T_9(10,13)][I_{10}F_{10}T_{10}(6,11)][;F_{11}][;F_{12};R_{12}][I_{13}F_oT_5(13,14)]\\
&\quad[I_{14}F_oT_{14}(2,13)]\#\qquad\qquad\qquad\qquad\#1110[IF(0)R]\#\\
&\#1112[;F_oT_o(0,1)][I_1F_1T_1(2,1)][;F_2T_2(0,3)][:F_3T_3(0,4)][I_4F_4(6/0)]\\
&\quad[;F_5T_5(6/5,5)][;F_6;R_6]\#\\
&\#1113[;F_o][I_1F_1;R_1][I_2F_2T_2(3,2)][I_3F_3][;F_4(0)]\#\\
&\#1114[I_oF_oT_o(1,2)R_o][I_1F_1T_1(3,0)][I_2F_2T_2(0,3)][I_3F_3(0)R_3]\#
\end{aligned}
\qquad (2)
$$

The unit that in spoken languages is the sentence, here is the state. The syntactic structure of a state description is simple enough to be understood by a nonspecialist. Each state is composed of the four elements I, F, T, and R, some of which can be missing; the order of the elements can be used for their recognition, in conjunction with the symbol ; for a missing element. Clearly the syntactic structure to be developed by a reader, or the parsing by a computer system are reduced to an elementery symplicity.

It should be clear that Fig. 7 is not a graphical representation of sentences in a language that (in turn) describes some procedure for implementing a process; rather it is the chosen model of the process, and the expression (2) is a string representation of that model. This inverted direction in the translation of the process description is a fundamental point.

For the same reason, Fig. 7 can not be assimilated in the conventional program flow charts. A flow chart is a summary (made a posteriori) of a command-language description of a procedure. The elements of this description are typically computer-oriented. Fig. 7 is the actual original model; its elements are typically problem-oriented. A flow chart is a graphical representation of point C in Fig. 1; Fig. 7 is a graphical representation of point A in Fig. 1.

2.5.5. FSMs as a programing language

2.5.5.1 General remarks

The use of abstract machines as a language for programing a computer is actually the subject of the entire work undertaken. In this section we attempt to clarify the relations between our language and the other known programing languages.

A real comparison between the language for programing a CPL system and languages for programing conventional computers is not possible, because the two types of computers are dissimilar. Conventional computers are factory-configurated and the task of the user programing-language is the management of the instruction sequences. The CPL system is configurated by the user and the task of the user programing-language is the implementation of these configurations. However, because in both cases the final goal is the same, that of obtaining a certain result by means of a man-made machine, a discussion on the relations and diversities of the two types of languages should have meaning.

Following a classification of Burkhardt (1965), programing languages for conventional computers range from

- machine codes

to - assembly languages

- procedural languages

- specification languages

and - declarative languages,

in accordance with the use made of interpretive or translating routines (compilers). Languages were also proposed that simply state the problems, without indicating the solution to be used (Cfr. Schlesinger, Sashkin, 1967). This extreme case could not be viewed simply as a programing language, but should be considered more as a system of solution finding. It is a characteristic of conventional programing that a process is described in several forms: in the user language, possibly in an intermediate language of the compiler, in an assembly language, and finally in the actual binary codes of the computer. In each one of these forms the process is completely described; each form is obtained from the previous one by translation.

In programing the CPL system, the solution is completely given by the user, in the form of an abstract machine that produces the desired process. The program consists precisely of describing that machine. We can say that the programing language is not procedural: neither is it descriptive of the process; it is descriptive of a machine that produces the process.

This description is made only once. There are not several forms, each translated from another, as in conventional programing. What is diversified, instead, is the degree of definition of this description. First, the user conceives the state diagram for his machine which is a model of the process . This diagram is composed in terms of the four

building blocks I, F, T, R. Then he, or somebody else, comes back to that machine and the building blocks are described in complete details. Finally each resulting piece of the program is written in the proper form and medium to be fed to the computer.

2.5.5.2. Aspects common with previous languages

APL

Among the programing languages that have been developed, APL (Iverson, 1962a) is one that suggests some similarity in structure and goals with the language here described. However, the similarity is more in the appearance because the two languages are in different frames.

First of all, more than a language for actually programing computers, APL is a system of concise and powerful notations applicable to a variety of descriptions and analyses. In particular, it can be used for describing a process for a computer if suitable compiler, or interpretive routines, are available (Falkoff, Iverson, 1967). APL per se does not provide data structuring, input and output, which are crucial points in computer use. The language described here, instead, is a method for actually programing a particular type of computer, the CPL system.

In APL, the emphasis is placed on conciseness in describing algorithms; this is inevitably paid for with a compulsory notation system that is difficult for the non-expert . Consideration to computers appears only in the structure as sequences of statements, clearly motivated by the hope that simple interpretive routines will be able to apply the languages to the different computers. Because these sequences often are very concise and use arrows for jumps, APL programs have some diagramatical

appearance, thus resembling structures of FSMs. However, there is complete absence of the notion of state, which is helpful both for visualizing the structure of a given process, and for gradually constructing a complex program. The viewpoint is fully that of sequence of statements.

The point is that APL reaches conciseness by means of elegant notations and not becoming involved in the execution. Iverson himself (1962a) says that the goal actually is to provide a language with such a descriptive and analytic power to repay the effort required for its mastery. He shows (Iverson,1964) the interesting analytical possibility of the language. In a sense, programing a computer is incidental. The language described here on the contrary reaches conciseness by prescribing an execution that is tailored to the model chosen by the user for visualizing the process. The notation to be used is not of primary relevance for the method, at least at the present state of development. We see that the scopes of the two languages are in different areas.

Iverson talks of common language for hardware, software, and applications (Iverson, 1962b). But what he means is that APL is very effective (concise) for describing and analyzing the working of a given piece of hardware, for describing and manipulating a given piece of software, and for expressing a given algorithm. All this is very valuable but is different from the goal expressed in Section 2.1 of the second Quarterly Report, that of merging the three points of Fig. 1. We are not interested in describing hardware, software, or algorithms per se and separately. In our approach, hardware, software and algorithms

are all aspects of the same structure. In this sense not only does a single language describe them, but it is actually a single description. For APL, there are three different descriptions for the three aspects. This different situation is a consequence of the fact that Iverson worked only on the language, accepting the computers as they are. Here also the computer is re-examined and changed together with the language.

Decision Tables

For more than ten years (Kavanagh, 1960) decision tables have been recognized to be a very effective programing method, easily understood by humans regardless of their background, and to be machine independent. One item of the FSM description, the function T, has in a sense the same philosophy of decision tables. Therefore similar advantages can be expected.

One difference is that conventional decision tables need to be compiled, in order to be understood by a computer. Here functions T are directly implemented by the loose hardware of the CPL system. Another difference is that common decision tables need some interface with the other general purpose programing languages. Here functions T are one of the constituents of the language, therefore they are well integrated in all kinds of programs.

Flowcharting

Flowcharting started with Goldstine and von Neumann (1947), "We therefore propose to begin the planning . . . by . . . the flow diagram . . .". The first computer programs were flow diagrams with an accompanying list of codes. Then computers developed, and today programers do not use flowcharts, except as a secondary, simplified documentation coming after the program has been written. Conversely,

in programing the CPL system, the first step (Section 2.5.6.1) is the production of a state diagram, which is the analogous of a flowchart.

The reason for all this is very simple. A graphical representation of the type of a flowchart is the most effective description of the behavior of a processing machine. At the early times programers were dealing directly with the actual actions of the computer, thus flowcharts were the most effective program representation. Then programers freed themselves from the actual working of computers and dealt with problems more and more in descriptive mathematical terms. In this situation, flowcharts are completely useless. Now, the FSM is a machine, and the programer deals directly with it, actually conceiving and constructing it; therefore a representation of the type of the flowchart becomes again the most effective program description. The difference is that in the early times of computers, the flowchart was describing the behavior of mechanical or electronic devices that exhibited no resemblance with the problem as seen by the user; here the state diagram describes the behavior of an abstract machine that is the concise model of the problem that the user is dealing with directly. Once this situation is achieved, it is not difficult to enrich the flowchart with a variety of features and notations to make it a very expressive, user-oriented representation of the problem.

The power of expression of a graphical representation is so obvious that program theorists often were intrigued with it, aside from its use for representing the actual work of the computer. It has been proposed to use flowcharts not only as a notation but even as a programing language (Burkhardt, 1965); however, it never has been adopted. Galler and Perlis (1970), in a general analysis of programing languages, raise the question,

"The clarity and precision we have achieved in representing algorithms by means of flowcharts leads one to ask what it is about flowcharts that makes them so much clearer than the verbal description". They recognize that it is not the two-dimensionality of the representation, because any flowchart can be easily transformed into a linear sequence, but they do not elaborate further.

In our interpretation, we recognize that the effectiveness of a graphical representation has a psychological basis. Starting in childhood we develop our model and our forecast of the behavior of the outside world in terms of an abstract mechanism that we construct in accordance with sensations, mainly visual. Therefore a graphical representation of an abstract mechanism is able to promote very rapidly, and without effort, a corresponding mechanism in our mind. A sequence of symbols, conveying the same information, needs first to be memorized in its entirety (and that implies an effort), then it is analyzed, and finally the mental mechanism starts to take shape. In the case of a program, we can say: when an algorithm is represented in a list form, what we perceive first as a unit is a single command, or declaration, and it requires a certain amount of work to reconstruct the entire mechanism from the many commands; when the algorithm is represented in graphical form, what we perceive first as a unit is the entire mechanism, and we then need little effort to focus on the single parts in order to make precise our knowledge of the algorithm.

2.5.5.2. A view of the language for the FSM description

From the programing language viewpoint, our FSM can be summarized as follows. Four primitive elements are identified:

1. Data transformation function F. This element is obviously always present if an activity on certain data has to be performed. Only at particular moments, F can be null because the process in those moments is in idle state, waiting for some events.

2. New-input-data prescription I. This element will be present at least in some initial part of the process, if manipulation of given data has to be accomplished. Even if the process consists only of the creation of data, certain initial conditions will always have to be given from the outside.

3. Output prescription R. This element also will aways be present, at least in some terminal part of the process, if an activity useful for the outside has to be produced.

4. Next state transition function T. Every time the process is not described as a single function F, transition functions are necessary. In fact, even in the case when the process is accomplished with one F description, the fact that the process should stop at that point can be viewed as a particular transition.

The FSM is a management of these four primitive elements. This management is described as a state diagram, where each state is a unit, a block, defined by a specific ensemble of the four elements F, I, R and T. In some states, some of the elements can be null.

It should be noted that only new input data need to be described, and not the current data (as in conventional languages), because the processing machine keeps in its structure all the data that has been inputed (by previous prescriptions Is) and not outputed (by previous prescriptions Rs, or substituted).

It should be noted also that common, quasi-steady information that in conventional programing is given in form of declarations, here is given in terms of code words that preconfigure the processing machine in such a way that the storage assumes the structure of the data and the operating network assumes a general structure corresponding to the activity to be performed.

The six types of data, y, k, I, F, T, and R (see Fig. 2), interact with each other during processing, but they are handled independently by the user, a fact that keeps the programing simple.

The language is not procedural for a given computer; it is not descriptive of the problem in terms of a given set of notations; but it is descriptive of a particular machine that executes the problem as its natural response. Because these particular machines are described in accordance with the abstract mechanisms we conceive in our mind, the language is claimed to be user oriented. Because these abstract mechanisms are those we choose for dealing with the problem at hand, the language is claimed to be problem oriented. It is a fact that the language is the machine language for a CPL system. This method of modeling processes may also have potential for programing conventional computers or for an intermediate language like the suggested UNCOL (Strong et al. 1958). Investigation of such potential is not undertaken here.

The work usually performed by the compiler is here done by the user; and the user knows a great deal about the data, the purposes, and the desired choices. Therefore many declarations that are needed in conventional programing, but constitute a somewhat artificial necessity of the language are not necessary here. One may think that in this way the

user might be overloaded by clerical activities, but this is not the case because the actual machine follows the image that the user has of the process.

It should not be overlooked that for humans what is difficult is what differs from the familiar, not what is complex in analytical terms. We can walk for hours through mountain paths without falling a single time; we can talk for hours with a close friend on sophisticated subjects, feeling the enjoyment rather than tiredness. Such activities are extremely complex from an analytical viewpoint. Conversely, a simple process such as the counting of objects moving on a line, a process that can be implemented with one photocell, a dozen flipflops and a simple circuit, is very tiring for humans and it is unlikely that one can do it for more than one minute without making a mistake.

We present the supposition that conventional programing languages often fall in the following trap. The user is deprived of the tasks that he is very capable of and willing to do; these tasks are automated with very sophisticated software devices; and then, in order to control those software devices, the user is loaded with activities which are inappropriate because of being too clerical and extraneous to his interest.

2.5.6 Programing the CPL system

As said in Section 2.1, programing the CPL system consists of developing an abstract machine M that produces the wanted process, and then writing a description m of that machine in a form acceptable by the CPL system to be used. Clearly we have two phases in the programing: (1) inventing a machine that can solve our problem, and (2) determining all the details as necessary for the actual CPL machine.

This division of the programing in two sequential efforts at different levels is one of the most interesting characteristics of the approach taken. In Section 2.5.1 it was noted that in conventional programing the user has no opportunity of starting a program until all the details are established. Therefore there is no flexibility for developing different strategies; and when a program is written, it has often a form so different from the original image of the process in the user's mind that discussion and changes are extremely difficult. Here instead, the structure of the program is developed first in a language suitable to the originator of the process; then the several parts of that structure are defined in details as needed by the computer, but still retaining the physiognomy given by the originator. At any time, the structure and the details can be examined and changed, having an easy overview of the entire process and an easy access to the several detailed parts.

To concretize these considerations, the three steps of programing the CPL 1 processor are described in the following.

1) The process we want to be executed is modelled in the form of abstract machines of the type described in Section 2.3. In this modeling, the user is considering only the characteristics of the process; there is no concern for machine limitations, because the abstract machines do not have physical limitations.

The end product of this step is a description of an abstract machine that performs the desired process. This description is in the form of a state diagram where each state is composed of the four items I, F, T, and R. This step is described in Section 2.5.6.1.

2) Operational configurations, possible for the real CPL system are designed in order to produce the functions F and T delineated in step 1. This phase of the programing corresponds to the mapping $F \rightarrow C$ referred to in Section 2.4. In this step, the abstract machine outlined in step 1 might be modified in order to meet the characteristics, the size, and the limitations of the actual CPL system available.

The abstract machine obtained at this point is the accepted model of our process and in the same time a realizable machine for our CPL system. This step is described in Section 2.5.6.2.

3) The completed description of the FSMs thus obtained has to be written in a medium readable by the machine, e.g. a punch card, with the proper codes. In this form the abstract machine is an actual program usable by the available CPL system. This is a clerical step, and is outlined in section 2.5.6.3.

2.5.6.1 Step 1: Modeling the process in the FSM form

In section 2.5.3 the innate inclination for thinking in terms of imaginary (abstract) mechanisms was discussed. In this step of programing, we have to use this innate facility in order to model our process in the form of an abstract machine with rigorous connotations, namely in the form of the FSM represented in Fig. 2, or of a system of these FSMs circulating in the structure represented in Fig.3 . The entire process should be framed in the general expressions (1) of section 2.3. Depending on the transitions between states (well discernable in the state diagram), expressions (1) act either as a set of independent functions, or as recursive functions, or any mixture of the two.

The process is thought out in its inherent phases, parts, or steps, and correspondingly a set of "states" will be delineated. A state is a part of the process for which is worth to define a quadruplet [IFTR]. When more than one FSM is involved in the process, each FSM will be conceived independently in the form of the automaton of Fig.2 , and then related through the storage P of Fig. 3.

A complex process can be modeled in several ways:

(i) through complexity of the functions F (which corresponds to a spatial configuration as decribed in step 2),

(ii) through the complexity of the sequential behavior of an FSM (see state diagram),

(iii) through an array of pages that interact through the auxiliary storage P of Fig. 3,

(iv) through complexity both of the page array and of the sequential behavior of each page,

(v) by means of the interaction with specialized devices or auxiliary storages in the environment.

The ingenuity of a program, its effectiveness and efficiency, are established here by the way the problem is modeled. In conventional computers,strategies may be used to exploit to the full, the structure of a particular computer or of a particular compiler language. In this case the user is forced to investigate these structures; but usually they are not of direct interest to him. In programing the CPL system, strategy has to be used in describing the problem, that is to say on the structure of the problem itself. In this case we may expect the user will be interested in expending effort in this direction.

Furthermore, later on he will not feel himself to be a slave of the computer, because, in preparing the model of his process, he designed the computer he is going to use.

The best use of the FSM modeling is made when the dynamic aspects of the process are mechanized in the dynamic behavior of the FSM. A poor use of the FSM modeling occurs when it is approached simply as a sequence of commands.

In this stage the structure of a program is established, and there is room here for the imaginative delineation of the program. Later, in step 2, skill can be applied to devising single configurations, but that will affect only the efficiency of single portions of the program. The remaining step is a simple mechanical manipulation.

2.5.6.2 Step 2: Design of the configurations

Specialized operating configurations have to be designed for the operating unit of the CPL system available in order for it to perform the functions F and T delineated in step 1 for each state.

In this step, both the requirements of the problem and the characteristics of the available machine should be considered. If some function conceived during step 1 cannot be implemented directly, other alternatives should be examined. A general expedient is to break down a state into several states, each containing simpler functions.

The programable networks

It was shown that there is a theoretical and practical basis by which for any numerical, or logical, function that we can rigorously describe on certain variables, it is possible to design a network of logical elements that performs that function with some coding of those variables.

In our application, this possibility alone is not sufficient; we need also a general procedure by which a non-professional person can easily produce these networks from functions expressed in whatsoever form. The basis for this possibility was previously discussed, and lies in the facility that human beings have for thinking of functions as abstract machines. In step 1 we were modeling an entire process in the form of an abstract machine, here we are modeling a function in the form of an abstract network. The level of complexity is different, but many points are similar.

For modeling a process, the suggested structure to think of was the automaton of Fig. 2 ; this automaton is a kind of loose sequential

machine. For modeling a function, the suggested structure is an abstract (symbolic) loose combinational network. The term combinational refers to the level at which the user looks at the functions: the actual electronic machine might execute those functions with some sequence of steps, but this is irrelevant, thus it will be ignored by the user. For some complex functions, the user may find it difficult to represent the function in the form of a combinational network; while he would be able to represent it easily in a sequence of few steps. In accordance to this fact, the functions F can be represented as a set of different networks that succeed in a given order on the same data. The processor CPL 1 has the capability to sequence up to three different configurations in order to implement the function F in each state.

For different types of functions, a different basic structure of the network is given to the user: on the basic structure, the user has to describe the operational character of the elements, the connections between elements, and all the necessary details in order to obtain the desired specific function. As an example, in Fig. 8, the basic structure for the arithmetic functions is reported. The boxes labeled A, B. C and D represent the internal variables y_i in the black box of the automaton of Fig.2 , the boxes a , b , c , d the new input variables x_i , and A', B', C', D' the variables y_i in the auxiliary page array (Ω_s in Fig. 4). Twenty-seven connections are possible between the boxes. Several operational characters can be attributed to the connections, such as transfer, sum, subtract, multiply, $\log^{-1}$, complement, shift, etc. The user has to devise a combination of connections and operational characters such that one or more networks will perform the desired data

transformation indicated as function F in that state.

Note that there is no concern for addresses or moving data from the memory. For the user, the data are always present as variables y and x in the operating unit. He has only to prepare operating networks; these networks will automatically be superimposed on the data, in succession as if transparent sheets such as Fig. 8 were succeeding on a basic data sheet. The user can then change or move the data, between cycles of the operating unit, by proper "new input prescription" I, and "routing" R.

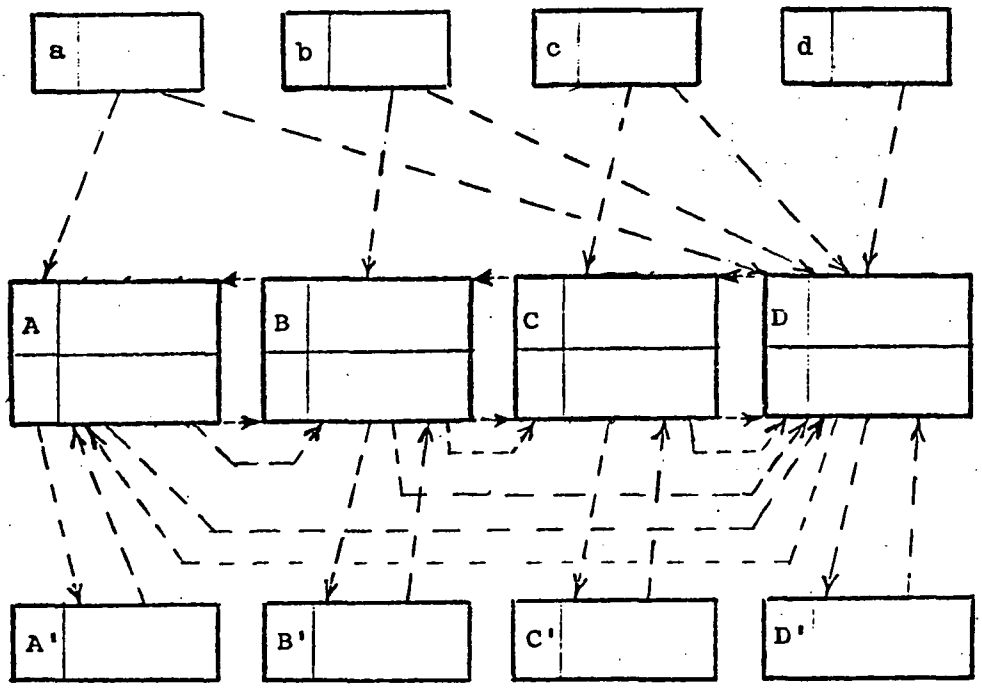

Fig. 8 - The basic structure for arithmetic operations

The language for describing the network

After having designed an operational network, we have to describe it in some recordable and unambiguous form. We need a language that is easy for the user and understood by the CPL system. Moreover, for several practical reasons, it is desirable that this description be concise.

In information theory it is well known that the information conveyed by a string of symbols over an alphabet is highly dependent on the coding used by the source. In accordance, we might seek for an optimum coding. But here it is not the case of a communication system that is designed only once by specialized engineers. Here the encoding is the language used by non-specialized people for describing the operational networks that they conceive. Therefore the primary requirement is that the encoding be simple for non-specialized users.

To solve this problem a type of coding has been adopted that is familiar to all of us because it is used in the spoken languages. All spoken languages use some kind of coding in assembling alphabetic symbols to form words. That coding is the part of the grammar that governs the word inflection. Some spoken languages have little coding and the words can be regarded simply as different combinations of the alphabetic symbols, only constrained by an acceptable pronounciation. The meaning of such words, usually short, can be learned only by memorization. Other languages have sophisticated coding and the meaning of the words, sometimes amazingly long, can be reconstructed from the

meaning of each group of symbols, following certain rules. Two examples are given in Fig. 9. A single German noun of 28 letters (Fig. 9a) means a place where certificate of paid fee (ticket) for passenger in flight are given. In Fig. 9b an Italian verb of 12 letters means that you (several people) would read again if a certain condition occurs. With such a procedure, an extremely large number of words, with very specialized meaning, can be constructed without the necessity of memorizing (or writing in a dictionary) all of them. The exact meaning of each word can be reconstructed from the meaning of the building blocks and the structure of the word.

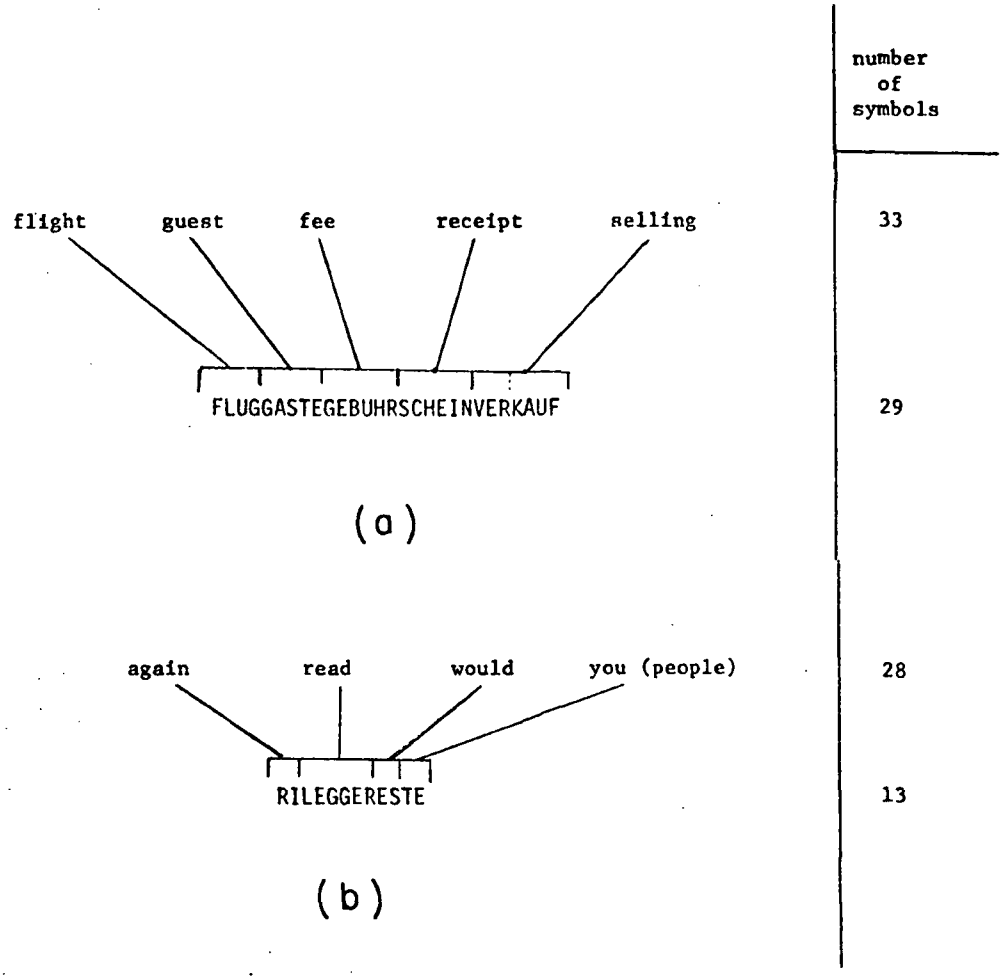

Fig. 9 - Examples of aglutinated words

Similar approaches are used here. Taking advantage of the fact that all the information related to an operational configuration should be simultaneously present in the operating unit, we ensemble all the characterization of a configuration in one unit corresponding to an highly inflected word of spoken languages. This means that the encoding of the user language is chosen as encoding function for the control of the programable network.

One could suspect that in so doing, the coding will be not optimum for the network. Or if we optimize the coding for the network, it will be not the most appropriate for the user language. In the design of the CPL 1 processor, the same coding turned out to be equally appropriate for the digital design of the programable network and for the language to be used by non-professional people. In a sense this is an experimental confirmation of the thesis discussed in section 2.2.

One of the main requirements for a spoken language is the capability to express an infinite variety of things without requiring people to learn a corresponding infinite number of independent utterances. This is the reason for the natural development of agglutination of different roots and of sintactic structures. Conversely, the shortness of the utterances is not a strong requirement in spoken languages, on the contrary a large amount of redundancy is required to overcome the distortions of the speaker, listener, and environment. Observing Fig. 9, we see a not large variation of the total number of symbols (the total number of symbols, plus one space per word, is indicated at the right-hand side of figure 9). In a language for computers, typically, we do not need redundancy, given the quiet environment and the reliability of the system. In this case also a large reduction in the number of symbols can be obtained.

In the processor CPL 1, twelve bit words, subdivided in parts, are used for describing the configurations. A typical organization of the word, one related to configurations of the type indicated in Fig. 8, is shown in Fig. 10. The root is related to the operation performed, the specifier describes the connections, the suffix indicates which variables are involved, and the prefix is related to some details peculiar for each type of configuration. All the possible choices for each part of the word are given by 8-16 entry tables, that are easily accessible in the dictionary of the processor, or can even be memorized. It has been attempted to give some memoric pattern to the assignment of the code, and in fact when a user becomes familiar to the use of this language, he seldom needs to look into the dictionary.

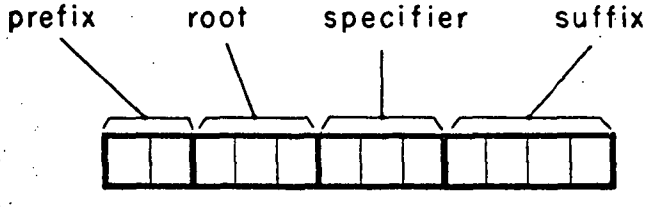

Fig. 10 - A word format of the CPL processor

In spoken languages certain words do not have inflections, but are simply a coded reference to an object or action: similarly, in this processor, certain specialized configurations that recur frequently are not constructed in the way previously described, but are simply called for by a coded number. Using this method, in a particular application of the processor, very specific configurations can be prepared in the operating unit, and in the program they are described by an F treated as a number.

2.5.6.3 Step 3 : Paging the program

The abstract machine described in detail in step 2 can be implemented by the CPL system available; in other words, it is a program for it. The elements of this program are I, F, T, R's, state labels, and code words. We can add a name (a number) to the program. The form in which the program was materialized, during its preparation, is irrelevant; presumably it will be in the form of a state diagram, or as state descriptions spread in note sheets.

Now it is necessary to write the program in a medium that can be read by the CPL system, and all the items should be located following certain rules known by the system. This organization we call pagination as mentioned in section 2.4.

In the CPL 1 processor, the medium is punch cards: the pagination is given by fixed fields in the card. Fig. 11 shows the fields for the items constituting an FSM. Usually a same configuration appears several times in an FSM, therefore it has been found convenient to write them not in the state descriptions but rather in a field labelled "common storage". Each state calls for the configurations by means of the number of the columns where they are written.

A punch card is a binary device, therefore all the information written in the card will be in the form of binary numbers or coded words of binary symbols.

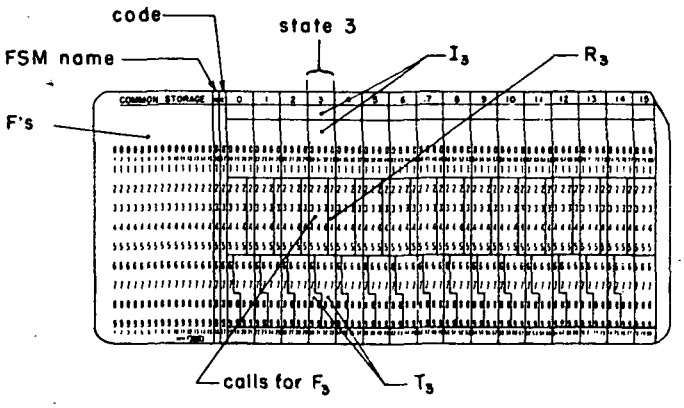

Fig. 11 - Program card for the CPL 1 processor

In conventional computers a card is typically related to a statement, here a card is typically related to an FSM, i.e. an entire process, or part of it. This high conciseness of the programs results from several causes:

1. Modeling the problem in the form of an FSM leads to a very concise description of the problem.
2. Describing the functions of the problem in the form of operating networks, and using coded words for describing the networks,leads to a very concise description of complex functions.
3. The absence of computer overhead eliminates all the numerous computer-related statements necessary in conventional programing.
4. The syntax (organization of fields, in the CPL 1 programs) used for describing an entire program allows much greater exploitation of the information capability of strings of symbols (binary numbers in the case of punch cards).

2.5.7 An example

As an example of programing with the language of Finite State Machines, a real-time processing for weather radars is described. This processing (Schaffner, 1972b) aims to measure wind distribution in the atmosphere from the movement of weather scatters.

Essentially, profiles of the echo intensity along a given line s are measured at two times differing of Δt, Fig. 12: then the two profiles are cross-correlated and the Δs for which the correlation is maximum is determined. The ratio $\Delta s/\Delta t$ is assumed as an estimate of the mean wind velocity in that interval Δt. As there is interest in ascertaining turbulence also , the echo intensity is determined for adjacent small cells forming a cartesian tri-dimensional volume, and cross-correlations are performed along three ortogorial axis, for all adjacent lines of cells. The radar scans space in polar coordinates, therefore a coordinate conversion is necessary in order to attribute the arriving echoes to the proper cartesian cells.

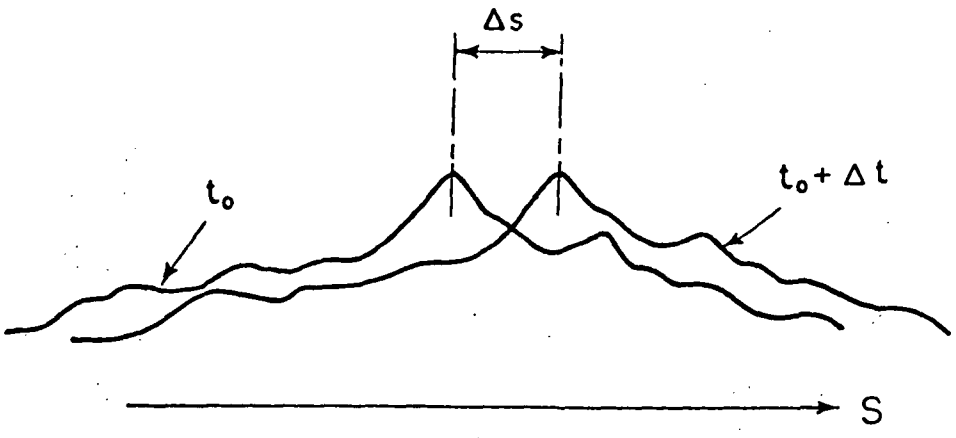

Fig. 12 - Echo profiles to be crosscorrelated

Undoubtedly such a process would present a very large overhead for a conventional computer. But if a specific abstract machine is invented for mechanizing the desired activity, execution of the process will be straighforward. The following is a first solution for such a machine.

Clearly this is the case of a system (Section 2.3.6 of the second Quarterly Report), composed of several FSM's (some implemented by several pages) all concurrently working toward the final task. In order to visualize the system, each page is represented as an elementary box in Fig. 13 and the flow of information among them indicated by arrows. The system is represented in a three-dimensional space in agreement with the fact that each page is related to a region of space explored by the radar beam. The coordinates chosen are: a slanted range of the radar, r, its horizontal transversal, t, and its vertical height, h.

An FSM is necessary for producing coordinated starting, stopping, and transferring in the other FSM's: this FSM is implemented by a single page, which we call control page CO. This page is located at the beginning of the circulation, in order to transmit orders directly to the following pages.

Another FSM provides to the integration of all the echoes originating inside each of the space cells presently illuminated by the radar. The results of these integrations are then sent into the corresponding storage cells. An independent integration should be performed for as many space cells as are crossed by the antenna beam in the predelimited volume, therefore several pages, called integrating pages IN, will implement this FSM. These pages circulate in appropriate synchronism with the radar in order to receive directly the proper echoes.

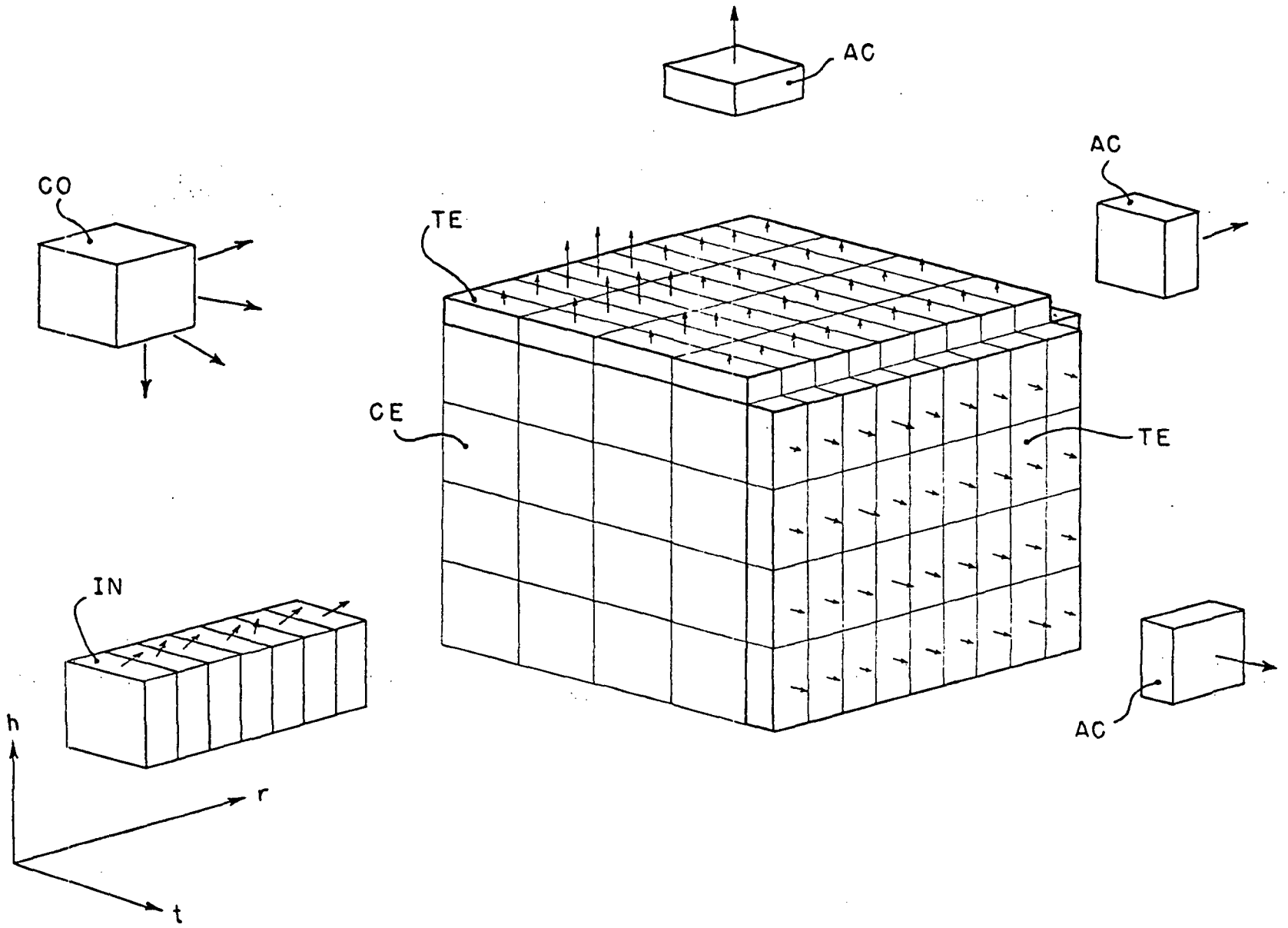

Fig. 13 - Symbolic representation of the several pages

Another FSM provides the storage and data manipulation related to the storage cells. A tri-dimensional array of cells is prescribed, therefore a corresponding array of pages, called cell pages CE, are performing this FSM. These pages sometimes will be at rest, simply capable of receiving data from the IN pages; other times they will be scanned in each of the r, t, h directions.

Then another FSM is used to collect and manipulate the results from the cross-correlation in each column and row of the CE page array. This FSM will be implemented by pages, called terminal pages TE, in rt, hr, and ht planes.

Finally, an FSM will provide the accumulation of the output of each group of terminal pages. This FSM will be implemented by three pages AC, one for the terminal pages of the rt plane, one for those of the hr plane, and one for those of the ht plane.

So far the strategy of an ensemble of abstract machines has been loosely outlined. Now a precise description of these machines has to be made, following figures 2 and 4. We think of these machines as abstract entities, formed of states and transitions. We visualize these machines in the form of state diagrams, representing states by circles and transitions by arrows as indicated in Section 2.5.3.2. A notation system for describing functions F and T has not yet developed in an organized form, therefore a mixture of commonly used notations will be used as needed. Each state (circle) will have up to four fields for the description of the four primary elements I, F, T, and R. In the following description of the FSMs, because they are made a posteriori after having known the solution, there is no sharp distinction between

step 1 and 2 of the programing: in other words, the FSMs are devised having already in mind a machine of the type of the CPL 1 processor.

FSM IN. This machine starts in state 0, Fig. 14, where the present coordinates rth, the present video sample, and a 1 are acquired as three variables y (Fig. 3) labeled A, C and D (Fig. 8). The coordinates rth are the cartesian coordinates (expressed as one word) of the point presently illuminated by the radar,with a resolution that determines the size of the cells to be considered. Then the FSM transfers to state 1 without movement (transition s in Table 2). In state 1, further samples are accumulated in D and units in C. After each accumulation, the present coordinates are compared with those stored in A: as soon as these coordinates differ, the FSM transfers to state 2. In state 2, the sample accumulation is divided by the number of accumulations, range-normalized, and routed to the cell CE that has coordinates rth equal to those in A. Then the FSM acquires new coordinates in state 0 and continues as described. With the implementation given in Fig. 14 only one page IN is necessary for averaging the video samples and transferring data to the CE pages; the sequence of IN pages of Fig. 13 refers to a different implementation of this FSM.

FSM CE. In state 0 of this machine, Fig. 15, the pages are resting in the memory and are capable only of data acquisition as indicated. At the end of the first and second radar scans, the pages go to state 1 by a forced transition (e in Table 2) produced by FSM CO. In state 1 the received data are normalized and transferred to a different y.

For the execution of the cross-correlations, each row and column of pages CE is circulated separately, under the control of FSM CO and transferred to state 2 by a forced transition. One of the echo profiles is transferred into C (state 2) and shifted by means of interchange between adjacent pages (state 3). In state 4 the summation of products is produced in Ω_s (Fig. 4). State 5 reverses the direction of relative movement of the echo profiles, which is produced for k cell steps either side. State 6 restores the original allocation of the two profiles.

FSM TE. Pages TE are at the end of the rows and columns of pages CE, therefore, when in state 2 (Fig. 16) they acquire the content of D in Ω_s and compare it with the content of A ; simultaneously, B is increased by one . Every time D is larger than A, D, and B substitute A and C respectively (state 3). In this way the Δs for the maximum of the cross-correlation (Fig. 12) is acquired. Pages TE go to state 2 (and connected states) 2k times in synchronism with the production of sums of products on the part of pages CE. Then the pages go to state 4, where the mean velocity is determined, accumulated into the storage Ω_s, and routed to the output. Because the several cross-correlations are produced serially, only one page TE would suffice, but here an entire surface of pages is maintained in circulation for possible further processing on the elementary wind components. Also a more precise determination of Δs is to be developed with an interpolation algorithm.

FSM AC. This machine consists of only one state, Fig. 17, where the accumulation from the TE pages is acquired and routed to the output.

FSM CO. The main tasks of this machine are the control of the previous FSMs and the production of a magnetic tape record containing the output data. In state 0, Fig. 18, the data acquisition is started by means of a forced transition to state 0 for pages IN. In state 1 the FSM waits for the completion of the radar scanning. In state 2 the cell pages are forced to state 1;and A, used as an index, provides for the acquisition during two scans. State 3 provides for the starting of the cross-correlation of a particular column or row of the CE pages by means of the variable coordinates α,β. In state 4 one of the coordinates is increased by 1, and the cross-correlation starts for another column or row. After m of these, in state 5 the other coordinate is increased by 1, and the series of cross-correlation is restarted. After mxm cross-correlations, a page AC is activated (state 6) and the coordinates for selections of pages CE and TE are rotated, in order to change the direction of the cross-correlations. Finally, in state 7, a record is produced and all the pages ended.

The entire system is composed of 25 states. If cards of the type of Fig. 11 are used, the entire program can be described in three cards, including a supervisor program for allocating in space the volume considered and prescribing the schedule of operation.

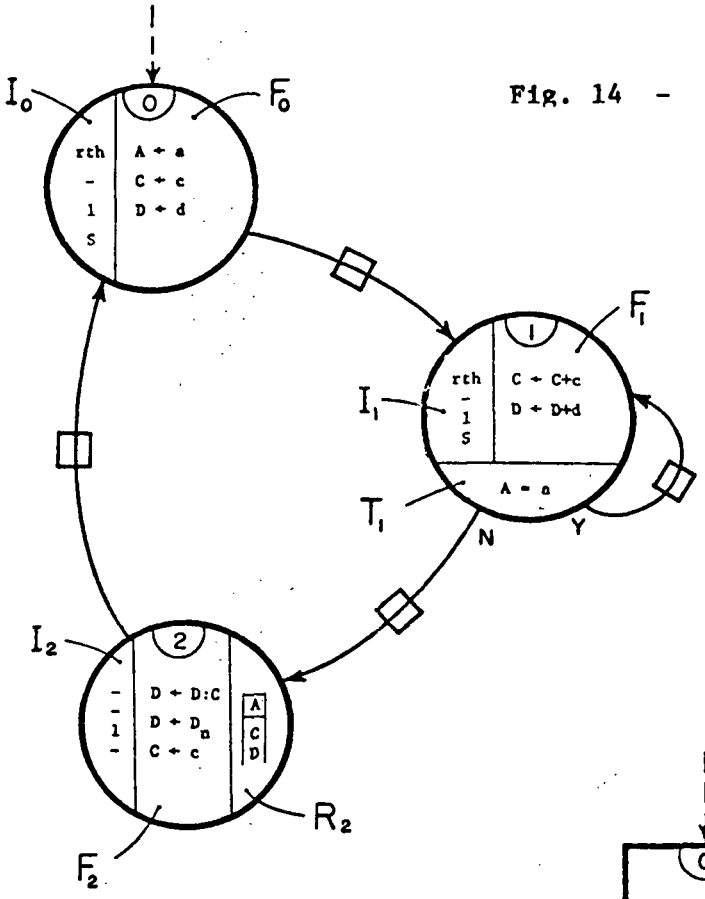

Fig. 14 - State diagram of the FSM IN

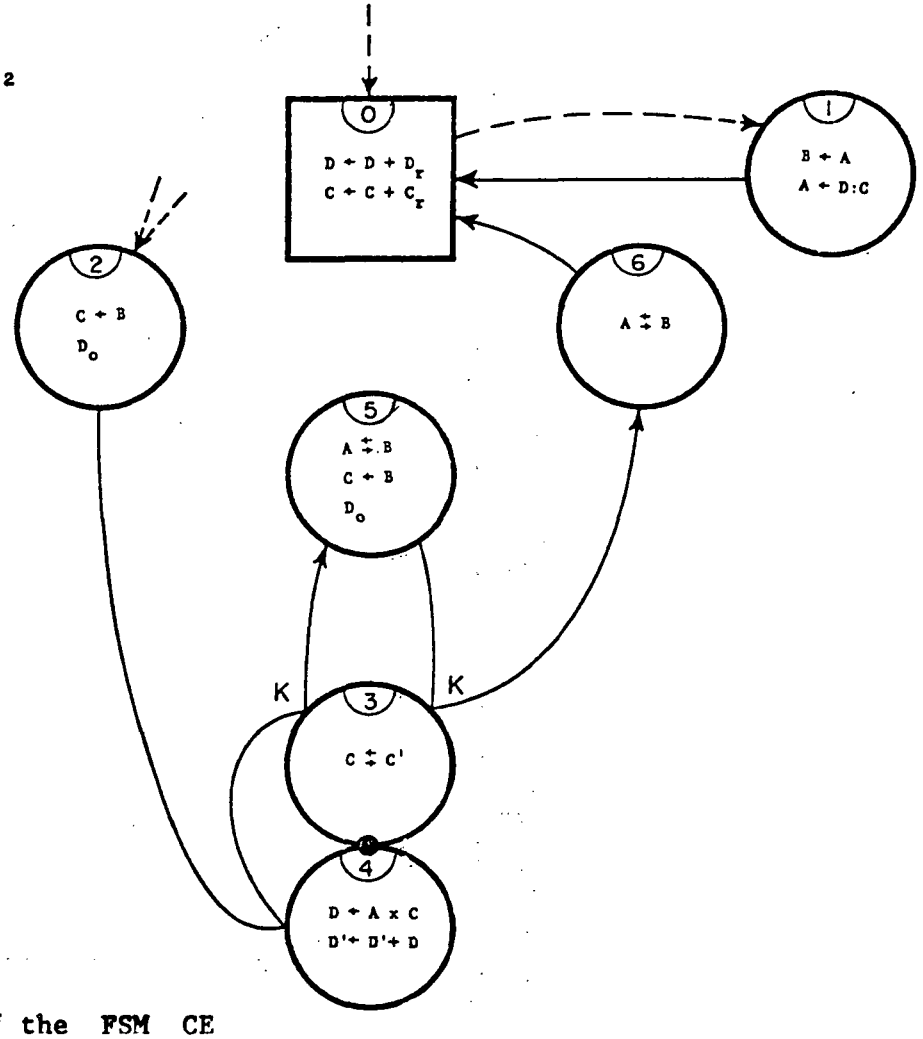

Fig. 15 - State diagram of the FSM CE

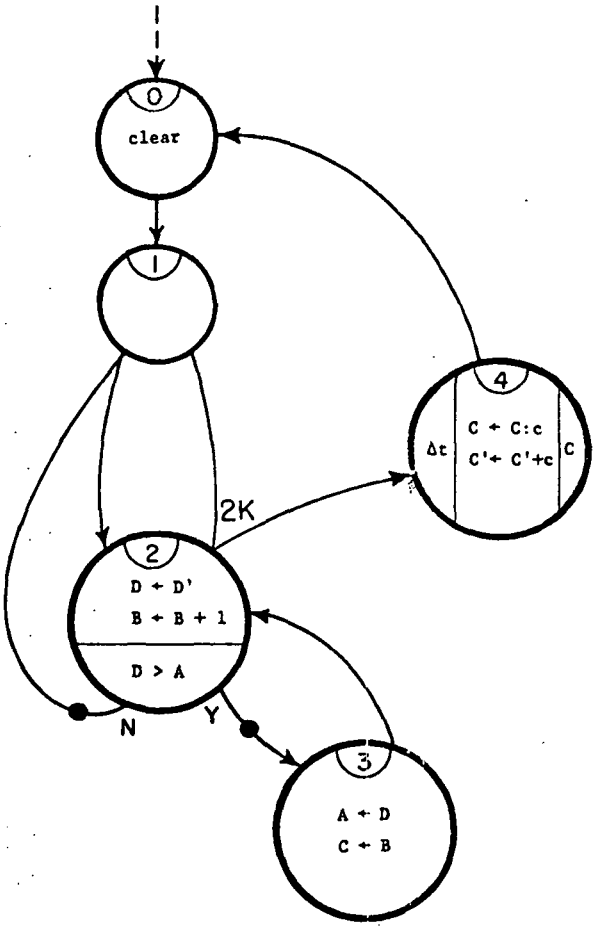

Fig. 16 - State diagram of the FSM TE

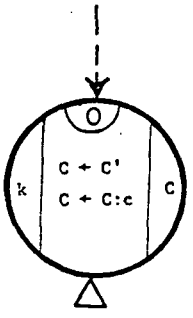

Fig. 17 - State diagram of the FSM AC

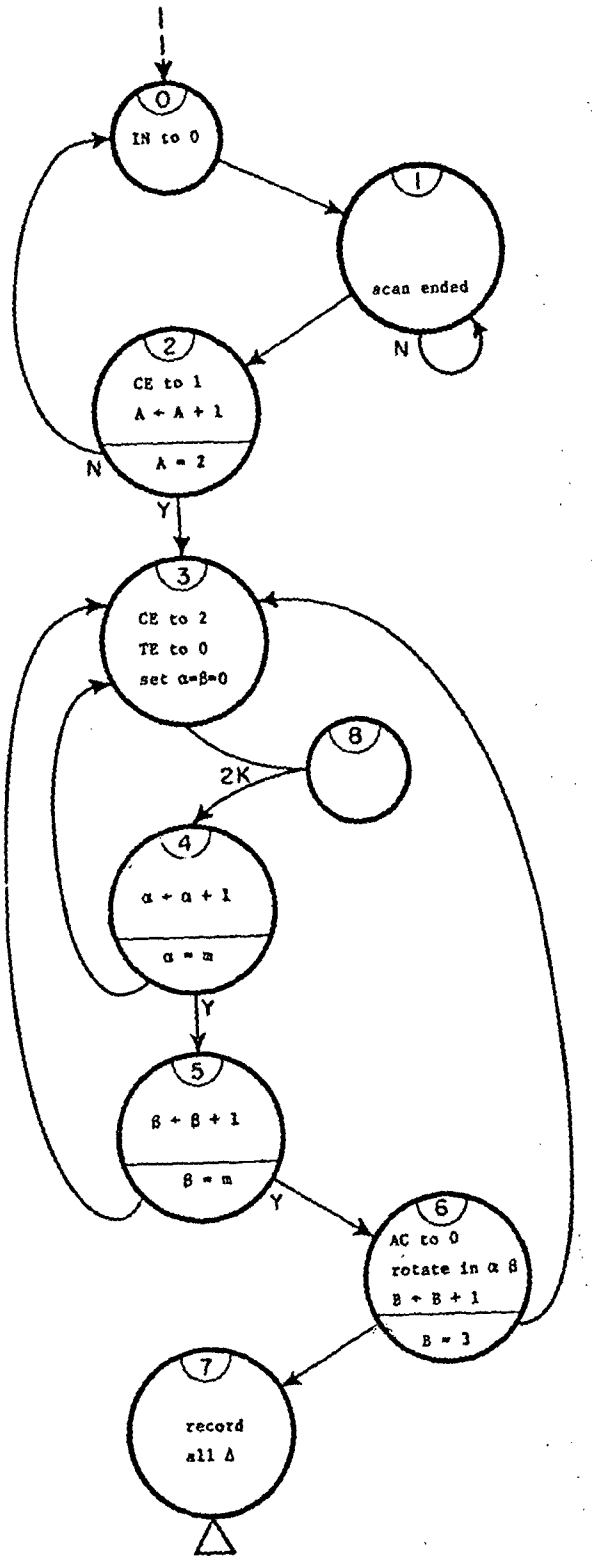

Fig. 18 - State diagram of the FSM CO

3. PLAN FOR THE NEXT QUARTERLY PERIOD

Following the plan outlined in Section 3 of the second Quarterly Report, the following three remaining tasks will be carried out in the fourth quarterly period.

1. Specifications for a computer architecture capable of executing processes directly in the form of FSMs in which they are modeled by the user. An outline of such an architecture has been given in Section 2.4 of the present report. A discussion, and a more detailed description will be given in accordance with the abstract models described in Section 2.3, and the programing language discussed in Section 2.5.

2. Comparative evaluation of programs. In the early age of computers, when people were looking at this new creature with fresh minds, von Neumann conjectured that for complex processes the description of an automaton that performs the process could be simpler than a symbolic description of the process itself. He was envisioning a mathematical theory of automata that could clarify this issue also. The work remained uncompleted, and the issue did not receive any further attention.

The results obtained with the restructurable processor analyzed in the present work revives the interest in the von Neumann conjecture. In the absence of mathematical means for evaluating the relative convenience of the two approaches for describing a process, we can analyze actual programs written in accordance with the two different approaches.

A set of test programs of different nature, written for a CPL system, have been selected. Programs for the same processes, but

written in conventional programing languages, are under preparation. The comparative analysis of these two sets of programs should provide information on the relative practical advantages and disadvantage of the two approaches.

3. Compilation of the Final Report. The entire analysis of the system, which has been gradually exposed in the Quarterly Reports, will be compiled and edited in a consistent form, including the results of the last quarterly period.

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