RADC-TDR-64-402
Final Report

THE EVALUATION OF TECHNIQUES AND DEVICES AS APPLIED TO PROBLEM SOLVING

TECHNICAL REPORT NO RADC-TDR-64-402
February 1965

Information Processing Branch
Rome Air Development Center
Research and Technology Division
Air Force Systems Command
Griffiss Air Force Base, New York

Best Available Copy

THE EVALUATION OF TECHNIQUES AND DEVICES AS APPLIED TO PROBLEM SOLVING

AIR FORCE, GOODWAY PRINTING CO., PHILADELPHIA, PA., 3/31/55, 115

FOREWORD

This final report was prepared for Rome Air Development Center under Contract No. AF30(602)-3065 by Morris Rubinoff, George Rowland, Donald F. Blumberg, R. Clelland, R. Faust, D. Hart, David Loev, and J. F. White, Jr. of The Moore School of Electrical Engineering, University of Pennsylvania, Philadelphia 4, Pennsylvania.

The project engineer was Duane Stone, EMIIH. The project number is 4594 and the task number is 459404.

This technical report has been reviewed and is approved.

Approved: DUANE STONE
Project Engineer

Approved: ROBERT J. QUINN, JR.
Colonel, USAF
Chief, Intel and Info Processing Division

FOR THE COMMANDER: IRVING J. GABELMAN
Chief, Advanced Studies Group

ABSTRACT

The problem of forcasting technological change is investigated. Machines and computer programs having "problem solving" capabilities are examined to determine their usefulness in aiding or replacing the human forecaster. The literature on human problem solving was also reviewed. The following conclusions were reached:

1. The nature of the forecasting problem precludes the use of computer-type problem solvers developed to date.

2. The application of information science techniques, namely; descriptors representing technological concepts, the forces acting to change the technology and the laws governing the change, appear to offer the most promise in assisting the human forecaster.

Accordingly, a quasimathematical model was developed using matrix notation to describe a technology. An example of a forecast of computer technology made several years ago is included.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont)

LIST OF ILLUSTRATIONS

THE EVALUATION OF TECHNIQUES AND DEVICES AS APPLIED TO PROBLEM SOLVING

1. SUMMARY OF THE STUDY AND RECOMMENDATIONS

This is the final report of a study project on the prediction of technological breakthroughs. The Purchase Request PR No. 63-317, Rome Air Development Center, referred to the study under the heading used above as the title of this report but requested "engineering services to perform an evaluation of monitoring scientific information to predict technological breakthroughs in advance. The first objective of this effort shall be to define the problem solving task — of predicting technological breakthroughs in specific and measurable terms ... The second objective is to conduct an investigation of those schemes ... which appear promising as replacements for the human problem solving activity ... Finally, the investigator shall describe the research program required to develop and evaluate those techniques ...."

The proposal submitted by The Moore School of Electrical Engineering, University of Pennsylvania, provided for engineering services for one year on the evaluation of techniques and devices as applied to problem solving. The study was to be pursued in the following four overlapping phases:

(1) a comprehensive literature review of psychological research into problem solving, decision making, invention and insight, and computer research into heuristic programming, artificial intelligence, and self-organising systems,

(2) the description, definition and identification of the qualitative features of creative thinking and problem solving,

(3) a critical review and evaluation of the potentials of electromechanical substitutes for human problem solving, and

(4) the preparation of a detailed program of research aimed at implementing the better potential substitutes evaluated in phase three.

Results of the first three phases form the body of sections 2, 3, and 4. The fourth phase was omitted at the written request of the sponsor to permit a greater expenditure of time and effort on the first objective of the PR. Other changes in direction were requested by the sponsor during the course of the study, leading to examination of additional topics. Results of the added studies are reported in sections 5 through 8.

Work began with a delineation of the following three areas of study:

(1) the characterization of the creative abilities of individuals and groups of people and of their motivations to attain the goals of society, of its science, and of its technology,

(2) the application of computers to problem solving, as well as to self-organizing techniques and the study of learning abilities,

(3) mathematical techniques of prediction theory, including statistical measures.

Major emphasis during the first half of the project was placed upon the most relevant aspect of the second study area, namely, mechanized problem solving procedures as an element of technological forecasting. The state of the art was reviewed and structured and a number of conclusions were drawn. Results of this work are discussed in section 2.

At the same time, a search and critique of the literature on (1) human problem solving and (2) creativity was initiated. These studies continued through the course of the project and their results are described in chapters 3 and 4.

A change in direction during the second quarter called for assessing and, where possible, describing the techniques used by human analysts in performing the prediction function, with a view to mechanization. The sponsor suggested that greater emphasis be placed upon the human forecasting aspects of the study while reducing emphasis on mechanical considerations.

In particular, research was initiated on descriptive task analysis of human creativity and human problem solving. This was recognized as a formidable task; however, a model was conjectured as a basis for the study. The model is described in section 5. It appeared that gaming would be useful to obtain experimental data for firming up the model. The use of gaming is discussed in section 8; it appears to have value beyond the determination of human forecasting procedures, and particularly in developing formal mechanizable forecasting techniques of the type now to be described.

From the study of machine-oriented problem solving, it became clear that certain elements of forecasting were omitted from machine-oriented problem solvers described to date; the latter dealt with problems having (a) a single specified goal to be reached from (b) known initial conditions in accordance with (c) explicitly prescribed rules. On the other hand, effective technological forecasting is characterized by:

(1) unspecified and subjectively indeterminate goals,

(2) multiplicity of potential goals,

(3) incomplete knowledge of the initial state of technology,

(4) incomplete knowledge of the forces being applied to the present state of technology, and

(5) incomplete knowledge of the laws of change, i.e. the effects of the various applied forces on the state of technology.

It soon became clear that the incomplete knowledge of initial state of technology, forces and laws of change was partly due to the lack of precise delineation of these factors. Formulation of precise delineations appears to require the application of techniques from information science, especially the use of descriptors representing technological concepts and relevant attributes of motivating forces. The laws of change can then be applied by linking and associating the technology and force descriptors through synonymic, generic, conceptual, interdisciplinary, and other relationships.

As mentioned, the descriptive techniques need to be applied not only to the state of technology but also to the motivating forces such as the activities of scientists, political leaders, and other key individuals; the goals of research and development organizations; the occurrence of meetings among key individuals and the significance of meeting places; scientific, economic, and political objectives and events; etc. This calls for advanced application of information storage and retrieval techniques, not only to the manipulation of documents but also to the information and intelligence contained in the documents.

The word "document" here refers to any available message relevant to the pertinent technology. Unfortunately, relevance cannot always be determined in advance; it often manifests itself only after an appreciation of technological developments has been gained. A discussion of the application of advanced information retrieval techniques is presented in section 6.

As a simple example of the application of information science, a mathematical model was developed during the third quarter which defined technological breakthrough as an extremely rapid change in the state of technology.

The state S_t at time t is described by one or more information matrices; essentially, these are selective projections of the total network description of technology (as described in section 6) onto two-dimensional surfaces. The particular example described in section 7 summarizes a successful technological forecast made some years ago for purposes of market planning. It happens to be an active two-party competitive model, i.e. one in which the first party (the forecaster) can influence developments in the hope of gaining advantage over the second party. In any case, it demonstrates a particular application of techniques for information association in matrix format for the purpose of technological forecasting in a semimechanical manner. The matrix model is described in section 7.

It is clear from the foregoing that progress has been made in understanding the elements of technological forecasting and that techniques for accomplishing mechanized forecasting have been suggested. These techniques need to be tested and refined. A possible approach is through game playing, which can also be used to study forecasting strategies by humans. A sketch of the relevant aspects of gaming is presented in section 8.

As often occurs in studies where the underlying problems are more complex and intractable than initially anticipated, there was a fair amount of searching for the significant areas of research, both by the study group and by the sponsor. As a consequence, the study was wider in scope and less intensive than originally anticipated. Nevertheless, important progress has been achieved.

The elements of technological forecasting are now better understood. For example, the forecasting model is now recognized to be an iterative model, moving forward from S_t to S_{t+1} to S_{t+2} ..., and using continuous prediction techniques. On the other hand, breakthrough forecasting is disjunctive, similar in character to the kind of heuristic (and hence sometimes erroneous) forecasting practised by science fiction writers, soothsayers, and visionaries. Heuristic forecasts are conjectures based upon incomplete knowledge, and hence with subjectively evaluated credibility subject to future confirmation. There can of course be disjunctive forecasts of some elements in an otherwise iterative forecast; for example, the development of a civilization is usually iterative but with elements in the civilization advancing disjunctively.

It appears that the most promising avenue toward mechanization of forecasting is through the use of information science techniques, by characterizing the "significant" parameters of a specified area of technology (device, concept, system, or process), the forces acting to advance or retard that area, and the laws governing the changes in technological state. Associated with the descriptions of the forces and the laws of change are certain measures of relevance to the technology and of interdependence among the descriptive parameters, as well as the interaction rules and their dynamics.

It is now evident that more time might profitably have been spent in conference with analysts accomplishing forecasting tasks, and would in fact be particularly effective now that the structure of the forecasting problem is better understood. The result would be a sharper definition of forecasting dynamics, research objectives and specific tasks to be accomplished.

As a logical continuation of this study, the investigator recommends that:

(1) the iterative model described in section 7 and its formal extension using the information science techniques described in section 6 should be applied in a technological area of strong interest to the sponsor;

(2) the model should be tested in that area, refined, and generalized;

(3) games should be designed and played to test the model and to guide its development and refinement; and

(4) the search for other forecasting models should be continued.

2. MACHINE-ORIENTED PROBLEM SOLVING

2.1 INTRODUCTION

In recent years there has been widespread investigation into the area of what is termed "Artifical Intelligence." Toward this end, various schemes have been advanced for devices which are capable of solving certain types of problems of varying degrees of complexity. Interesting problem-solving devices attempt solution to problems for which no formal solution procedure or algorithm is known. These devices employ "heuristic" or empirical rules, which either produce a shortcut to solution or no solution at all. The more advanced problem-solving schemes employ learning devices which permit the overall problem solver to improve itself with experience.

A survey and comparison of the various problem-solving schemes is made, both of specific problem solvers and of general models. A discussion of learning and learning schemes follows.

A problem consists of three sets of entities, a set of initial objects (axioms, postulates, "facts," state of existence), a set of operating rules ("moves," operations, transformations, manipulations), and a goal description (final states, desirable terminal conditions, winning configurations). A valid solution to a problem consists of successive application of the operating rules to the initial conditions in such a way that the goal description is satisfied. A problem does not necessarily have a valid solution and it may have more than one.

A trivial problem consists of small sets of initial conditions and operating rules which combine in a necessarily small number of ways. All possible combinations of these initial conditions and rules can then be examined, so that if any valid solutions exist, they will be discovered. This procedure is known as solution by exhaustive search. An example of a trivial problem is illustrated in Figure 2.1 which is a simple maze in which the initial condition is "you are in state A," the single rule is "you may move from any state to any other state which is connected to it by a line," and the goal description is "to be in state B." Clearly, an exhaustive search is feasible.

A more interesting problem is one which is not trivial, that is, one in which an exhaustive search for the solution is not possible because of time, storage, and/or energy limitations. If such a problem has not been solved before, and a valid solution is not known, one must turn to inexact methods to attempt solution.

To characterize the problem of predicting technological breakthroughs in terms of problem solving by machine, three levels of problem complexity are distinguished here. At the simplest level, the objects are named and the axioms or rules are specified in advance and the goal is identified in an explicit statement. The problem is simply to find a path, preferably but not necessarily close to the minimum path, from the given objects and rules to the proof or disproof of the statement. A problem solving machine at this simplest level is simply a "proving machine." A typical example is the propositional calculus problem solver illustrated in Figures 2.2, 2.3, and 2.4. Note that this level of problem solving corresponds to specifying A and B in Figure 2.1, with the further assumption that all paths eventually lead to B.

In the second level of problem solver, the task is rendered more difficult because the goal is specified as a general statement, such as "win the game." The objects are named as before but only the primitive rules are specified. Typical examples are checkers and chess, the major difference between the two being the implicitly greater complexity of the latter. Both games permit a large variety of alternatives at each move, with exponentially growing alternatives possible at each successive move, as indicated in Figure 2.5. Look-ahead to every achievable eventuality is impractical, if not impossible, even with the fastest computing machines proposed to date. The number of ways in which the game can be won, particularly in chess, precludes the strategy of aiming for a small number of specified goals. The usual approach is to derive composite or heuristic rules ("control the center of the board," "don't move the queen until position has been established") to speed the look-ahead process by limiting alternatives, even at the risk of occasional poorer moves. The complexity of the problem and the multiplicity of acceptable solutions characterize this second level of problem solver.

In the third and most difficult level of problem solving, the objects are not all named, the rules are only partially specified, and the goal is only vaguely stated. There may be more than one valid solution. Moreover, valid solutions may not be recognized; they may in some cases not even be recognizable in the absence of added information or pragmatic interpretation. Irrelevant information may be provided and part of the problem may be the (pragmatic) evaluation of information relevance. Mechanized problem solvers at this level have not been described in the open literature. Nevertheless, this is the level of problem solving required for predicting technological breakthroughs. Because of the pragmatic considerations, it is likely that advances in this area will be aided by developments in mechanized intelligence retrieval or in the somewhat more easily mechanized document and information retrieval field.

2.2 THE STATEMENT OF PROBLEMS

A problem statement may be either formal or informal. A formal problem statement is one in which each of the three entities comprising the problem (initial conditions, operating rules, goal description) is explicitly stated, so that they comprise a completely defined set. This set is identical for the problem stater and the problem solver. The size and complexity of the problem is irrelevant. An example of a formal problem might be: "Given all the rules of chess as the operating rules, and given this position of the chessboard as the initial condition, mate in three moves." The goal is then a set of three move sets, each of which leads to mate, and each one of which is a response for certain moves by the opponent.

An informal problem is one for which the initial conditions and the operating rules, although they may be restricted in some way by the problem stater, depend upon the experience and a priori knowledge of the problem solver. It is the informal problem which is most generally encountered by human beings, and which, at least at present, can only be solved by human beings. Deterministically, the initial conditions of the problem include the state of the problem solver, although this state is not (entirely) known to the problem stater. Nevertheless, the problem stater need not state all conditions and rules of the problem, for he knows that the problem solver is already aware of many of them in some form or other. An example of an informal problem might be "Go to the movies." Inherent in this problem is donning the proper attire for the theater in question, acquiring the necessary fee and transportation to the theater, getting there at the correct time for the show, etc., etc. The problem solver need not follow the course of action that the problem stater would have, nor could the problem stater have predicted this course of action accurately.

Goal statements are also generally incomplete in informal problems, and the solver is expected to complete or interpret them. The example "Clean the house" illustrates a problem statement for which there might be differences of opinion as to whether more specifically stated goals apply. Would "Sweep the floors" be sufficient to fit the goal description "Clean the house?" This depends on the solver, and yet problems (informal ones) are often stated in this way.

2.3 THE HEURISTIC APPROACH

When a problem solver has been active for a while, he will presumably have met with some successes and some failures. If these are recorded, successes may be repeated, and failures possibly averted when identical situations recur. Further, rules may be abstracted from similar situations to assist in proper choice of method of solution. These empirical rules are called heuristics. A heuristic is an empirical rule which, in a given problem situation, favors certain approaches over others. The application of heuristics to a problem which cannot be solved exhaustively makes solution possible within available resources. The heuristic approach does not, however, guarantee the discovery of all, or even any solutions. The better the heuristic, the higher the probability, in a given situation, that its application will yield the (or a) correct path toward a valid solution.

A problem solver who is able to record and learn from his experience, and subsequently construct and test new heuristics is obviously superior to one who is not able to do so. A heuristic is, by definition, an <u>imperfect</u> procedure for problem solving. A procedure which always yields a solution for a specific type of problem is known as an algorithm. An algorithm is preferable to a heuristic, but for most problems, algorithms do not exist. For very complex problems, heuristics improve with experience.

An example of a heuristic in chess might be "take an opponent's piece when you are able." This heuristic might be useful in some instances but disastrous in others. An improved heuristic might be "take an opponent's piece when you are able, unless you will lose more valuable pieces in an exchange." Still other improvements are possible.

Heuristics are often arranged in a hierarchy, so that when more than one applies, the one which is most likely to yield a valid solution within the situation will be applied.

2.4 THE FORMAL PROBLEM

Numerous investigations have been made into nonhuman problem solving devices. The only feasible method, at present, for the construction of these devices is through the use of a general purpose digital computer. Most of the investigations have restricted themselves to specialized problem solvers which operate within a very specific area, that is, which solve only one specific type of problem. Only formal problems have been discussed extensively to date. Formal problem solvers lend themselves to construction on digital computers, for an explicit set of operating rules can be symbolically represented, as well as the initial conditions and the goal description. The hierarchy of heuristics built into the problem solver determine its approach to the problem. Examples of the specialized formal problem solvers are chess playing machines (1) (2) (3), a geometry theorem proving machine (4), and a simple propositional calculus proof machine (5). It will be noted that the set of operating rules of each of the above examples is small, and with the growth of a set of operating rules, the possible approaches to valid solution grows exponentially.

A further clarification of the shady difference between a formal and an informal problem statement can be given in terms of the language of communications. The hierarchy of computer languages which exist and can be written today serve well for formal problem solving devices (although the construction of memories which serve efficiently in learning devices are still crude). Informal problems, however, are generally stated in a human language, where meanings of various symbols are not only inexact, but also changing with time. A problem stated in human language renders the problem informal. An example might be the chess heuristic: "defend the king." Unless very specific strategies are outlined as to the meaning of king defense, the heuristic, and therefore the problem solver, must be informal.

2.5 STATIC AND DYNAMIC PROBLEM SOLVERS

It is our general experience that human problem solvers improve their technique with experience, and it might very well be that this principle holds for formal devices as well, i.e., that devices which are designed to "learn" from experience improve their problem solving ability beyond the specific capabilities built into them by their designers. The designers of each of the problem solving devices discussed in this paper recognized this principle, and discussed "learning" in problem solvers at least to some extent. A problem solver which is capable of changing its automaton status or "input-output transfer function" with time (in an attempt to improve its problem solving ability) will be termed a dynamic problem solver. A dynamic problem solver is illustrated in Figure 2.6.

Static problem solvers are more or less "stuck" with the heuristics supplied them. These might be very good heuristics, and quite adequate to validate the existence of the problem solver. Heuristics always lend themselves, however, to some improvement, and the concept of learning in a formal device merits further study.

Learning is probably least useful at the lowest level described, for it is nothing more than rote. There are probably very few situations in which this type of learning alone can be applied directly. A more practical learning situation is that of the second type, and is the one most discussed by the authors of the various problem solving devices. The third level of learning might be termed "abstraction and generalization," and has an inherent "self-organizing" quality. It is undoubtably the highest level, for a problem solving device with such a capability would construct heuristics which had not been foreseen by its builder. It would do so to further its goal or "survival."[8]

2.6 REFERENCES

1. Newell, Shaw and Simon, "Chess Playing Programs and the Problem of Complexity," IBM Journal for Research and Development, Vol. 2, No. 4, October 1958, pp. 320-335.

2. Bernstein, et al., "A Chess Playing Program for the IBM 704," Proceedings of 1958 West Joint Computer Conference, May 1958.

3. Kister, et al., "Experiments in Chess," Journal of the Association for Computing Machinery, Vol. 4, No. 2, April 1957.

4. Gelernter and Rochester, "Intelligent Behavior in Problem Solving Machines," IBM Journal of Research and Development, Vol. 2, No. 4, October 1958, pp. 336-345.

5. Walters, "Heuristic Theorem Proving," (A Machine Procedure for Efficient Generation of Simplest Proofs in the Propositional Calculus), Final Report No. 1, Project No. 5632, RCA Laboratories, May 30, 1962.

6. Newell, Shaw, and Simon, "Report on a General Problem Solving Program," The Rand Corporation, p. 1584, 30 December 1958, Revised 9 February 1959.

7. Amarel, "An Approach to Problem Solving by Computer," Final Report No. 1, Project No. 5632, RCA Laboratories, May 30, 1962.

8. Newell (ed.) Information Processing Language - V Manual (The Rand Corporation), New Jersey, Prentice Hall, 1961.

9. Ashby, "Design for a Brain," New York, J. Wiley, 1960.

10. Polya, "How to Solve It," New York, Doubleday, 1957.

11. Newell, Shaw, and Simon, "A Variety of Intelligent Learning in a General Problem Solver," Self Organizing Systems, Pergamon Press, New York, 1960.

12. Wexelblat, "A Simple Program for Computer Learning Based on the Game of Renjyu," (unpublished paper), The Moore School of Electrical Engineering, University of Pennsylvania, April 1961.

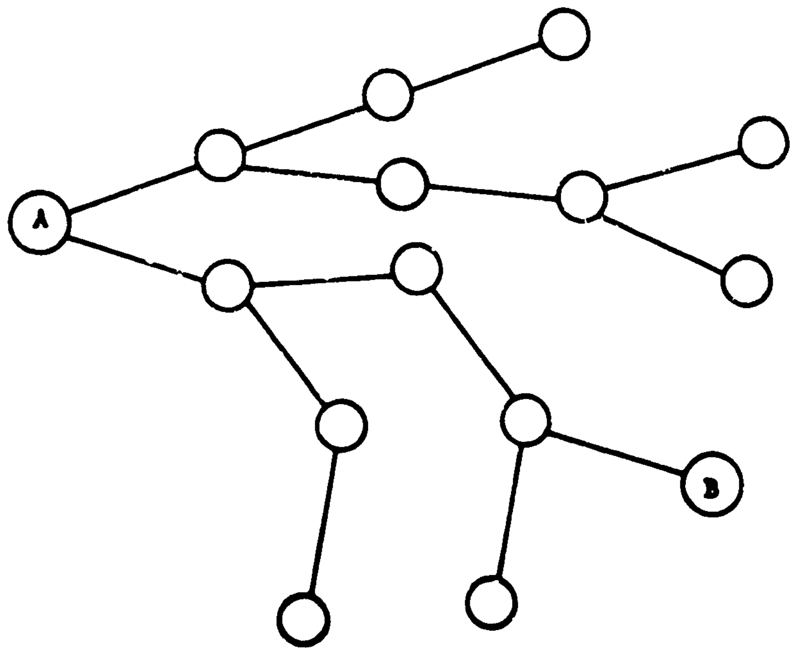

Figure 2.1. Solution by Exhaustive Search

(EXAMPLE: LOGIC)

OPERATORS

R1 $A \vee B \longrightarrow B \vee A$
$AB \longrightarrow BA$

R2 $A \supset B \longrightarrow \sim B \supset \sim A$

R3 $A \vee A \longleftrightarrow A, \quad AA \longleftrightarrow A$

R4 $A \vee (B \vee C) \longrightarrow (A \vee B) \vee C$
$A(BC) \longleftrightarrow (AB)C$

R5 $A \vee B \longleftrightarrow \sim (\sim A \sim B)$

R6 $A \supset B \longleftrightarrow \sim A \vee B$

R7 $A \vee BC \longleftrightarrow (A \vee B)(A \vee C)$
$A(B \vee C) \longleftrightarrow AB \vee AC$

R8 $AB \longrightarrow A$
$BA \longrightarrow B$

R9 $A \longrightarrow A \vee X$

R10 $(A, \quad B) \rightarrow AB$

R11 $(A \supset B, \quad A) \quad B$

R12 $(A \supset B, \quad B \supset C) \rightarrow A \supset C$

Figure 2.2. Operators

Δ V variable

Δ N number

Δ T sign

Δ C connective

Δ G grouping

Δ P position

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12
Δ V								-	+	+	-	x
Δ N			x				x	-	+	+	-	x
Δ T		x			x	x						
Δ C					x	x	x					
Δ G				x			x					
Δ P	x	x										

Figure 2.3. Differences and Operator Difference Table

```
Given:     L1 = R.(-P⊃Q)
Obtain:    L0 = (Qvp).R

Goal 1:  Transform L1 into L0
    Match produces position difference (ΔP).
    Goal 2:  Reduce ΔP between L1 and L0.
        First operator found is R1.
        Goal 3:  Apply R1 to L1.
            Goal 4:  Transform L1 into C(R1).
                Match succeeds with A = R and B = -P⊃Q.
            Produce new object:

              L2 = (-P⊃Q).R

Goal 5:  Transform L2 into L0.
    Match produces connective difference (ΔC) in left subexpression.
    Goal 6:  Reduce ΔC between left of L2 and left of L0.
        First operator found is R5.
        Goal 7:  Apply R5 to left of L2.
            Goal 8:  Transform left of L2 into C(R5).
                Match produces connective difference (ΔC) in left sub-
                expression.
                Goal 9:  Reduce ΔC between left of L2 and C(R5).
                    Goal rejected:  difference is no easier than
                                    difference in Goal 6.
        Second operator found is R6.
        Goal 10:  Apply R6 to left of L2.
            Goal 11:  Transform left of L2 into C(R6).
                Match succeeds with A = -P and B = Q.
            Produce new object:

              L3 = (PvQ).R

Goal 12:  Transform L3 into L0.
    Match produces position difference ( ΔP) in left subexpression.
    Goal 13:  Reduce ΔP between left of L3 and left of L0.
        First operator found is R1.
        Goal 14:  Apply R1 to left of L3.
            Goal 15:  Transform left of L3 into C(R1).
                Match succeeds with A = P and B = Q.
            Produce new object:

              L4 = (QvP).R

Goal 16:  Transform L4 into L0
    Match shows L4 is identical with L0, QED.
```

Figure 2.4. Example of Logic Theorem Proof

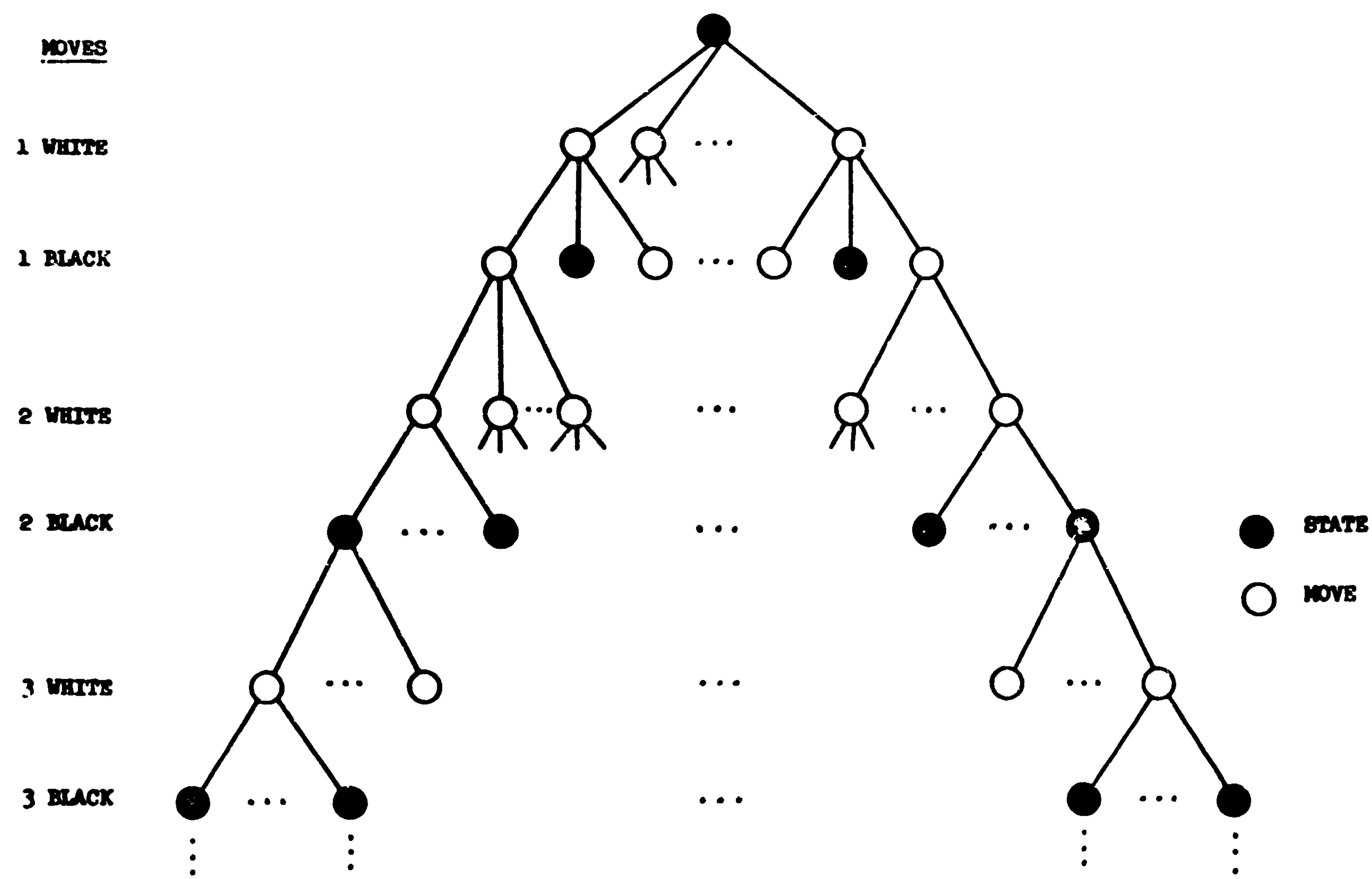

Figure 2.5. Checkers and Chess

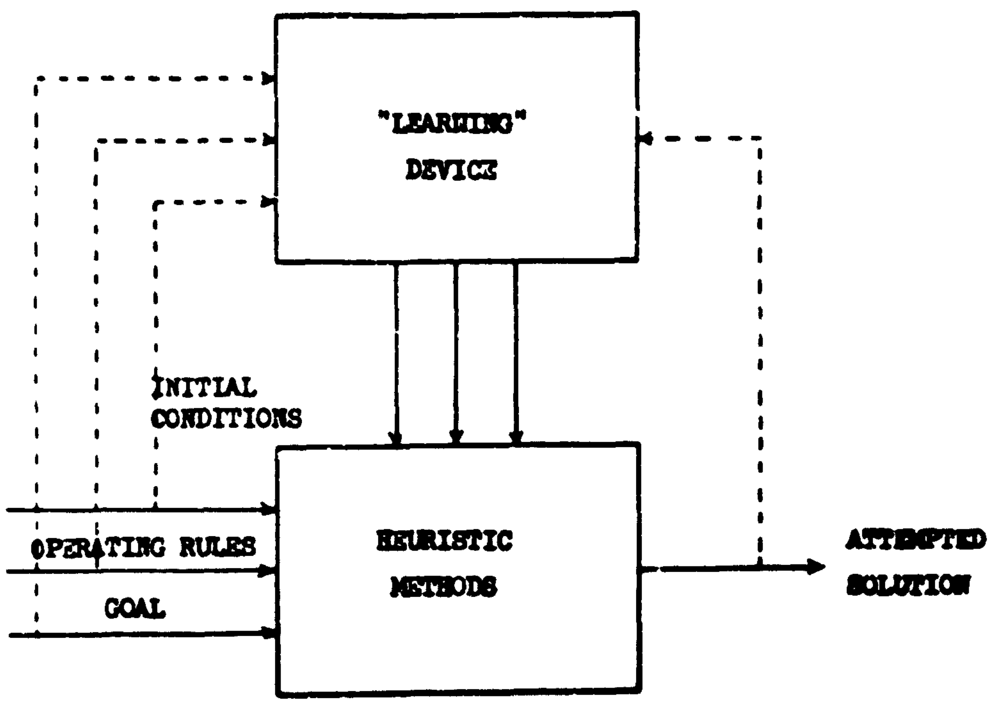

Figure 2.6. Dynamic Problem Solver

3. PROBLEM SOLVING BY HUMANS

As a first approach to a very complex subject, this section sets forth some definitions and concepts which prevade most of the literature on problem solving. Like many other areas in psychology, there are no definitive answers to be given. Experimentation has been interpreted in terms of the experimenters' own theoretical outlook; the conflict between S-R and S-S thinking will evidence itself in some of the theoretical discussions which will follow.

3.1 PROBLEM-SOLVING BEHAVIOR

The first presentation will be based largely on W. Edgar Vinacke's The Psychology of Thinking which appears to discuss more of the key issues in problem solving than any other source located.

Vinacke's first distinction in setting the scene for defining problem solving behavior is that mental processors are bipolar in nature, determined on the one hand by the external world, and on the other, by inner needs. From moment to moment these influences interplay in the course of thought, with external stimuli dominating at one time and internal stimuli at another. At no time can it be said that either is independent of the other, but it is possible to distinguish general conditions under which one set of factors has a stronger influence than others. "In problem situations, the normal person is behaving more in relation to the demands made by the external conditions; in imaginative thinking, the individual is responding more to the inner-need condition of the moment, more or less independently of the external condition."(p. 160) Vinacke then goes on to say that he conceives of problem solving as a form of thinking beyond the learning phases. He then goes on to develop the following schema for describing human problem solving.

In analyzing behavior in a problem solving situation three stages may logically be distinguished:(pp. 161-162)

"1. Confrontation by a problem. In this first stage, a situation ... is present involving a goal together with an obstacle or difficulty between it and the individual. There follows some realization by the individual that such a situation exists. Motivations to overcome the difficulty ensues, accompanied by effort to attain the goal."

"2. Working toward a solution. In the intermediate periods, the individual engages in activity to relieve the tension built up in the first stage. There may be mental or symbolic processes ... manipulation and ... verbalization."

"3. Solution. As an outcome of the foregoing activities, the individual may reach the goal or he may fail to reach it. Results in the individual may be understanding, relief of tension, emotional effects such as satisfaction or pleasure, a cessation of activity, or some modification of behavior. Results in the environment may be an organization or reorganization of materials or relationships, removal of the obstacle or a change in the situation .... Also... failure may be an outcome ..."

Bruner, Goodnow, and Austin in A Study of Thinking, approach problem solving from a somewhat different framework, but nevertheless their listing of primary consideration on categorizing with probabilistic cues bears some similarity to Vinacke's schema.

1. Conception of the task and of its final resolution. The authors of A Study of Thinking seem to assume that the subject is aware of the problem but point out that the form of the awareness has implications for the approach to it. If S views his task as one in which a final and unique solution is possible, "then his categorizing procedure may well be different from that of (one) who sees the situation as always and forever one into which uncertainty will enter." "One difference which the conception of the task makes is in the attitude toward taking a chance and making an error. The individual who aspires to eventual certainty and who expects to be able to continue categorizing and exploring will often risk errors more readily on the assumption that a successful final solution will negate the errors incurred along the way." (pp. 186-187)

2. Presence of potentially criterial cues. There are some situations in which individuals can be guided only by the relative frequency with which instances turn out to belong to one category or another — situations, for instance, where there is such a poverty of discriminate attributes that it is hard to know where to start. In these sorts of situations one observes cue searching, "an attempt to find attributes that can be used as a basis for deciding whether a particular object should be placed in one category or another." (p. 185)

3. Payoff matrix governing categorizing decision. If the individual believes that an event has a small number, r, of distinct possible types of outcomes, and if there are in his opinion a small number, s, of alternative actions available to him, the situation may be represented in an "operative payoff matrix." Both the extent to which the individual likes each of the outcomes and his probability estimates of their occurrences affect the decision he makes. It is in general a difficult task to establish preference ordering and probability estimates, and hence to determine how a particular series of decisions is made. (p. 186)

4. Opportunity for validation. One difference which can be observed between these two problem solving situations is their degree of generality. Vinacke's is quite general while that set forth by Bruner, Goodnow, and Austin is fairly specific, highly analytic and rational. These differences seem to reflect a difference in focus of attention. Obviously one cannot describe all problem solving behavior in terms of highly rational activity. Vinacke delineates three basic varieties of problem solving behavior: trial and error, insight, and gradual analysis. We shall now take a look at each of these mechanisms for problem solving.

3.2 TRIAL AND ERROR

Woodworth has clearly defined what he believes to be the minimum essentials of trial and error as revealed by animal experiments. (See Vinacke, page 164.)

"1. A 'set' to reach a certain goal.

2. Inability to see any clear way to the goal.

3. Exploring the situation.

4. Seeing or somehow finding leads, possible ways to reach the goal.

5. Trying these leads.

6. Backing off when blocked in one lead, and trying another.

7. Finally finding a good lead and reaching the goal."

In reality this does not separate trial and error from other behavior in problem solving situations since T and E may serve as a prelude to other modes of attack. C. L. Morgan is cited by Vinacke as pointing out that "If there is no way to figure out in advance how to solve the problem, if a multiple, varied attack is required (e.g. to familiarize oneself with various alternatives) and if it is necessary to go through preliminary stages before the whole situation can be understood, then some trial and error, whether "blind" or not must occur." It appears that Morgan has identified important dimension of problems (really of the person or group confronted with the problem) i.e. whether a problem is solvable on the basis of a single action or whether some sort of sequential activity is required. In summary it might be said that trial and error problem solving is essentially mechanistic in nature and would probably appeal strongly to any SR theorist.

3.3 INSIGHT

This is a term fraught with confused meanings. Several different levels of conceptualization are represented by this word. For example (Vinacke page 166):

"1. Insight means that the individual understands what he is doing or has done and how the solution was achieved.

2. Insight refers to a mode of attack--an approach where the inner relations of basic principles are sought (as contrasted with a blind attack--a limited view of trial and error).

3. Insight refers to the kind of solution achieved, i.e. one which is sudden, confident and complete."

For our purposes, we will be principally concerned with the second usage--wherein the person confronted with a problem seeks to understand or define inner relations, principles, etc. As we can now see, it is to this category that one might assign Bruner, Goodnow and Austin's schema for categorization with probablistic cues.

At least twenty rather distinct characteristics of insight have been suggested. Among them are general factors like the ability of the subject to repeat the solution readily and to transfer the solution or principle thereof to other situations. Insight has been linked with various aspects of behavior prior to solution, including the application of relevant past experience, controlled attention, and foresight. More often, it is likely to be defined in relation to the solution itself, namely in terms of suddenness, confidence, completeness, etc.

Wolfgang Kohler and Robert M. Yerkes are credited with having done the basic experimentation on insight. Their work on primates has been carried forward by other experimenters and the journey to the top of the phylogenetic order has now been made. One representative experiment of Kohler's is cited for the reader's benefit.

"1. Using an Implement

On the second day after his arrival..., Koko was, as usual, fastened to a tree with a collar and chain. A thin stick was secretly pushed within this reach; he did not notice it at first, then he gnawed at it for a minute. When a hour had elapsed, a banana was laid upon the ground, outside the circle which his chain formed a radius, and beyond his reach. After some useless attempts to grasp it with his hand, Koko suddenly seized the stick, which lay about one meter behind him, gazed at his objective, then again let fall the stick. He then made vigorous efforts to grasp the objective with his foot, which could reach farther than his hand, owing to the chain being attached to his neck, and then gave up this method of approach. Then he took the stick again and drew the objective toward himself, though very clumsily." (Vinacke, page 168)

Is the behavior just reported really insight? These excerpts are quite suggestive and are open to a variety of interpretations. "For example, it would be easy to overlook the preliminary behavior of the animal and to stress only the final solution, even more important it would be easy to forget that each animal progressed through a protracted series of tests, during which acquaintance and skill with the problems and materials were gradually built up." (Vinacke, page 170) Likewise, Yerkes Congo seemed to have insightful solutions only after considerable preliminary learning.

A. Alpert observed 44 children ranging in age from 19 to 49 months in two series of standardized situations. "The first series consisted of five problems in which it was necessary to use an object (a large block, a chair, or a box and a block) to attain a toy suspended from the ceiling. The second series involved the use of implements to reach objects located at a distance from a play pen." (Vinacke page 171)

Alpert observed four categories of responses: 1. primitive, 2. random, 3. exploration and elimination, and 4. immediate solution. Primitive might be exemplified by the child simply reaching out with its hand, with random (or rare) exploration and elimination characterized as the deliberate trying out of possibilities.

Primitive behavior led most often to failure but when it did work the solutions tended to be of the immediate variety. Exploration and elimination were associated more often with successes than failures. Of the successes, gradual solutions with complete insight were most frequent. Also it is noted that exploration and elimination led to more solutions with sudden insight than did other types of PS behavior. Experiments conducted by E. A. Matheson and B. C. Ling with nursery school children yielded results very similar to those of Alpert.

3.4 DUNCKER'S EXPERIMENTS

The conditions of performance which interested Duncker were those associated with the successful solution of thought problems. "For him insightful signified intelligent; the degree to which an individual is able to respond effectively, i.e. in a "good" manner, to relevant features of the situation." (Vinacke, page 172) The types of problems he presented might be found in adult tests of reasoning ability. He concluded that the process of solution has two principal aspects: 1. analysis of the situation and 2. analysis of the goal. In essence the subject analyzes the situation to determine where the trouble lies and tries to find out what can be used to remove the difficulty. The individual also analyzes the goal, and considers what must be done if the solution is to be achieved. In what is apparently an attempt to better define the interplay between an individual and a problem situation, Duncker talks about signaling. Signaling is his way of identifying the subject's perception and conception of a given problem. The flexibility required to solve complex problems demands that the subject be able to recenter and this indeed is tied in with the subject's manner of perceiving the problem. Duncker lists seven factors which may hinder efficient signaling

"1. Lack of signaling: The model of search may be too vague or inadequate to lead to a perception of something which can be used.

2. Strength of attachment of some specific function to an object which must be used for some different function: This connection may represent a property which is seemingly the only function of the object, or it may represent the only function familiar to the individual.

3. Fixity of the required function: The individual may be able to see only one object as possessing the real function.

4. Necessity for altering an object: To fulfill the real function, it may be necessary to change, or modify, or reconstruct materials or objects at hand.

5. Original function actually given as a fact: An object may be present in the situation in its proper function, although it could be used in a different function.

6. Use of the same object for one function and later for a new function.

7. Poor suitability of an object for a new function." (Vinacke, page 175)

Max Wertheimer, a gestaltist, sees the processes of centering and recentering as being at the focal points of productive problem solving behavior. He believes, that the subject must understand the structural and functional relationships of the situation. Meanings and inner relationships must be grasped. He sees two main dynamic processes — centering of attention upon the essential elements of the problem and their relation to the basic difficulty. However, to solve the problem there must be some reorganization of the elements or some modification of already known principles, with a resulting recentering of attention. In other words, understanding relationships existing in the problem and previous experience and flexibility of outlook and approach are of critical importance.

Vinacke concluded with regard to insight that the efficient management of a present situation depends upon the development and application of modes of attack or appropriate sets. That is, relationship principles, attitudes, methods, etc. are more significant than specific content or specific operations or specific rules.

3.5 SUMMARY OF VINACKE'S VIEWPOINT

There seem to be at least five processes which take place in human problem solving as described by Vinacke:

1. Recognition of the problem. (evidence, S's verbalizations, repeating instructions, etc.).

2. Manipulation or exploration of some kind. This exploration may be verbal or actual overt movement. Sometimes it takes the form of random familiarization with materials and at other times the deliberate testing of various possibilities.

3. Analysis. "Another characteristic usually noted is that the subject attempts to formulate the goal or the problem or to work out the nature of the difficulty. Apparently there are wide variations in this behavior ranging from a highly controlled, rational extreme to a more generalized, less deliberate extreme."

4. Partial Solving. "Except in simple situations, or in those in which the entire solution depends upon the application of a single principle, the solving of successive steps appears to be an integral part of the performance."

5. Emotional Responses. Some may regard emotional responses as incidental, but nevertheless, the initial presentation of the problem, the activities of working toward the solution, and the solution itself are usually associated with varying emotional reactions, as well as with manipulation, formulation of hypotheses, etc.

Adding it all up, it may be said that human problem solving as seen by Vinacke consists most typically of the following processes: apprehension or recognition of the problem; manipulation or exploration of the situation; some degree of control or direction of performance; the understanding or mastery of intermediate requirements or steps; and emotional responses representing some degree of personal involvement in the situation.

3.6 JOHNSON'S SCHEMA

We will now sketch the conceptions of Donald Johnson with regard to human problem solving. His schema of explaining human problem solving behavior appears to emphasize the processes attendant to the recognition and preparation for the solution of the problem more than does the scheme set forth by Vinacke. In a chapter of his book The Psychology of Thought and Judgment, entitled, "Preparation for Thought and Judgment" (page 158) Johnson states, "In solving these problems the thinker contributes much more to the preparatory set than in the simple forms of thought, instructions for which establish a set that permits immediate production of responses." In short, it is Johnson's viewpoint that the consideration of the total problem situation results in the problem solver either creating in himself a set or, in a sense, perhaps deciding upon strategies to employ in the solution of the problem before the initiation of, in his terminology, the production of responses. Johnson further elaborates by saying: "In the complex problems of human concern, the goal or solution may not be so clearly specified that the thinker can begin at once to produce tentative solutions. The preparation for thought may therefore include an analysis of the goal making it more explicit." (page 162)

Johnson goes on to acknowledge that this preparatory activity is quite difficult to identify in the complexity of human behavior. In carrying forward his idea that the human organism must prepare itself for undertaking the solution of a problem, and must in particular have a clear goal in mind, he cites work accomplished by Reid in 1951. Reid attempted to demonstrate the importance of specification of the goal by experimental variations of the conditions of his experiments. Quoting Johnson, "He had college students work construction problems with match sticks and solid objects. Experimental groups received a standard series of aids designed to explicate the goal, while control groups received a parallel series of aids without explicatory contents. For example, one aid was as follows: 'It means that each match must form two triangle sides. If that is your original triangle there (pointing with finger), each of those three matches is already existing in one triangle. How can you put each of those three matches into two triangles at the same time?' The corresponding aid for the control group was as follows: 'People often find this problem rather difficult.' Such explication was helpful. The experimental group solved significantly more problems than the control groups. There is no doubt that these statements by the experimenter were effective aids, and it seems likely that their effect was due to explication of the goal, at least it was a hypothesis about explications of the goal that framed these statements." (page 162)

This is one of the experimental studies on which Johnson based his notion that a clear goal is helpful to subjects in attempting to solve problems. Assuming then, that specification of the goal is desirable and necessary for problem solution, Johnson then goes to query what factors determine how the problem is formulated and how the goal is specified. It is his feeling that motivation, social interaction and previous experience or one might call it the apperceptive mass, all enter into these matters. They play a particularly important role in the solution of more complex problems since it is only in complex problems that the specification of a goal or the formulation of a problem is difficult. Indeed, this may be a very good criterion for establishing problem "difficulty."

Johnson goes on about the other two essential elements in the problem solving process known as the production process and judgment. Without delving into all the rationale behind his schema, one can say that the production process is the activity which results from the preparatory phase of the solution. This is when the subject is trying to achieve a solution. As each try is made it is then necessary for the subject to make a judgment as to the adequacy of the response he has made, whether it be verbal, mechanical or what have you. This judgmental process concludes the solution of the problem if indeed the subject perceives this as an adequate solution; or it triggers off another phase in the production process if this is not so. In short, Johnson sees a preparatory production and judgmental phase as being descriptive of the three essential phases involved in human problem solving. He particularly stresses the impact that the set generated during the preparatory phase has on the ultimate solution.

3.7 CONCEPT FORMATION

Now having taken a look at Johnson's schema for problem solving, we will turn to another element in the problem solving process; that of concept formation. It will become obvious that concept formation has been talked about by both Vinacke and Johnson but not named as such. It is our impression that this is a valuable concept and embodies some aspects not specified by either Vinacke or Johnson and is therefore worth considering.

Osler and Fivel designed experiments in concept attainment among school children between the ages of 6 and 14.[5] Without delving into the success of these experiments, it is interesting to note the following observations in their report. "One other factor that may be related to performance must be considered. The instruction given to subjects did not direct them explicitly to try to discover a concept, but merely stated that attending to the stimuli would help them win. Theoretically, therefore, it is possible that the experimental task consisted of two stages: (a) discovery of the problem, that is, that a concept is to be sought, and (b) the solution, that is, the discovery of the specific concept." (Osler and Fivel, page 7)

It is interesting to speculate that just this sort of behavior is probably found in most complex problem solving situations. It would seem that this idea of concept attainment, that is, the derivation of a general goal and objective from the variety of specifics constituting the problem is a necessary facet of problem solving behavior in the human organism in all but the simplest problems. It is further interesting to consider the observation made by the authors concerning the two-step process required for attainment of the concept in their experiment, that is, that first the subject had to determine that a concept was needed and then determine what the specific concept was which was needed to solve the problem. It is highly probable that almost any problems with creative elements involved in them require this same dual process to occur.

First, the person who is being subjected to various stimuli must recognize the need for a particular type of problem solution and then must try to achieve it. Without recognizing the existence of a problem and identifying it, the solution of a problem is impossible. Thus, we can see that in any problem that is not made explicit to the subject, it is first necessary for the subject to conceive of the problem as existing and conceive of some sort of potential terms in which a solution might be made. These terms in which a solution might be formulated would probably be equated to Johnson's goal formulation which he spoke of as taking place during the preparatory phases of the problem solving process.

3.8 SOCIAL INTERACTION IN PROBLEM SOLVING

Having looked at quite a few facets of the problem solving process, both in problem situations which are quite highly structured and having also considered the necessary prerequisites for the solution of problems involving somewhat creative or original elements, still another area will now be explored. This area is the area of the effect of social interaction upon problem solving. It is well known by all behavioral scientists that the behavior manifested by the human organism in group situations and in individual situations often differs. Most of the experimental data underlying the theories which have been discussed thus far have been based on experimentation done on individual people. It therefore would seem interesting and profitable to explore the impact of group interaction on the problem solving process.

A study by James Davis and Frank Restle serves as a good basis for introducing this topic.(2) In setting the scene for this study Davis and Restle made a brief review of the field of group problem solving. They reported a classic study done by Shaw in 1932 which showed that groups attained a higher proportion of solutions than individuals and provided evidence for the hypothesis that group interaction facilitates individual cognitive processes. They also reported that Lorge and Marguardt in 1955 have suggested that the group advantage results from a statistical pooling of the abilities or accomplishments of their members and that some experimental evidence seems to support this assertion (Davis and Restle, page 104).

The authors then go on to discuss the hierarchical and equalitarian models of group problem solving. Essentially the hierarchical models suggest that able and efficient subjects will dominate the group and the less-efficient members will be excluded from effective participation in the solution of the problem. However, the equalitarian model suggests that all group members contribute about the same amount of talk though some are not actually contributing to the solution.

In their experiment, Restle and Davis presented three different problems to groups and individuals at Michigan State University. They report that in a direct comparison, group problem was found to be clearly superior to individual problem solving. In analyzing the data from their experiment, the authors stated: "The data in the equalitarian model indicate that in terms of man-hours it is cheaper to have individual problems solved separately than to use groups. Individuals in separate rooms will, on the average, solve a problem sooner than the same four individuals in a face to face group....though individuals will, on the average, obtain a correct answer before a group, they may also obtain some wrong answers. Working separately, four individuals would not separate the correct from the wrong answers.... In this sense the group is slower but surer." (page 115) At this point in the study, the authors caution that this sort of theory applies only when one is searching for unique, correct answers to problems. They indicate that the answering of human relation type problems where a multiplicity of possible answers might be formulated may be very different.

The authors go on to say "...Within the context of this study, any assertions that inter-member interaction results in a 'superpooling' effect or the assertion that group problem solving derives from a simple pooling effect are both seriously in question." (page 116). Following this line of reasoning, it would then appear that the real advantage possessed by a group is in the checking of possible divergency of viewpoint which would result in more careful evaluation of potentially correct alternatives rather than in the generation of these alternatives. In conclusion the authors state, "Social psychological data in this study agree quite well with the supposition that groups were organized in an equalitarian structure. The success of the equalitarian model suggests that members who are on the wrong track contribute their share to the discussions. The data on choice of future partners failed to reveal any noticeable trace of stable leadership within groups." (pp. 116-117)

Considering still another factor in cooperative problem solving, it was hypothesized by Smelser(6) that subjects would perform best in a cooperative problem solving task having a dominant and a submissive role if they were assigned to their tasks with respect to their scores on a dominance-submissiveness test. Smelser administered a short form of Gough's California Psychological Inventory (CPI) which contains a dominance scale to categorize his 748 subjects. The experimenter selected subjects from the extremes of the distribution on this test and made up various two-person groups from the total grouping of subjects.

The experimental task devised for this test involved the manipulation of model railroad trains. It was the task of the subjects to complete as many mutually complete trips as possible around a circular track with several sidings in a three minute period. The results reported by the author include the following interesting information. "The most productive group was composed of pairs in which the dominant subject was assigned the dominant role, and the submissive partner the submissive role. The least productive group was composed of these pairings with the roles reversed. Paired dominant subjects were more successful than paired submissive subjects and both of these pairings achieved more when assigned roles. All groups shows significant increases in performance across trials..."It was concluded that congruence of role and habitual pattern within the subject and complimentarity of patterns as between subject were major determining variables in cooperative achievement." (page 541)

This appears to be still another important factor in the performance of problem solving involving groups of persons. At first look, these findings would appear to be in divergence with those of Davis and Restle which assert that an equalitarian power structure appears to prevail in group problem solving situations. However, it can be observed that there was no need for a dominant role in the thought-type problem solving situation in which their subjects were employed. Therefore it would seem that the congruence of personality traits which result in primarily dominant or submissive behavior become important factors in instituting group solving problems which require a dominant or controlling force.

Yet another aspect of group problem solving was investigated by L. Richard Hoffman and Norman R. F. Maier of the University of Michigan.(3) Their general interest was in exploring the idea that groups composed of people with varied personality structures would be superior as problem solver when compared with groups of more homogeneous composition. An excellent synopsis of their findings is presented in their summary: "A wider variety of problems was used to test the generality of Hoffman's (1959) earlier findings that groups composed of people heterogeneous with respect to personality were superior in solving problems to groups composed of people with homogeneous personalities. Sixteen homogeneous and twenty-five heterogeneous four-person groups were initially formed in the laboratory section of an undergraduate course in the psychology of human relations. Homogeneous groups consisted of people with high positive profile correlations among their scores on Gilvord-Zimmerman Temperament Survey, heterogeneous groups of people with near 0 or negative correlations. The group members interacted weakly in case discussions, problem solving and role-playing.

Five different problems were used to test the relative ability of the two types of groups, four with some component of quality and one only involving acceptance. The subjects were also questioned about their satisfaction with the solution and with their influence over the solution for each problem.

The following results were obtained:

1. Heterogeneous groups produced a higher proportion of high quality solutions than did homogeneous groups to three of the four problems with quality components. On the fourth problem there was little difference and both types of groups produced poor solutions for the most part.

2. Mixed sex groups tended to produce higher quality solutions then did all male groups.

3. Satisfaction with the problem solutions was about the same in the homogeneous and heterogeneous types of groups.

4. Satisfaction with the solutions was shown to be more strongly correlated with the member's satisfaction with the amount of influence he had over the solutions, than with the objective quality of the solution or with the member's actual amount of influence.

It is suggested that solutions with high quality and high acceptance can be obtained from groups in which the members have substantially different perspectives on the problem and in which these differences are expressed and used by the group in arriving at their final decision." (pp. 406-407)

Thus still another dimension seems to be added to the psychology of group problem solving. These findings of Hoffman and Maier would seem to indicate that heterogeneity and attitudinal components among groups members which permit participation on the part of all members would promote the generation of high quality, highly satisfying problem solutions.

We have now looked at several dimensions of problem solving in a social context. The first experimental work, that of Davis and Restle, indicated that for sureness of solutions as opposed to speed of solutions, groups appear to do best. The work of Smelser indicated that in the situations where dominance is necessitated in a problem solving situation, the assignments of dominant and submissive roles is best done such that people are acting in accordance with their habitual personality structure. Finally, Hoffman and Maier's work suggests that heterogeneity among problem solving groups promotes the generation of high quality solutions.

3.9 SUMMARY

It would seem that one can state with a reasonable amount of certainty that there is some form of preparatory activity preceding the attempt of the human organism to solve a problem. Depending probably upon the complexity of the problem and the nature of the stimuli impinging upon the human, this preparatory activity may simply involve summoning up a repertory of well-worn responses from the apperceptive man or it may involve the drawing together of a multitude of impinging stimuli and deriving from them a conception of the existence of a problem before even the preliminary phases of problem solution can begin.

No doubt there is during this phase, as suggested by Johnson, some sort of goal acknowledgment or goal setting activity. Without this, responses emitted by the organism would have no direction. After this phase is completed, once again going along with Johnson's schema, trial responses are produced. It is evident that there is not a hard and fast boundary between these two stages because continual feedback and continual modification of both goals and responses would appear to occur in many types of problem solving.

Following the generation of a particular trial solution for response whether on the verbal, mental, or manipulative level there must be some sort of judgmental process which assesses or analyzes the adequacy of this response. If this response does not meet the goal set in the first portion of the process, then presumably the subject will run through the process again.

As for the influence of social groupings on human problem solving behavior, it would appear that this behavior is different from that generated by the individual human organism. The characteristics identified in the experimental literature include the fact that group problem solving is surer but slower than individual problem solving; that if a situation demands a dominant person that the dominant person be so assigned in the problem solving task and the submissive person or persons likewise be assigned to roles congruent to their personality structure. Still another vein in the literature suggests that groups composed of people of heterogeneous personality structures are most productive of meaningful quality problem solutions.

The preparatory activity preceding human problem solving is closely related to the retrieval of information (objects and rules of behavior) structured in accordance with the current field of interest or goal. This points to the discussion of information retrieval techniques in section 7, as well as to the machine-oriented problem solving described in section 2. The latter is particularly relevant to the repetition of trial solutions with the improvement of heuristics at each repetition, a process used to improve the checker and chess playing machines at the conclusion of or during a game.

BIBLIOGRAPHY

1. Bruner, J.S., Goodnow, J.J., Austin, G.A.; A Study of Thinking, John Wiley and Sons, Inc., New York, New York, 1956.

2. Davis, J.H. and Restle, F.; "The Analysis of Problems and Prediction of Group Problem Solving," Journal of Abnormal Social Psychology, 1963, 66, pp. 103-117.

3. Hoffman, L.R. and Maier, N.R.F.; "Quality and Acceptance of Problem Solutions by Members of Homogeneous and Heterogeneous Groups," Journal of Abnormal Social Psychology, 1961, 62, pp. 401-407.

4. Johnson, Donald M.; The Psychology of Thought and Judgment, Harper & Bros., New York, 1955.

5. Osler, S.S. and Fivel, N.W.; "Concept Attainment: I. The Role of Age and Intelligence in Concept Attainment by Induction," Journal of Experimental Psychology, 1961, 62, pp. 1-8.

6. Smelser, W.T.; "Dominance as a Factor in Achievement and Perception in Cooperative Problem Solving Interactions," Journal of Abnormal Social Psychology, 1961, 62, pp. 535-542.

7. Vinacke, W.E.; The Psychology of Thinking, McGraw Hill, New York, 1952.

4. CREATIVITY IN HUMANS

4.1 DEFINITION

In an attempt to define the term creativity some basic issues are dealt with:

1. Is there but one kind of creativity or are there many kinds?

2. Are the mechanisms involved with creativity innate or learned, or both?

3. How do the constructs, creativity and problem solving, relate to one another?

A. Kinds of Creativity

MacKinnon (1962) sees two kinds of creativity: artistic and scientific.

Artistic Creativity -- Includes poets, novelists, artists. The individual who manifests artistic creativity externalizes something of himself into the public field.

Scientific Creativity -- The scientifically creative individual acts as a mediator between externally defined needs and goals. He operates on some aspect of his environment in such a manner as to produce a novel and appropriate product, but he adds little of himself or of his style as a person to the resultant. Included among the scientifically creative are industrial researchers, physical scientists, engineers.

The opposite point of view is held by many and is illustrated by Hall (1962) who says: "a distinction is sometimes made between the creative activity of those working in fine arts and of those working in science. Again, both of these impractical pursuits are sometimes said to be creative while business activity is not. These are both false dichotomies. The same human imagination and creativity occurs in all these fields.'

Eric Fromm supports the latter position with his "creative attitude" concept. The creative attitude is characterized by inquisitiveness, avoidance of sets, and the courage to try strange ways of doing things.

In either event, creativity is an approach to solving problems, whatever the problem might be. Creativity is a function of individual differences with respect to approach and the nature of the problems involved.

B. Creativity, Innate or Learned?

The ability to find creative solutions to problems seems to be normally distributed. Individuals are able to increase their capacity for creativity, but only within limits. Some individuals appear to have a higher potential for creative solutions, but nearly everyone can become more creative.

C. Creativity and Problem Solving

Man's day to day existence might be defined in terms of a series of problem solving situations. Some of the problems an individual could be faced with in one day are: what necktie to wear; pleasing his wife; and discovering a new heat resistant metal alloy for space vehicles. Each one of these problems might be approached in a creative manner. However, the more difficult the problems become the more creativity is a requisite for solution.

Most problems dealt with by the human being are assumed to have solutions. Solutions result from the proper combination of associative elements which may not be easily perceived. In other words, a solution to any problem involves the mediation of associative elements into ideational contiguity. The more remote the requisite associative elements are, the more creative an individual needs to be to draw them together. Sarnoff Mednick (1962) hypothesizes three ways of attaining creative solutions, which are methods of bringing the requisite associative elements together:

1. Serendipity. In this case the requisite associative elements may be evoked contiguously by the contiguous environmental appearance (usually an accidental contiguity) of stimuli which elicit these associative elements.

2. Similarity. Requisite associative elements are evoked in contiguity as a result of their apparent similarity.

3. Mediation. The requisite associative elements are evoked in contiguity through the mediation of common elements. Mediation is the process often referred to as creative thinking.

The definition given above allows the factors that will make for individual differences in the probability of achieving creative solutions to be deduced. Any abilities or characteristics which serve to bring otherwise mutually remote ideas into contiguity will facilitate a creative solution, any abilities or characteristics which serve to prohibit remote ideas from contiguous evocation will inhibit the creative solution.

One of the mechanisms which is largely responsible for the inhibition of creative thinking (mediation) is set. For one reason or another, problem solving techniques become rather rigid. When a problem presents itself, the average problem solver can see only a narrow range of possible solutions. The unique, the original solution is arrived at by only those who are capable of going beyond the obvious, of wading through the stereotypes.

4.2 APPROACHES TO THE STUDY OF CREATIVITY

Some of the questions which are raised as one attempts to study creativity are as follows:

1. Is there a process amenable to analysis and synthesis?

2. Should great people, or creative people, people who are judged to be creative, be studied to analyze their modes of operation, their personality traits, and/or their backgrounds?

3. Are certain environments more conducive to creativity, than others?

When Stuart E. Golann (1963) reviewed the literature, he identified four main emphases in the study of creativity. They are products, process, measurement, and personality.

A. Products as Criteria

The study of products with respect to creativity involves viewing products as criteria of creativity. This assumes that a trait of creativity either unitary or multi-faceted, will be associated with end-products that result from certain types of behavior. Products are studied and judged for creativeness. The term creative is then applied to behavior which produced the end-products which were judged to be creative products.

There are studies in which the relationship between criteria variables such as number of publications, number of patents, and judges of creativity ratings are investigated. These approaches are quantitative rather than qualitative, and may in many cases be inappropriate. For example, some truly creative persons may labor all their lives on a few extremely difficult problems. The quantitative criteria of end-products then would not reflect their creativity.

B. Process

Here the study of creativity is accomplished through emphasis upon the processes involved rather than the end-products. One major difficulty here is that man is studying himself. He must learn to introspect and to be objective when dealing with subjective materials if you will. He must rely on observable behavior and then draw inferences.

Wallas (1926) described the stages of forming a new thought as follows: preparation, incubation, illumination, and verification. Preparation involves gathering data, and building an apperceptive mass. Incubation involves resting the brain in order to rid oneself of all incorrect sets. Illumination involves inspiration, insight or for a course of action to become clear during this phase. His fourth step, verification, is merely to behave, to do that which one has decided to do.

A question to be raised at this point is: Is the creative process systematized, goal directed or plastic. One example of the systematized or goal directed type defines the creative process in terms of six steps.

1. Realizing the need

2. Gathering information

3. Thinking through

4. Imagining solutions

5. Verifying

6. Putting ideas to work

The author of the above six steps stated that the difference between the illuminated minds of genius and ordinary people is the speed with which they proceed from step one to step six. This obviously implies that everyone goes through the same steps. That was a systematized, goal directed view of the creative process. An example of a different view is given by Taylor (1962): "The rules of logic and scientific method are a psychological strait-jacket for creative thought." Examining over one hundred definitions of creativity which occurred in the literature, Taylor identified five major levels of creativity. The are:

1. Expressive creati ity which is an independent expression where skills, originality, and quality are unimportant.

2. Productive creativity. A new level of accomplishment when skills allow development of finished products.

3. Inventive creativity. Here a flexibility in perceiving new and unusual relationships between previously separate parts occur, not new ideas, but new uses of old parts.

4. Innovative creativity. Basic foundation principles are sufficiently understood so as to allow improvement through modification.

5. Emergentive creativity. Here the conception of an entirely new principle at a most fundamental and abstract level occurs.

It appears to the present author that if man is to understand creativity, the answer will result finally in understanding the processes involved.

C. Measurement

Accordingly to authorities, tests used to measure creative abilities have not changed much in the last fifty years, but the methods of analysis have become more complex. One approach is the factor analysis approach. Guilford (1962) says that the lack of psychological knowledge in the area of creativity may be attributable to the inappropriateness of the SR model, for the study of higher processes. So he used the trait approach in the study of creativity, and used factor analysis to discover dependable traits. Noting some forty-seven factors of intellect, Guilford identified the following factorial aptitude traits to be related to creativity: the ability to see problems, fluency of thinking, which would be word fluency and ideational fluency, flexibility of thinking, originality, re-definition, and elaboration.

Some of Guilford's tests require individuals to state defects or deficiencies in common implements or institutions; to produce words containing a specified letter or combination of letters; to produce in a limited time as many synonyms as they can from a stimulus word; to produce phrases or sentences; to name objects with certain properties, for example, objects that are hard, white and edible; or give various uses for a common object. Guilford's practice in scoring these fluency factors is to emphasize sheer quantity rather than quality. Once again, the question is raised as to the appropriateness of this approach.

Another measurement approach other than the factor analytic approach is the criterion group empirical approach. The Welsh Figure Preference Test is a nonlingual test which is composed of 400 India ink drawings to which each examinee must respond "like" or "don't like." An empirical scale was developed by comparing the likes and dislikes of 37 artists to 150 people in general.

The revised scale consists of 30 pictures which artists liked more frequently than people do in general and 30 drawings which artists disliked more frequently than people in general. The basic assumption here, of course, is that artists are creative and that artistic creativity is composed of the stuff of which all creativity is made, which is an issue which has been discussed above. One would have reason to question this approach. However, rank order correlations of 0.40 and 0.35 between scores of the Welsh Test and creative writing instructor's ratings and originality and creativity of their students were reported by Welsh Gough (1961) reported that the scale showed the highest single correlation 0.41 with criterion judgments of research workers creativity.

Other tests which did not correlate well with the criterion judgments were three ability measures, the Allport-Vernon Value Scales, 56 of the 57 strong vocational inventory scales, Baron's Originality Scale, Baron's Preference for Complexity Scale, and 6 Guilford Measures.

Criteria and Predictors

The criterion problem with respect to measurement of creativity is probably the most critical and yet least studied problem. Insofar as research is concerned, some of the techniques which have been used to develop criteria are as follows:

1. Overall performance ratings by supervisors

2. Creative rating by supervisors

3. Quantity of patents

The criterion problem arises with the consideration of each new predictor. Predictors can only be as valid as the criteria which are developed. At this point in time the most successful method of establishing criteria for creativity is rating by experts.

Predictors

Some of the techniques which are used as predictors are as follows:

1. Biographical information

2. Self-rating

3. Personality and originality inventories

4. Aptitude and intelligence measures

5. Situational influences (parental attitudes)

6. Interest and motivation scales

7. Academic grades

8. Ratings by others

D. Personality

Another major emphasis within the psychological study of creativity is the study of personality. Specifically, the study of the personalities of persons rated or judged to be creative persons. These studies appear to be subdivided into two major categories: 1) the study of motivation in creative behavior; and 2) the study of personality characteristics of creative individuals.

The studies of motivation in creative behavior seemed to be characterized by two divergent views. One view is that creativity is a property which emerges and matures as an individual attempts to realize his fullest potentials in his interaction with his environment. Concepts that seem to be related to this notion are: Allport's functional atonomy, Goldstein and Rogers' self-actualization, Mays' motives for creativity. Individuals are creative because it is satisfying to them since they have a need to relate to the world around them. So they may experience themselves in action.

In contrast to the more positive motivations referred to in the concepts of self-actualization, and motives for creativity, is the other point of view in which creativity is a by-product of repressed or unacceptable impulses. Freud's sublimation is a case in point. There do not appear to be any studies in which these two approaches were experimentally compared. Perhaps the lack of critical experiments to test these two theories is due to the fact that the two groups of theorists mean something different when they speak of creativity. The Freudians seem to discuss painting and writing when they deal with creativity, whereas the self-actualizing group have a more general approach. Also, the concepts of self-actualization and sublimation, which they use to explain creative behavior are themselves constructs and difficult ones at that to define.

In studies of personality attributes of creative individuals, the basic approach employed is to contrast criterion groups on self-description, other descriptions, test performance, life history materials, and work habits. The criterion groups are selected on the basis of ratings of creativity, performance on Guilford tests, scores on the Welsh Figure Preference Test, and nomination of individuals of outstanding creativity by a panel of experts in their field.

The relationship between self-description and degree of creativity has been studied a great deal. Barron (1952) reported that subjects at the lower extreme on the Welsh Figure Preference Test described themselves as contented, gentle, conservative, unaffected, patient and peaceable. The high scorers characterized themselves as gloomy, loud, unstable, bitter, cool, dissatisfied, pessimistic, emotional, irritable, and pleasure-seeking.

Crutchfield (1961) attempted to describe personality attributes which tend to characterize creative individuals in general. He reported that in cognitive spheres, they are more flexible and fluent. Their perceptions and cognitions are unique. In approach to problems they are intuitive, emphatic, perceptually open and prefer complexity. In emotional, motivational spheres, they demonstrate freedom from excessive control, achieve via independence rather than conformity, are individualistic and have strong, sustained intrinsic motivation in their field of work.

4.3 AN APPROACH TO THE STUDY OF CREATIVITY

A study by MacKinnon (1962) is an example of a way of studying personality attributes by contrasting criterion groups. When referring to MacKinnon's work, it will be in terms of only the architectural group. He studied many groups representing engineering groups, scientists, business men, poets, artists, and different types, etc. However, for the purpose of studying his methodology employed, we have selected only the one.

MacKinnon himself accepted the notion that there is a difference between artistic creativity and scientific creativity. Consequently, he placed a great deal of emphasis upon his architect group, feeling that they bridged the gap between artistic creativity and scientific creativity. The architect has opportunity to express his own inner states much as poets and novelists do, as well as being a mediator between externally defined needs and goals in the same manner as industrial researchers, physical scientists and engineers do.

He chose a panel of experts, five professors of architecture, who nominated forty highly creative architects. Two additional samples were selected for study, both of which matched the highly creative sample with respect to age and geographic location of practice. The first group we will refer to henceforth as Architects 1. The first supplementary sample, Architects 2, had at least two years of work experience and association with one of the originally nominated creative architects. The second additional sample, Architects 3, was composed of architects who had never worked with any of the nominated creatives. The mean rating for creativity for each of the three groups, the ratings having been made on a nine point scale by six groups of architects and experts on architecture, was for Architects 1 -- 5.46; for Architects 2 -- 4.25; and for Architects 3 -- 3.54, the difference in mean ratings between each group being statistically highly significant.

All three groups were exposed to the same psychological examinations and interviews. Traits which were derived from the three groups are listed below:

1. Architects 1 have good opinions of themselves.

2. The self-images of the three groups were different. A1 described themselves as inventive, independent, individualistic, enthusiastic and industrious. A2 and A3 described themselves as responsible, reliable, sincere, dependable, clear-thinking, tolerant, and understanding.

3. There were no relationships between creativity and intelligence.

4. Architects 1 scored five to ten points higher on each of the following MMBI Scales: depression, hysteria, paranoia, schizophrenia. This was interpreted as good intellect, complexity and richness of personality, general lack of defensiveness, candor in self-description rather than psychopathology.

5. Architects 1 scored extremely high on the femininity scale.

6. All groups showed a clear preference for the complex and the asymmetrical.

7. The Myers-Briggs-type indicator test was used to measure openness to experience. The idea is that whenever the mind is used, either an act of perception takes place, in which the individual becomes aware of something; or an act of judgment takes place, in which a conclusion about something is reached. Everyone does both, but most people tend to show a consistent preference for one or the other of these two ways of using the mind. Creative writers, mathematicians and architects are perceptive types, research scientists, the majority of them at least, are judging types.

   The second preference measured by the type indicator is (1) sense perception, which is an awareness linked directly to sense and possibilities, and (2) intuitive perception, or indirect perception of deeper meanings. Twenty-five percent of the general population show preference for intuitive perception. Ninety percent of the creative writers show preference for intuitive perception. Ninety-two percent of the mathematicians showed preference for intuitive perception. Ninety-three percent of the research scientists showed preference for intuitive perception and one hundred percent of the architects showed preference of intuitive percention.

8. On the introversion, extroversion dimension, two-thirds of all creative groups score as introverts.

9. On the Strong vocational interest blank all creative subjects have shown interests similar to: Psychologist, Author-Journalists, Lawyer, Architect, Artist, and Missionary; and interests unlike: Purchasing Agent, Office Man, Banker, Farmer, Carpenter, Veterinarian, Policeman, and Mortician.

10. On the Allport-Vernon-Linsy Study of Values Scale, in which there are six basic values: theoretical, economic, aesthetic, social, political and religious; all have as their highest values, theoretical and aesthetic.

11. With respect to the life history studies, the following was found: Parents showed extraordinary respect for the child and confidence in his ability to do what was appropriate. Discipline was almost always consistent and predictable. Personal ethical codes were emphasized rather than formal religious practices.

A summary description of the creative person, especially of the creative architect, as he reveals himself in his profile on the California Psychological Inventory (Gough, 1957), reads as follows: "He is dominant; possessed of those qualities and attributes which underly and lead to the achievement of social status; poised, spontaneous, and self-confident in personal and social interaction; though not of an especially sociable or participative temperament; intelligent; outspoken; sharp-witted; demanding; aggressive; and self-centered; persuasive and verbally fluent; self-confident and self-assured; and relatively uninhibited in expressing his worries and complaints."

"He is relatively free from conventional restraints and inhibitions, not preoccupied with the impression he makes on others, and thus perhaps capable of great independence and autonomy and relatively ready to recognize and admit self-views that are unusual and unconventional."

"He is strongly motivated to achieve in situations in which independence in thought and action is called for but unlike his less creative colleagues he is less inclined to strive for achievement in settings where conforming behavior is expected or required. In efficiency and steadiness of intellectual effort, however, he does not differ from his fellow workers. Finally, he is definitely more psychologically minded, more flexible and possessed of more femininity of interests than architects in general."

4.4 RELATION TO FORECASTING

The three ways described in section 4.1 for attaining creative solutions, serendipity, similarity, and mediation, are all based upon the association of elements which make their appearance contiguously in an environment motivated by the problem to be solved. This parallels the forecasting process in which information is filtered from the total data file using the techniques of accidental discovery of relevant material, association of closely related concepts and processes, and tracing paths into related subject fields through synonymic, homonymic, and generic relationships. The inhibition of creative thinking through conceptual set, mentioned in section 4.1 as a mechanism which narrows the range of possible solutions, has its counterpart in the rigid structuring of technology into narrow fields of specialization which inhibits the prediction of developments resting upon interdisciplinary interaction and/or the creation of a new conceptual specialization. It is important to note that these aspects of creativity and forecasting are directly related to the associative manipulation of descriptors or index terms in mechanized information retrieval systems based upon concept coordination, as discussed in section 6.

The information retrieval approach applies with equal power to the stages of forming a new thought enumerated by Wallas, as described in section 4.2. None of these approaches through semantic association provides for a numerical measure of the data. But the linkages do allow for correlation and statistical measures, such as the factor analysis applied by Guilford. It is not surprising that factor analysis has also been applied to descriptors in information retrieval with the intention of measuring joint conceptual interrelationships. The study of human creativity strengthens the conjecture that the mechanization of forecasting is, at least to a substantial extent, the application of principles and techniques of information retrieval.

BIBLIOGRAPHY

1. Barron, F.; "Personality Style and Perceptual Choice," J. Pers., 1952, 20, pp. 385-401.

2. Crutchfield, R.; "The Creative Process," In, Conference on the Creative Person, Berkeley: University of California, Institute of Personality Assessment and Research, 1961.

3. Golann, S. E.; "Psychological Study of Creativity," Psychol. Bul., 1963, 60, 6, pp. 548-605.

4. Gough, H. G.; California Psychological Inventory Manual. Palo Alto, California: Consulting Psychologists Press, 1957.

5. Gough, H. G.; "Technique for Identifying the Creative Research Scientist," In, Conference on the Creative Person, Berkeley: University of California, Institute of Personality Assessment and Research, 1961.

6. Guilford, J. P.; "Factors that Aid and Hinder Creativity," Teachers Coll. Rec., 1962, 63, pp. 390-392.

7. Hall, A. D.; A Methodology for Systems Engineering, Princeton: D. Van Nostrand Co., 1962.

8. MacKinnon, D. W.; "The Nature and Nurture of Creative Talent," Amer. Psychologist, 1962, 17, 7, pp. 484-49[illegible]

9. Mednick, S. A.; "The Associative Basis of the Creative Process," Psychol. Rev., 1962, 69, 3, pp. 220-232.

10. Taylor, C. and Holland, J. L.; "Development and Application of Tests of Creativity," Rev. Educ. Res., 1962, 32, 1, pp. 91-102.

11. Wallas, G.; The Art of Thought, New York: Harcourt, Brace & Co., 1926.

5. DESCRIPTIVE TASK ANALYSIS OF TECHNOLOGICAL FORECASTING

The preceding two sections discussed human problem solving and creativity from the vantage point of the psychologist. The discussions were based upon extensive study of the literature, with special emphasis upon material relevant to descriptive task analyses of problem solving and creativity which contribute to better understanding of the operations engaged in by intelligence analysts. Although a small amount of light was shed on the latter, it is evident that much more research is needed to reach a satisfactory level of knowledge on this topic.

From the discussion of machine-oriented problem solving in section two, it is clear that mechanized technological forecasting in its most general form is a formidable task, hindered by incomplete information regarding relevant activities and developments, high noise level introduced by irrelevant information, and unknown goals (breakthroughs) which are not only unspecified but may even be rejected through skepticism or sheer lack of recognition.

If progress is to be made, it appears that a more limited objective should be set as a first milestone. This might consist of an intensive examination of the Air Force definition of forecasting by talking to Air Force analysts and developing a system model of the forecasting process in their environment including all aspects from acquisition of source data through generation of forecast. The derivation of the model would of necessity uncover questions concerning individual steps in the forecasting process and suggest specific research tasks to provide answers.

Since the study to develop a forecasting model was beyond the scope of the current study, a beginning was made by preparing a conjectured model to serve as a guide for further study as well as a framework for the other work on the project. The conjectured model is illustrated in flow chart format in Figure 5.

The text which follows is a highly abbreviated explanation of the various blocks in the chart.

1. The situation or milieu is the sum of the events and situations comprising the real world. Since events are continually occurring, the situation is constantly changing. We think of the situation advancing in discrete steps through 1, 2, 3, ..., N.

2. Many blocks in the flow chart represent a filter (F). Since no human being ever perceives the all of reality and since the human can only work with information which is perceived, the filters represent the total effects of selective perception, sensory limitations, etc., which tend to modify human perceptions of the real world.

3. The analyst makes a preliminary effort to organize those percepts of the real world situation remaining after the filtering process.

4. In the act of structuring the information concerning situation N, certain aspects of the information available are seen to be less important than others. The total information content is again reduced by a filtering process.

5. The structured information resulting from 4 is entered into the bank. The bank is conceived of as the total organism - nervous system, thoughts, memories, aperceptive mass, etc. In short, the structured information becomes a part of the total analyzing organism.

6. Out of the totality of experience and capabilities represented by the bank, the analyst will compare the new information to existing conscious ideas, concepts, and information already within the memory.

7 - 10. Blocks 7 and 9 represent the alternatives available to the organism as a result of the comparison process. If the information as structured in 3 is thought to be unique it will be reentered in the dynamic bank (10) with that label. If the information is not considered unique it may be forgotten (8) or entered into the bank (10) as nonunique information.

11, 12 and 15. The information entered in the bank (10) can either be reorganized and restructured (15) on the basis of the comparisons made or the information can precipitate a reexamination of the total situation based on the action thought most appropriate by the analyst. It must be emphasized that situation N is now situation N + 1 because time has elapsed during the time the preceding steps took place.

13 and 14. The reexamination of the situation results in a new set of inputs which are then filtered (13) and identified as being either confirmatory of the inputs of situation N or as being different from them in some way.

15 - 19. The reorganization (15) following the second-look inputs is followed by filtering (16), entry into a bank (17) and filtering (18) again as the restructured information is drawn upon for supporting the formation of concepts (19). Having formed concepts as to general trends or implications of the perceptual inputs, there are two basic paths through the next phase of the process.

20 - 26. One path involves the use of the concepts formed (19) earlier as a basis for generating tentative hypotheses (21) about the implications of the data. Both the inputs and outputs of this stage are filtered perceptually (20, 22, 23).

24 - 26. Having formulated tentative hypotheses, the analyst must begin looking for means to verify or reject the H. He can look to either the outside world (24) or inside world (bank) (26) in order to identify potential additional data sources (25). After filtering (30) the analyst then selects (31) those sources having the most promise of being useful in validating the H's he has.

27 - 28. The other path from concept formation involves the establishment of tentative criteria (28) for validating of the H. Block 29 shows the idea that at this juncture the analyst forms a criterion against which the first H will be tested.

Carrying forward the additional data collection process, the selected data sources (31) are further reduced by filtering and it is then time for the analyst to take a look at these sources.

34 - 38. This data is gathered from either the outside world (34) or bank (38), filtered (35, 37) and finally collected (36).

39. A series of relevance tests (39) are then applied to this data both with respect to validating data and validating criteria.

40 - 42. The results of these relevance tests are used to classify data for storage 40. The act of data storage is portrayed in 41. Data retrieval (42) for the final structuring (43) prior to analysis (44) and interpretation (45) is then accomplished.

46 - 49. The tentative hypothesis generated in block 21 is then tested (46) in relation to the criteria generated in 28 and 29 and the results of the analysis of the immediately preceding steps. The results of this test are then portrayed in 47 and 48. These outcomes are then put in the bank for future use in future steps in the analytic process.

50. The analyst, based upon earlier data from the data bank, seeks to single out possible actions which could be appropriate in settling the issues before him.

51, 53, and 55. Filters which screen out various courses of action (things he cannot bring himself to try, cannot think of, etc.).

52. Behavioral or data possibilities from reality (note that "reality" is part of the world from which the problem originated). The process of using the same world to suggest ideas, supply data, and provide the criterion is somewhat difficult to conceive and probably accounts for much error and poor progress.

54. The usual memory process.

56. Analyst thinks up ways to test validity of his further data collections.

57. Feasibility estimates are made to identify the activities which would result in supplemental data.

58. The alternatives are evaluated and selected.

59. Due to nonavailability, forgetting, selective recall or other filtering processes, the actions which actually get executed (60) are considerably reduced.

61 and 62. These indicate that there are successive repetitions of the data acquisition and consideration processes. Presumably these steps would be reduced to zero in cases involving insightful problem solving processes.

63. Having data to compare to expectations, the analyst can now compare to his preestablished criteria. Regardless of how this comparison turns out he needs to go back out to compare to the real world again. It needs to be noted that the world changes with time so a preestablished criterion may no longer be appropriate. Note also that the world is a product of perception.

65 and 66. These show the result of the comparison and, in either case, the outcome of the comparison in 64 is placed into memory in 67 where, if thought to be a good lead, one would capitalize on it, 69, and use it, 70. Otherwise, one would forget it (68) though one might also forget a good lead too. History seems to have numerous examples wherein

good ideas were lost because they were not recognized as immediate goals or even as good ideas.

It is apparent that we know least about the contents of boxes 15, 19. 28, 40, 42, 43, 44, 45, 57, 64, and 69. These must be better defined through further research, as discussed at the beginning of the chapter.

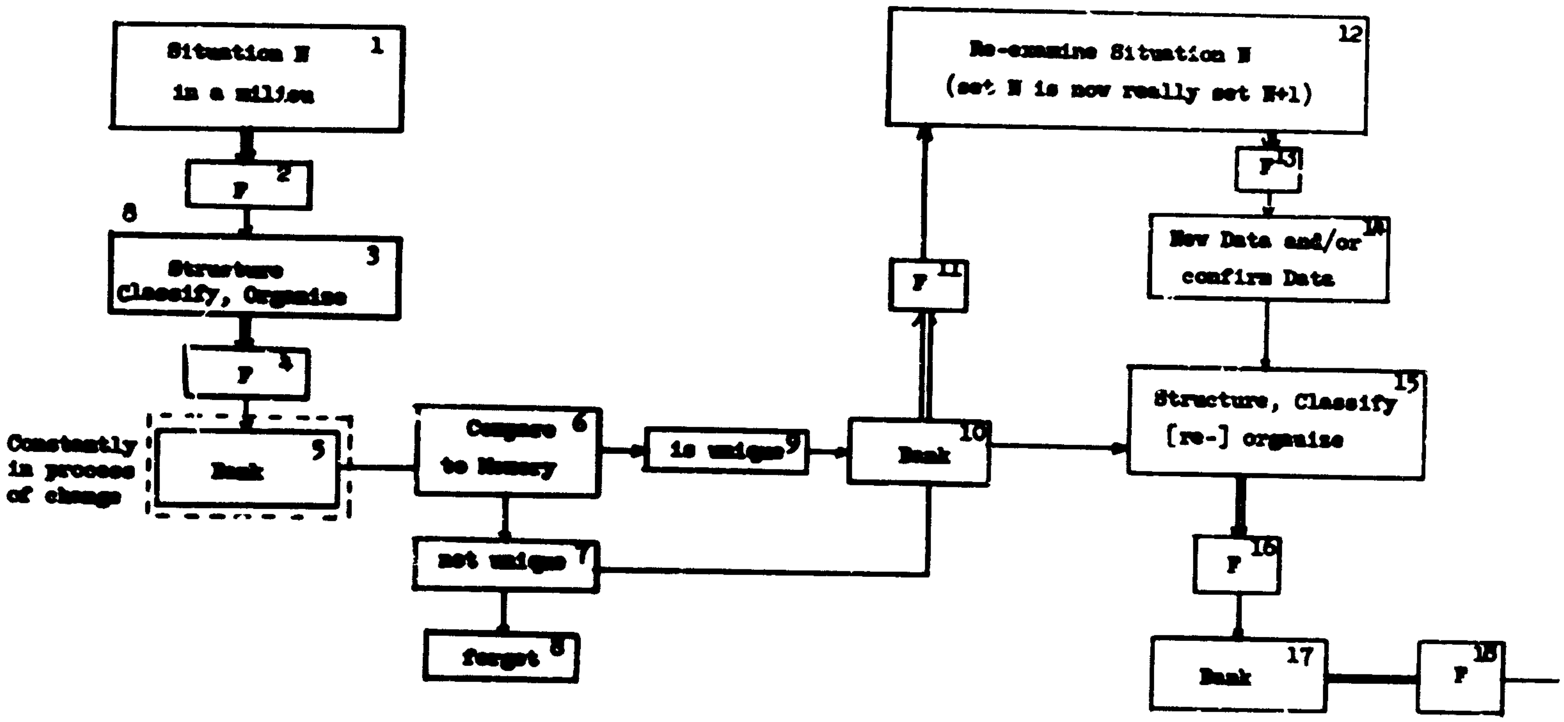

Figure 5. Conjectured Flow Chart of a Model of Technological Forecasting (Sheet 1 of 7)

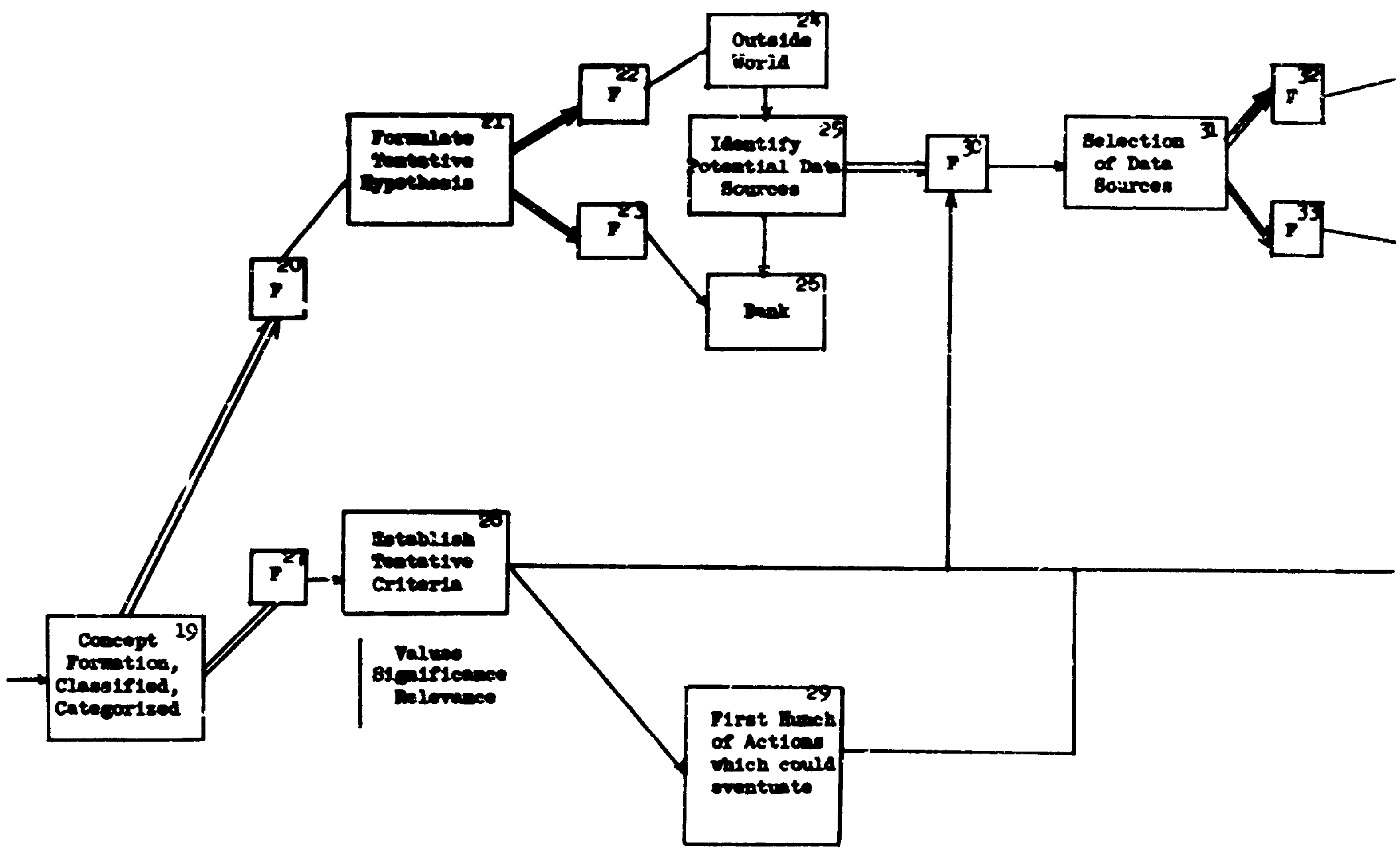

Figure 5. Conjectured Flow Chart of a Model of Technological Forecasting (Sheet 2 of 7)

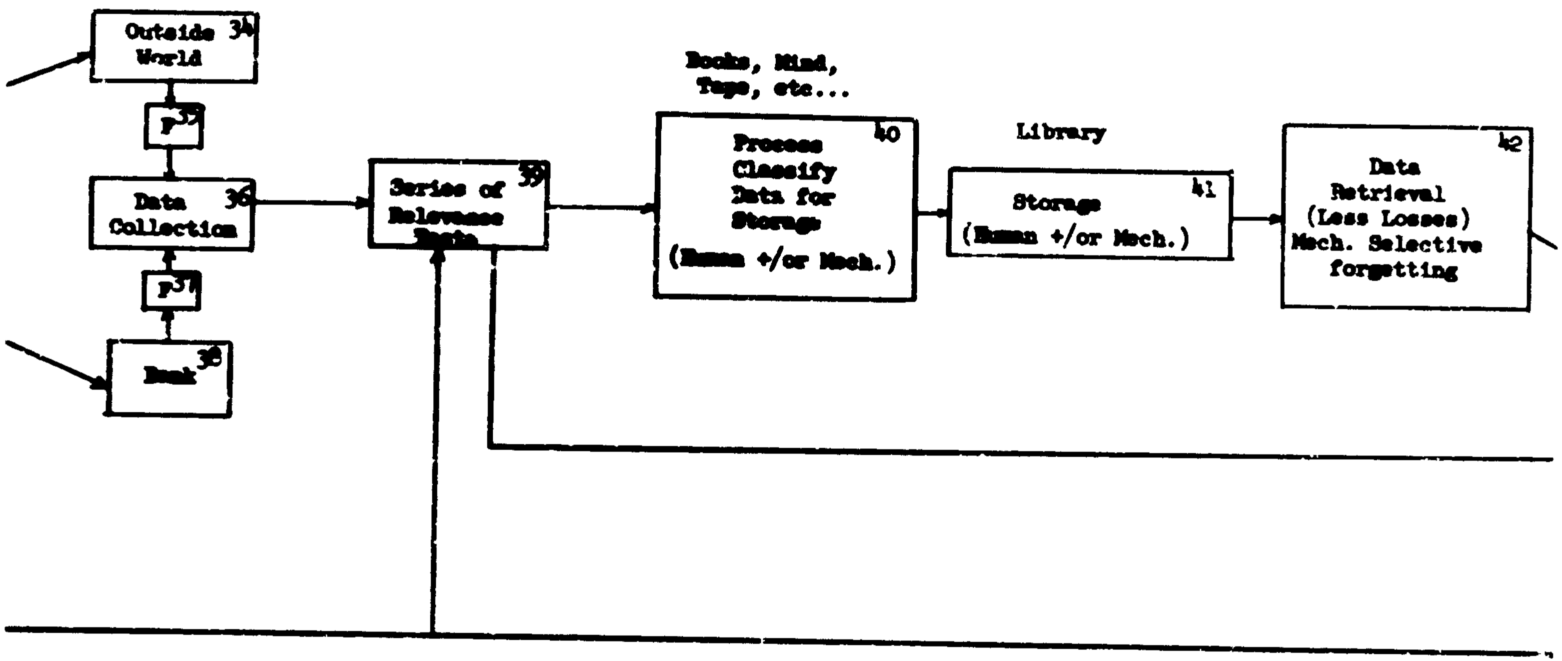

Figure 5. Conjectured Flow Chart of a Model of Technological Forecasting (Sheet 3 of 7)

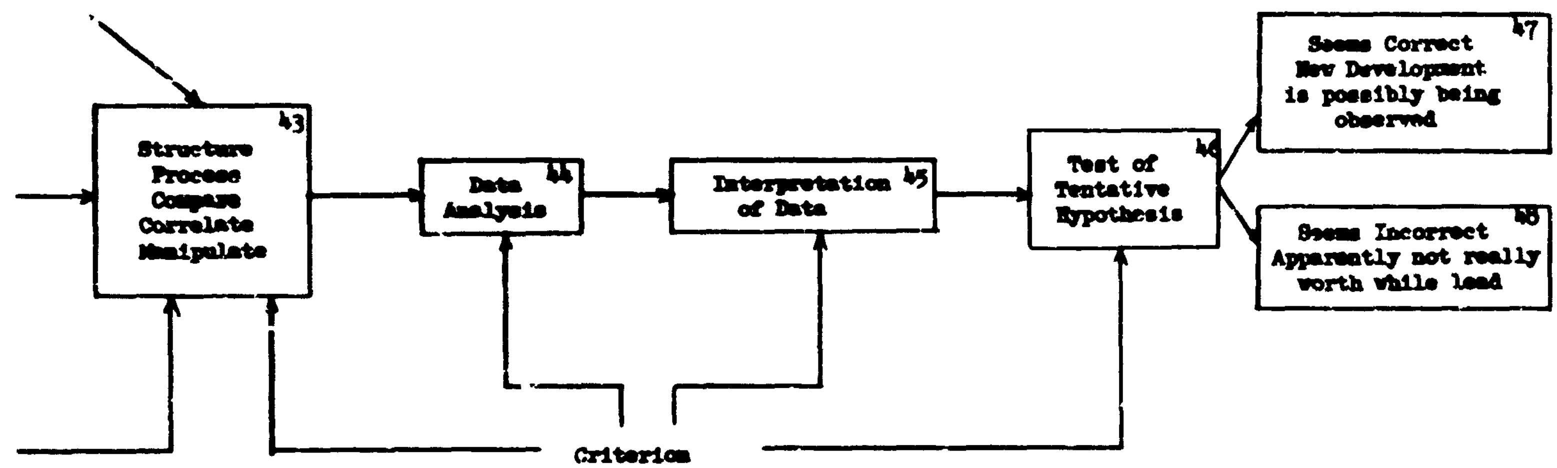

Figure 5. Conjectured Flow Chart of a Model of Technological Forecasting (Sheet   of 7)

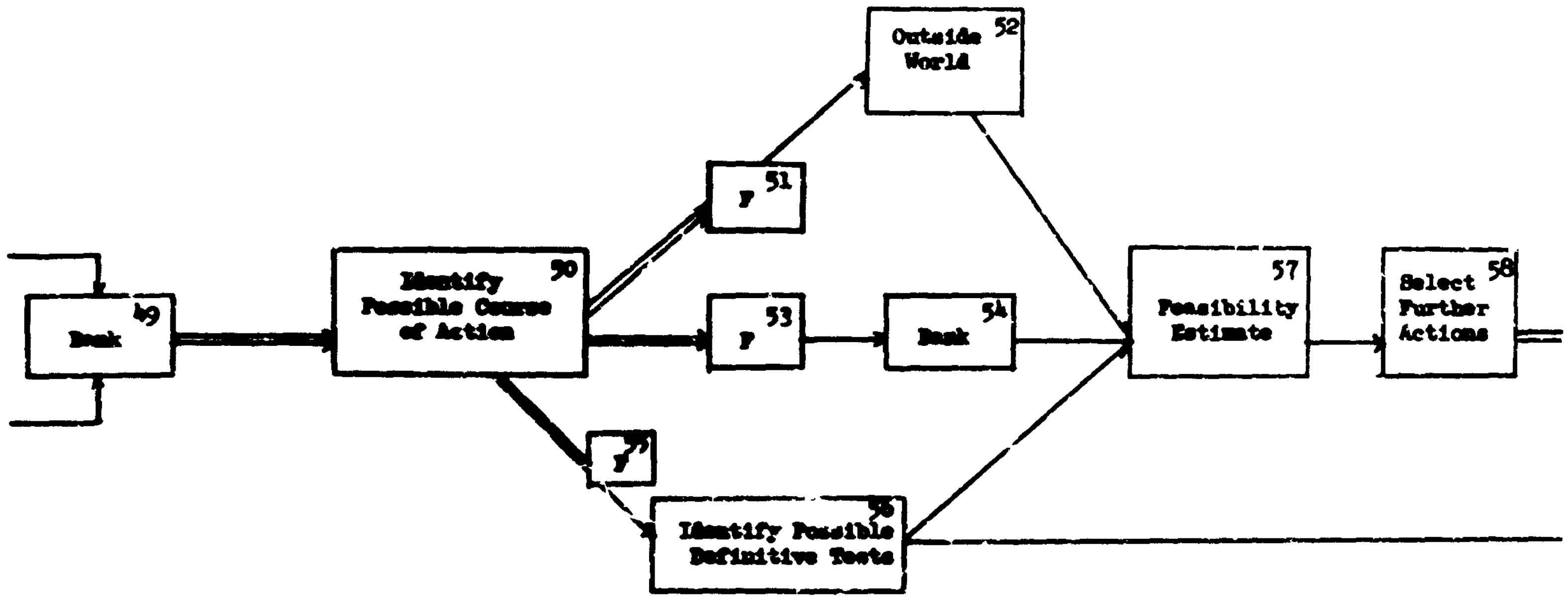

Figure 5. Conjectured Flow Chart of a Model of Technological Forecasting (Sheet 5 of 7)

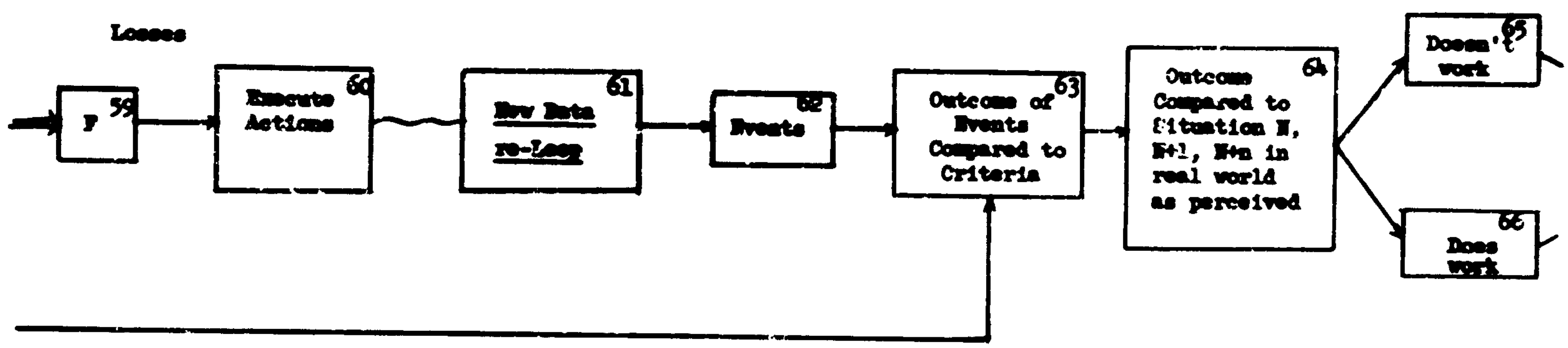

Figure 5. Conjectured Flow Chart of a Model of Technological Forecasting (Sheet 6 of 7)

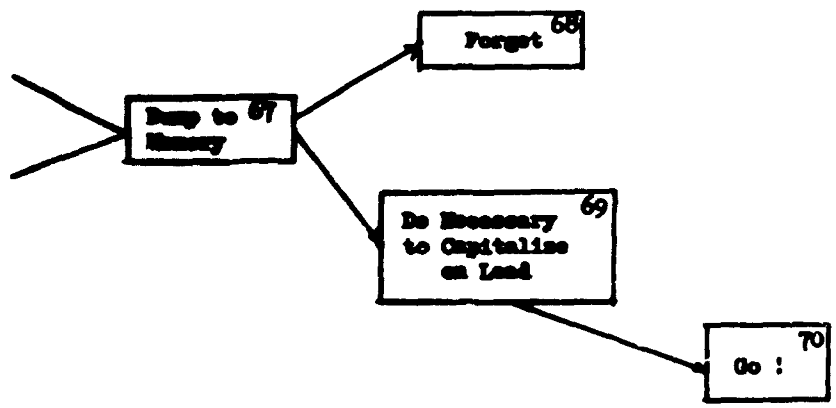

Figure 5. Conjectured Flow Chart of a Model of Technological Forecasting (Sheet 7 of 7)

6. INFORMATION SCIENCE APPLIED TO FORECASTING

Study of the discussions in the preceding chapters leads to the conclusion that problem solving, creativity, and forecasting have an important element in common. They are all concerned primarily with information handling. Technological forecasting is in fact a particular kind of information processing.

There is a basic difference between information processing in problem solving and that in forecasting. As described in Chapter 2 (section 2.1) a problem is composed of a set of initial objects, a set of operational rules, and a specified goal description. Problem solving consists of repeatedly applying the rules to the objects, with the objective of reducing the distance to (and eventually reaching) the goal. In a sense, this is a static game which can be played over and over again, with the differences among games determined only by the paths taken between the initial conditions and the achievement of the goal.

On the other hand, forecasting is a dynamic game in which the goals themselves are not known in advance. Thus, different games based upon the same initial conditions may lead to different goals, all of which must be accepted as feasible even though they may differ in credibility. Moreover, once a goal has been achieved, the previously unknown conditions thereby discovered become themselves part of the initial conditions for future games.

Technological forecasting may be likened to the Newton dynamics of physical objects, as illustrated schematically in Figure 6.1. The initial objects are the present state and present trends of technology, which may be compared with particle positions and velocities in a Newtonian space. Many forces are brought to bear upon the present state of technology, ranging from individual human curiosity through material propensities of society to socially or politically recognized communal needs. These forces act upon the present state in accordance with laws of change which are at present only vaguely understood and are certainly much more complicated than Newton's $F = ma$; better understanding of these laws of change is an area of research worthy of support if the forecasting process is to be mechanized effectively. The result of the application of the laws of change is a technology of the future which, when reached, becomes the new present state and present trends of technology.

The schematic illustration in Figure 6.1 may be extended by analogy to the dynamics of a gas. The molecules of the gas correspond to the individual bits of technological information currently known, molecular collisions correspond to association or correlation of technological concepts, and chemical reaction uniting two or more molecules into a new supermolecule corresponds to conceptual associations leading to an advanced novel superconcept or development in technology.

From the preceding discussion it is evident that a primary activity of any analyst/forecaster is the handling of information. It follows that the mechanization of technological forecasting is heavily dependent upon the foundations of information science. The balance of this chapter will be devoted to a discussion of the handling of information in preparation for its use in a mechanized technological forecasting system.

6.1 THE ORGANIZATION OF FORECASTING INFORMATION

The ultimate goal is the retrieval and manipulation of information in support of intelligence analysis and forecasting. Retrieval implies prior storage of not only relevant information but also control data for selective access to stored information. Manipulation implies associating information of different kinds and from different sources to relate existing forces to the present state of technology and to apply the laws of change; more specifically, it implies (1) filtering out all the "irrelevant" information while retaining all the "relevant" information, (2) guessing at missing "relevant" information, and (3) propounding a goal or goals which the information appears to support. Or conversely, it implies conjecturing a goal and successively implementing different associations of the retrieved information in attempts to prove or (preferably) disprove the conjecture.

For forecasting purposes it is not enough to store only technological information since this describes only present state and trends. It is necessary also to store characterizations of people, organizations, events, socio-economic and political motivations, etc., to reconstruct, diagnose, or simply guess at forces acting to create changes. If the system is to make tentative forecasting conjectures, then the laws of change and the criteria for recognizing significant developments must also be stored.

It should already be clear that the amount of stored information is enormous. An added complication is that the characterization of the information depends upon the specific interests of the eventual user; the significance of an item varies with the conjectured goal, so that its relevance depends upon the point of view of the analyst/forecaster. The control data which are used as "labels" or "indicial keys" or "index terms" or "descriptors" for the pragmatic retrieval of information items, must be carefully assigned in the light of an interdisciplinary and changing world of technology. The use of a single preassigned hierarchy of technological concepts no longer applies in ordinary library practices; it is a fortiori unacceptable for labeling the forecaster's files.

Technological information is in fact no different from knowledge in general. Its structure is a nonplanar network of concepts, with each concept connected to many other concepts through a multiplicity of association linkages, as illustrated in Figure 6.2. The concept A has a number of slightly different meanings

From the preceding discussion it is evident that a primary activity of any analyst/forecaster is the handling of information. It follows that the mechanization of technological forecasting is heavily dependent upon the foundations of information science. The balance of this chapter will be devoted to a discussion of the handling of information in preparation for its use in a mechanized technological forecasting system.

6.1 THE ORGANIZATION OF FORECASTING INFORMATION

The ultimate goal is the retrieval and manipulation of information in support of intelligence analysis and forecasting. Retrieval implies prior storage of not only relevant information but also control data for selective access to stored information. Manipulation implies associating information of different kinds and from different sources to relate existing forces to the present state of technology and to apply the laws of change; more specifically, it implies (1) filtering out all the "irrelevant" information while retaining all the "relevant" information, (2) guessing at missing "relevant" information, and (3) propounding a goal or goals which the information appears to support. Or conversely, it implies conjecturing a goal and successively implementing different associations of the retrieved information in attempts to prove or (preferably) disprove the conjecture.

For forecasting purposes it is not enough to store only technological information since this describes only present state and trends. It is necessary also to store characterizations of people, organizations, events, socio-economic and political motivations, etc., to reconstruct, diagnose, or simply guess at forces acting to create changes. If the system is to make tentative forecasting conjectures, then the laws of change and the criteria for recognizing significant developments must also be stored.

It should already be clear that the amount of stored information is enormous. An added complication is that the characterization of the information depends upon the specific interests of the eventual user; the significance of an item varies with the conjectured goal, so that its relevance depends upon the point of view of the analyst/forecaster. The control data which are used as "labels" or "indicial keys" or "index terms" or "descriptors" for the pragmatic retrieval of information items, must be carefully assigned in the light of an interdisciplinary and changing world of technology. The use of a single preassigned hierarchy of technological concepts no longer applies in ordinary library practices; it is a fortiori unacceptable for labeling the forecaster's files.

Technological information is in fact no different from knowledge in general. Its structure is a nonplanar network of concepts, with each concept connected to many other concepts through a multiplicity of association linkages, as illustrated in Figure 6.2. The concept A has a number of slightly different meanings

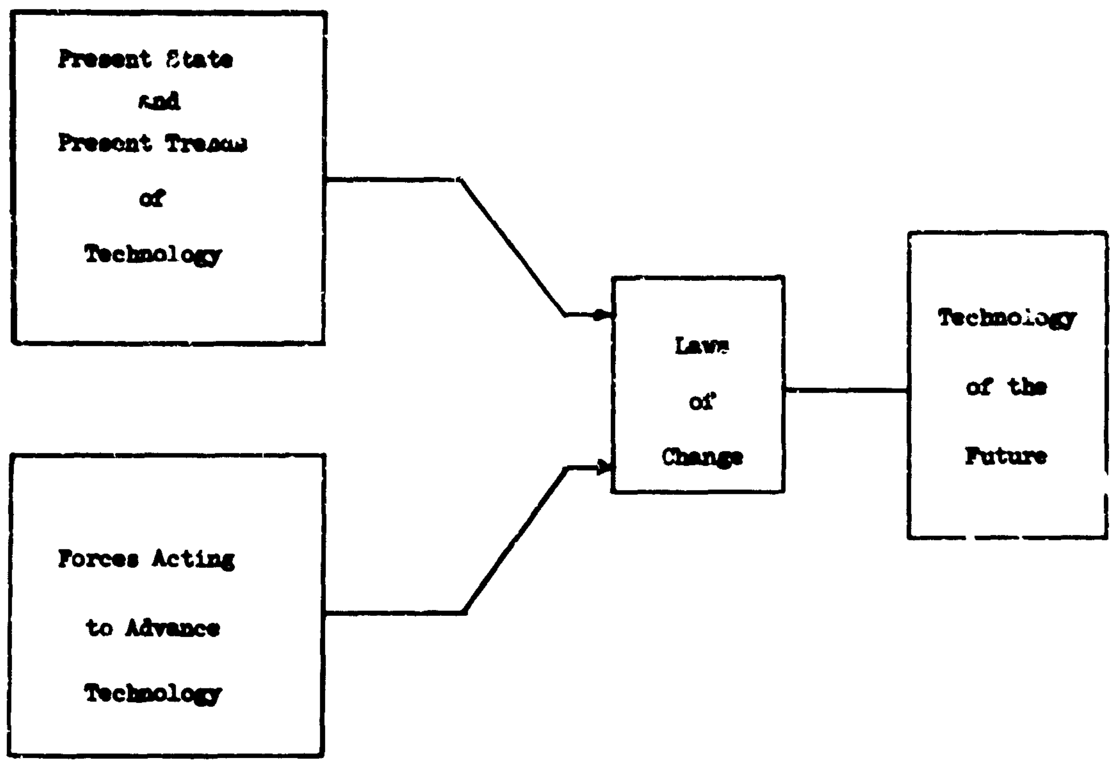

Figure 6.1. The Dynamics of Forecasting

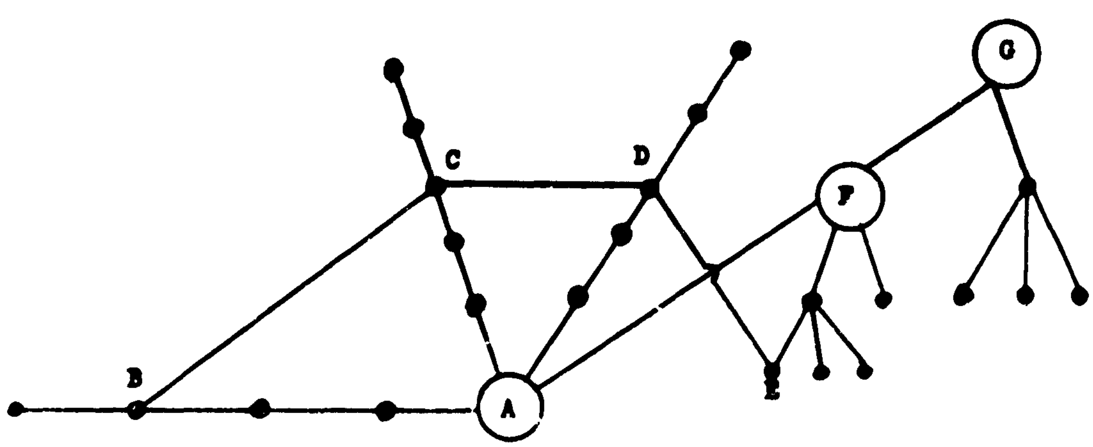

Figure 6.2. The Structure of Technological Information

which associate it with near-synonyms in three sets AB, AC, and AD. At the same time, A is generically related to F and G in tree structure, while B, C, and D have a conceptual association with E in the FG tree. There is nothing to indicate nor any reason to expect any closer relationship between A and E. The following example is taken from Roget's Thesaurus:

G - affections (Class VI)

F - personal affections (Section II). (Sibling sections are - moral affections, sympathetic affections, religious affections)

Under moral affections are many terms, including impropriety, exemption, contempt, flattery, and punishment (#972). Under punishment are a number of forms of punishment including

E - execution, which has a relation to

D - expression (in music, #416)

C - acting (in drama, #599), and

B - action (#680).

B, C, and D are all connected through A, "performance." In this example, A is not in the FG tree (Class VI): however, D is in Class III, Section III; C is in Class IV, Section II; B is in Class V, Section I; and A is of course in all three Classes.

Moreover, the generic relationship between A and F depends upon the analyst's point of view. For example, computer specialists rank automatic control as a particular specialty within information processing; control specialists rank information processing as a particular specialty within automatic process control. From their own specialized points of view, both are correct.

The point to emphasize is that information of itself is amorphous. It is the scientist/engineer who provides the structure to serve his specialized needs. Moreover, the assigned structure colors his point of view by providing a biased and unbalanced characterization, with his area of specialization at the center of the technological universe. Such a biased viewpoint is detrimental both to progress and to forecasting. Specialty-centered indexing of knowledge must be continually guarded against if mechanized support of forecasting is to be accomplished.

With full recognition of the enormity of the task of acquiring and storing all the technological, control, and force data to provide worthwhile support of forecasting, it appears feasible to make a substantial start through efficient use of information science. Discussion of specific aspects of an implementation procedure will now be discussed.

6.2 SPECIFIC ASPECTS OF FORECASTING INFORMATION

In addition to the multiplicity of sorts of information, and the complexity of the organization handling it, intelligence material includes numerous qualifiers or ancillary tags, such as:

Security classification

Need to know

Precedence of handling

General reliability of source

Specific credibility of instant information

Volatility with time of instant information

Date acquired or received

. . .

Report routine with respect to time

Report routine with respect to (referenced) event

Requested report

Happenstance acquisition

. . .

Initial material

Confirming material

Conflicting material

Updating material

Supplementing material

. . .

Forecasting probably requires repeated recourse to a file of information which is shared with others, some of whom are involved in minor but necessary tasks such as preparing current awareness digests for selective dissemination. Periodically the central file would be purged or updated, while ability would be retained for the analysts, etc., to recover information which they had once learned to recall.

Some other system parameters would be: A large file of interdisciplinary information which is occasionally reoriented with respect to projects or subject interests, a high degree of detail needed for indicial keys and output information, some means of performing validity checks as material is processed, methods of controlling and recording access to classified material, and high value ascribed to system speed of response. Complicated operating instructions might be permitted since the users would be a closed set. A prime objective of the system would be the shaping or confirming of speculations.

Factors regarding forecasting, just cited, mitigate in favor of mechanized information storage and retrieval. But information retrieval is not a "solved" art. Information is subjective in nature; its assessment depends upon the viewer and the occasion. Purveyors of information are troublesome; they sometimes omit details upon which we would like to base our system. However, certain expedients have been time-tested, and these should be useful to forecasting systems:

- Redundancy is assignment of index terms — which may permit uncertainty as to one element to be clarified via others.

- Assignment of chaining keys which may appear to have no value in themselves, but which are useful in establishing relationships.

Simple examples of special chaining keys could be times and places of events; related events might be discovered by searching in temporal or special neighborhoods - subject, perhaps, to other specifications. The general idea of chains is illustrated in Figure 6.3, in which ALGOL, a digital computer programming language, could be (1) the specialty of a person, (2) the name of software for listed equipment, (3) involved in the reason for existence of an organization, and (4) one aspect of an event.

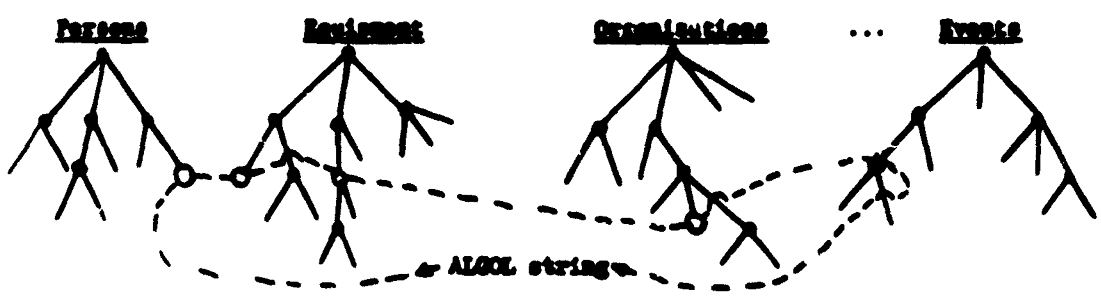

Figure 6.3. Illustrating a Chaining Key

The figure illustrates how such multiple associations could be traced. Some simplicity may be achieved by means of the Multilist attribute-value approach (e.g., attribute EQUIPMENT - value ALGOL). Specific tasks to which information retrieval systems may be addressed include the following:

(1) Concept coordination - e.g., locating persons, organizations, documents, etc., as described by a conjunction or other logical arrangement of indicial keys.

(2) Searches in neighborhoods or along strings, perhaps starting from some previously located node or intersection.

(3) Investigation of associations, their nature and degree; forming associations at prescribed removes.

Some emphasis on second and higher order associations may be in order. Quiliano, et al., has pointed out that near-synonyms are sometimes discovered via second order relationships. (He gives a matrix manipulation technique and an analogue model for investigating same.) Two usages are immediately foreseen for higher order associations:

(1) Searching in neighborhoods - such as requesting all items at one remove from a specific node - or at one remove subject to stated restrictions, etc.

(2) Relating documents to users, users to organizations, forces and events to subsequent events; as well as documents to documents, etc.

The chaining techniques which we suggest initially are those extending the Gray-Prywes Multilist System, perhaps with some attention to Cheydleur's SHIEF.

Information storage and retrieval systems now have demonstrable value in assisting formulation and reformulation of search requests. We suggest that simple extension of this capability may also spark the speculative processes of human analysts and forecasters, as well as retrieve correlating information from a complicated file.

6.3 POTENTIALLY APPLICABLE MEASURES

For purposes of exposition, we may regard measurement as being done according to the following progression:

(1) By naming the thing measured (a "thing" being the same no matter who views it).

(2) By associating it with other things (which involves abstracting a quality, consciously or otherwise).

(3) By ranking the thing in order along with other things - within the context of a specified quality.

(4) By assigning numbers via units on a scale for the abstracted quality.

(5) By relating the thing measured to a "law of nature" or to empirically determined, repeatable results.

But measurement of information - as opposed to data independent of context - is difficult. We can name indicial elements such as person and organization referents, and even "subject headings," with some hope of agreement with others with whom we work closely. We can ascribe relationships and associations; in a simplest case, we may denote whether an item is or is not a member of some set. We can qualify relationships so that they will be applied only with respect to some point of view. Ordering or ranking may be fairly easy when done with respect to continua of time and space, and situationally it may be easy to establish hierarchies of inclusion, etc. Our possibilities in assigning numbers and in discovering "laws of nature" or of logic need not be utterly discouraging; consider for example PERT-charting, which permits simulation and examination of consequences of failures of projected activities or events.

Conventional measure, using numbers, can be invoked profitably at this time in establishing statistics of occurrences, and of co-occurrences, to the end that subsequent discovery of similar patterns can cue investigations as to possible repetition of previously observed results.

However, for the present, human judgment is considered necessary in determining whether a major advance or breakthrough has occurred, or is forecast. A mechanized system could nevertheless provide alerting signals -- possibly based on indications such as the following:

- New trends in plotted curves.
- Norms exceeded (e.g., helicopter rotor blades exceeding the speed of sound).
- Projected time schedules out of limits.
- Dependent or supporting organizations activated or closed.
- New priorities assigned.
- Contracts or projects initiated or canceled.
- Other new forces applied.

Extreme changes could signify breakthroughs. Confirmation might be had through recourse to a "freakish or implausible indications" file.

We suspect that maintenance of such a "freak file," access to which would be available to the various analysts and forecasters, could result in more frequent or confident estimates and forecasts. Therefore, we suggest that characterizations of items of the various sorts of information filed be tagged -- to indicate items involving unusually high, or low, standards of excellence and/or high degree of aberration. For example, utilization of a low quality component in an overall precise assembly might indicate either improved redundancy techniques (i.e., obtaining high performance with unreliable components) or development of, say, non-linear control so that previously important quality factors are diminished.

Our central thought in this section is that speculation is best conducted by the human brain, but that intelligence forecasts incur a high demand for supporting data and information.

?.4 GENERAL NOTES ON INDICIAL KEYS

In the following section, potentially useful indicial keys are listed of the following sorts:

Documents

Persons

Organizations

Equipment

Forces

"Laws" of Change

Events

Times

Places

These are rough-cut at present, and are presented chiefly to illustrate the ideas of indexing multiplicity of types of information, and of providing chains via many types of connections. The scheme is generally the same as that which we have been considering in connection with the document retrieval system (the ACM Repository) which is located at The Moore School, and which appears amenable to attribute-value Multilist techniques.

Under each attribute, provision would be made for showing where a value is not assigned for unspecified reasons (i.e., the indexer is "not saying" why the omission appears) versus cases where a value could be assigned but it would be among the set of "everything other than those specified in the authority list." This distinction arises due to occasional indeterminacy or gaps in sources of information.

For each indicial key, ancillary tags could be used to signal where amplifying or expository remarks are available upon demand.

Each indexed item could be tagged according to its "freakishness."

As a major point, indexed terms - be they documents, persons, organizations, or whatever - would be numbered and then chained with as many other documents, persons, etc. as reasonable; this chaining might be via times and places even where these appear to be of no significance.

Chaining connections conceivably could be tagged as follows, although techniques capitalizing on this have been poorly explored as yet.

- Directed versus undirected (i.e., "arrowheaded").
- Sequence material versus sequence immaterial.
- Inclusion indicated/not indicated by "arrowheads".
- Connected items are/are not synonymic (subject or not subject to qualification).
- Connected items are/are not antonymic (subject or not subject to qualification).
- Connected items are/are not unspecifiably related - as when they are just members of the same, unordered set.

6.5 POTENTIAL CLASSIFICATIONS FOR FORECASTING INFORMATION ITEMS

6.5.1 Published Technical Documents

A - General Nature of the Text

1 - Advanced Research (Decimalize to show whether (1) "original scientific paper," (2) "provisional communication or preliminary notes," or (3) "subject review article" in accordance with UNESCO/ISC standards.)
2 - For Subject Specialists
3 - Tutorial

4 - Survey
5 - Promotional/advertisement
6 - Reference material/handbook
7 - Tables
. . .

B - Qualifiers as to Authenticity or Completeness

1 - The Original
2 - Copy
3 - Mass Reproduction
4 - Draft
. . .
10 - Abstract
11 - Extract
12 - Review
. . .

C - Professional Societies or Activities Referrent

1 - Various, Not Indexed Here
2 - Association for Computing Machinery
3 - Institute of Electrical and Electronic Engineers
. . .

D - Type of Interest by Professional Society

1 - National or International
2 - Regional
3 - Specialty within a Society
. . .

E - Educational Institution Referrent

1 - Various, Not Indexed Here
2 - University of Pennsylvania
. . .

F - Type of Output from Academic Institution

1 - Doctoral Dissertation
2 - Master's Thesis (MS)
3 - Master's Thesis (MA)
4 - Research Report
. . .

G - Private Research Foundation or Institution Referrent

1 - Various, Not Indexed Here
2 - Institute for Advanced Study, Princeton
. . .

H - Foreign Work Described in the Document

1 - British
2 - Canadian
. . .

I - (Not Used)

J - Language Used in Stored Document

(Use same list as H).

K - Military Activity Referrent

1 - Various, Not Indexed Here
2 - U.S. Department of Defense (Note: Be more specific if possible).
3 - IDA (Institute for Defense Analyses)
. . .
8 - U.S. Air Force.
. . .

L - Government Activity Referrent (Non-military)

1 - Various, Not Indexed Here
2 - Office of the President of the U.S.
. . .

M - Documentation Activity Referrent

1 - Various, Not Indexed Here
2 - Library of Congress
3 - DDC (ex-ASTIA)
. . .

N - Physical Type of Document

1 - Bound Book
2 - Journal/periodical
. . .

6 - Microfilm Roll

. . .

O - (Not Used)

P - Physical Condition of Document

1 - Good
2 - Legibility Marginal: Fading, etc.
. . .

Q - Type of Cover/Container of Document

1 - No Cover
. . .

R - Color of Cover/Container

1 - Extreme Mixture
2 - Blue/Purple
. . .

S - Special Contents of Document

1 - Abstract
. . .
4 - Photographs
. . .

T - Manufacturer or Private Company Referrent

. . .

U - Machinery (Hardware) Referrent

. . .

V - Software Referrent

. . .

W - Other Versions of This Document Which are in Stored File

(Use accession number of other version).

X - Number of Copies Held

. . .

Y - (Special Indicators Used in Conjunction with Z-Code)

. . .

Z - Special Code (used to connect with identifying numbers in the document, contract or project numbers, sponsors of work described or of the document itself, etc.)

Note: Covered by other means are:

- Conventional Bibliographic Elements (e.g., authors, title, issuing agency/publisher, date of issue, number of pages, number of figures . . .).

- Freely assigned descriptors and index terms.

Storage and control is via accession numbers.

6.5.2 Persons

A - Theorists/Methodologists/Practitioners/Politicians/Social & Entertainers/Workers
- Workers
  - White Collar
  - Blue Collar
- Practitioners
  - Top Executives
  - Senior Managers
  - Line Managers
  - Staff Managers

B - Attachment to Organizations
- Class (e.g., U.S. Navy)
- Specific (e.g., Bureau of Naval Weapons)

C - Attachment to Disciplines (e.g., high energy nuclear physicist)

D - Generalized Function
- Seller or provider
- Buyer or acquirer
- Custodian
- With minimized contacts

E - Education
- Level
- Specialty

F - Training/Special Skills

G - Language Abilities — Spoken / Written

H - Nationality — Of origin / Of previous times / Of the present

I - Security Clearance — Level / Need to know

J - Age

K - Sex

L - Physical Attributes

M - Health

N - Indications as to Level of Performance

O - Avocations

P - Indications of Aberrations or Peculiarities

Q - Continuing Chains to Persons, Equipment, Etc. (by classes)

R - Chains to Specific Items.

Note: Classify selected individuals as well as groups in batches.

3.5.3 Organizations

A - General Class or Mission — Governmental / Military / Research / Educational / Commercial

B - Products — Hardware / Software

C - Facilities Occupied

D - Equipment Utilized

E - Types and Numbers of Employees

F - Locations Occupied (Geographic)

G - Nations with which associated

H - Capitalization

I - Relationship to Other Organizations
- Vends to ______
- Receives from ______
- Warehouses for ______
- Distributes to/for ______
- Organizations to which senior
- Organizations to which junior
- Organizations with which affiliated
- Organizations loosely related

J - Continuing Chains (by classes)

K - Chains to Specific Items

6.5.4 Equipment

A - Hardware/Software

B - Producer: General Class/Specific Named Organization

C - User: General Class/Specific Named Organization

D - Warehouser: General Class/Specific Named Organization

E - Distributor: General Class/Specific Named Organization

F - Definitions
- Material of which made
- Process by which built
- Formal description of structure (e.g., geometric features)
- End-Use to which applied

G - Environment in which Useful/not usable

H - Cost/Weight/Size

I - External Power Required

J - Mobility: portable, transportable, fixed, etc.

K - Subassembly of ___ /Major Assembly of ___ /Software (or Hardware) Related ___

L - Continuing Chains

M - Chains to Specific Items

6.5.5 Forces

A - Assigned Priority < By which organizations / By which persons

B - Natural Priority

C - Contracts or projects

D - Funds Allocated

E - Facilities Allocated

F - Organizations Allocated

G - Persons Allocated < By names / By groups

H - Equipment Allocated

I - "Laws" of Change Related

J - Continuing Chains

K - Chains to Specific Items

6.5.6 "Laws" or Rules of Change

A - Discrete/Continuous

B - Probabilistic/Deterministic/Indeterminate

C - Monotonic/Non-monotonic

D - Single-valued/Multi-valued (discrete)/Zonal

E - Accelerating/Decelerating

F - Relation to Referenced Schedule < Ahead / Behind / In accord

G - Continuing Chains

H - Chains to Specific Items

6.5.7 Events

A - Time — At start; Duration

B - Place

C - Sponsor

D - Purpose — To discover; To teach; To influence or persuade; To entertain, for social pleasure

E - Likelihood of Occurrence

F - Persons Participating — Names; Groups

G - Organizations Participating — By names; Classes

H - Forces Related

I - Facilities Utilized

J - Continuing Chains

K - Chains to Specific Items

L - Areas of Impact — Basic Science, Military, Socio-political; Economic, National, International

6.5.8 Times

A - Local (date-time)

B - General Reference (such as Greenwich date-time)

C - Day/night

D - Season

E - Weather

F - Continuing Chains

G - Chains to Specific Items

6.5.9 Places

A - Name of Place

B - Location on World Grid (coordinates)

C - Organization

D - Nation(s) < date established
date terminated

E - Continuing Chains

F - Chains to Specific Items

7. A MATHEMATICAL MODEL FOR TECHNOLOGICAL PREDICTION

As has been discussed in the previous sections, the general problem of forecasting technological breakthroughs is complicated by incomplete knowledge of the present state of technology, incomplete knowledge of the forces acting to change knowledge, and incomplete knowledge of the laws of technological change in response to the applied forces. In this section, a mathematical model is derived which defines technological change in terms of change of present state and presents statistical correlation procedures for minimizing or at least reducing the uncertainties introduced by incomplete information. The model bypasses the other complications of generalized forecasting, namely the unspecified indeterminate multiplicity of goals, by specifying a particular goal.

The model addresses itself to the prediction of advances to be anticipated in specific aspects of a particular technological specialty. As stressed in the preceding section, forecasting is a special case of information manipulation and association. It is therefore natural to find that the model is based upon the descriptor techniques of information science.

7.1 PREDICTION MODEL PARAMETERS

Since the problem is only that of prediction, the model need not and does not consider actions that might be needed as a consequence of the prediction. Moreover, since the prediction is limited to technological developments, only those data which relate to technology and its growth need to be incorporated into the information file. There are certain parameters which must now be assumed within the framework established above.

1. Time must be considered as an explicit, independent variable. To identify a development after the development has occurred is not prediction but merely information retrieval.

2. Not only the state but also the structure of technology is changing in time. If we define S_t as the "technological structure" at time t, we recognize that the basic plan requires acquiring the maximum possible knowledge of S_t to achieve some (as yet undefined) comprehensive knowledge concerning the technological structure. In addition, the passage of time (and the inherent advance in technical knowledge) will modify S_t to S_{t+1}. For the area of interest, S_t may or may not be equivalent to S_{t+1}.

3. A key element of prediction is the question of what constitutes a "change." Technological development and breakthrough can be defined in the following manner: Given an information matrix S_t and S_{t+1}, separately derived, then

   a. A new product-device "line-item" appearing at time $t+1$ should be directly related to one or more research line-items at t. The appearance of this new line item constitutes a technological development, but not a breakthrough.

   b. A technological breakthrough occurs when:

      1) the set of descriptors at $t+1$ is different from the set at t, and in particular:

      2) the set of descriptors at time t is not sufficient to describe the new line-items, and either:

         a) one or more new descriptors must be added without violating the criterion of "necessary and sufficient" implied in Step 3 of the procedures for developing the information matrix (see section 7.2 below).

         b) a new information matrix (in addition to the existing one) must be created.

4. A fourth parameter involves the degree of confidence and the degree of detail which must be provided by the system before one can declare the prediction has been successfully made. At the lower end of the scale is a system which simply indicates a change that will occur with a given (but low) probability at some time in the future, without identifying either the nature of the change or its impact on observers. This could very easily be done on the basis of a priori statistics. At the extremely high end of the scale, one could report with high probability that Prof. Jones will, on July 15th, 1965 carry out experiments which will successfully demonstrate that there is a fourth dimension. Clearly this could be done only through an extremely elaborate intelligence network, and some god-like prescience. The system for which we are searching lies somewhere between these two extremes; some of the changes from S_t to S_{t+1} with high probability.

5. A fifth and final parameter involves the value function or payoff criterion to be used to evaluate the degree of effectiveness of the problem solving technique to be used. At first glance, the value function would appear to be S_∞. That is, the ultimate objective of the problem solving system under consideration is to effect a mapping of any S_t into S_∞ with a minimum effort and/or elapsed time. However, S_∞ is, by its very nature, undefined and we are thus faced with the task of evaluating whether S_{t+1} is significantly nearer to S_∞ than S_t. In short, we lack a quantitative value function. A poor alternative may be simply to assume that more information, per se, laid on S_t will lead to S_∞.

The above serve to indicate that much attention should be given to the definition of the problem solving task, before further effort is devoted to problem solving techniques, per se.

7.2 PROCEDURES FOR DEVELOPING THE INFORMATION MATRIX

As mentioned above, the model is based upon the descriptor techniques of information science. Although general information has a network interrelationship structure, specification of the subject of interest in the prediction (the "line-item") permits a projection of the information network onto a plane into the structure of an information matrix. An illustrative matrix is shown Figure 7.1; a more general matrix is shown in Figure 7.2. Justification for this simplication is its successful application to the forecasting of trends in a number of technological areas; an actual example is described below. Procedures for generating the matrix are as follows:

Step 1. At any time t, gather all data/information on a subject area of interest. The area must contain one or more product-device "line-items."

Step 2. Evaluate this data base and identify product-device "line-items." For example, for the computer subject field, a line item might be the "7090 Computer."

Step 3. Consider the set of "line-items" and develop a list of descriptors which categorize these line-items. The number of descriptors must be sufficient to differentiate between each line-item, yet must not be greater than the minimum number to identify all items without redundancy.

Step 4. Set up a matrix of line-items versus descriptors and fill in with known data as of time t_0.

Step 5. Identify all research under way which may affect one or more of the above descriptors. Call each research project or project class a research "line-item."

Step 6. Evaluate each research line-item relative to the set of descriptors and establish (for every relevant intersection), the impact of that research on that descriptor, and the estimated time of any breakthrough(s) which are projected to occur. Impact will be described in terms of a linear scale from 0 to 1.0.

Step 7. Add all research "line-items" to matrix.

This process is repeated for each matrix at every new time period, until production data and comparison tables, and cross-correlation factors have been built up, such that each new matrix can be automatically predicted in advance.

7.3 TYPICAL DESCRIPTORS FOR A SPECIFIC FORECASTING EXAMPLE

D_1 General

1.1 Cost of the basic system; purchase price in dollars of a minimum workable installation; composed of commonly used input and output, minimum logic and control and storage, internal working.

1.2 Cost of average system; the purchase price in dollars of an average of actual installations at time if such is available. If not available an estimate should be developed based on the usage of similar systems at the time.

1.3 & 1.4 Monthly rental (for items 1 and 2 respectively).

1.5 Initial installation; the date the first system was delivered to the customer.

D_2 System Technology

2.1 Logic type; the type of hardware element(s) used in logical circuits, e.g., Magnetic Cores, Transistors, Diodes

2.2 Ability to add modules.

D_3 Processing

3.1 Basic Pulse Repetition Rate (in megacycles per second).

3.2 Timing; synchronous or asynchronous.

3.3 Operation; sequential or parallel.

3.4 Number of addresses per instruction.

3.5 Number of index registers.

3.6 Binary word size (number of bits).

3.7 Decimal word size (number of digits).

3.8 Alphanumeric word size (number of characters).

3.9 Add time — (Microseconds, excluding access).

3.10 Add time — (Microseconds, including access).

3.11 Multiply time — Microseconds (excluding access).

3.12 Multiply time — Microseconds (including access).

3.13 Special features (specify).

D_4 Storage

For each type of storage;

4.1 Relation to Computer

Internal; storage facilities forming an integral physical part of the computer and directly controlled by the computer; the total storage automatically accessible to the computer.

Secondary; storage facilities not an integral part of the computer but directly connected to and controlled by the computer

External; storage facilities divorced from the computer itself but holding information in the form prescribed for the computer.

Buffer storage; a synchronizing element between two different forms of storage, usually between internal and external.

4.2 Media; delay line, CRT, drum, tape, core.

4.3 Characteristics

Average access time; the time interval in microseconds between the instant at which information is called from storage and the instant at which delivery is completed, or ready for storage and the instant at which storage is completed.

Transfer Rate; the number of units of information per second that can be read or written, at the maximum rate.

Capacity, (minimum or basic); number of units of information that the basic system is equipped with or the minimum number of units that can be obtained.

Capacity, (maximum); maximum number of units of information that the system is capable of using.

D_5 Input

5.1 Maximum number of inputs to basic or minimum system allowing some output.

5.2 Maximum number of inputs to maximum system allowing some output.

5.3 For each type of input possible; maximum number of this type possible, maximum rate, special features.

D_6 Communications

6.1 Type; off-line, on-line, land-line.

6.2 Channels; (number)

6.3 Rate; bits/second, decimal digits/second, characters/second.

D_7 Output

7.1 Maximum number of outputs of basic or minimum system allowing some input.

7.2 Maximum number of outputs of maximum system allowing some input.

7.3 For each type of output possible; maximum number of this type possible, maximum rate, special features.

D_8 Physical

8.1 Power of the basic or minimum system (in KVA or KW).

8.2 Size of the basic system (in square feet).

8.3 Volume of the basic system (in cubic feet).

8.4 Weight of the basic system (in pounds).

8.5 Minimum and maximum operating temperature (degrees).

8.6 Relative humidity range, upper and lower limits (percent).

A partly completed matrix is shown in Figure 7.3.

7.4 FORECASTING ESTIMATES FROM RESEARCH AREAS

The preceding matrix displayed information on the current state of technology. To this must be added the forces acting to alter the technology. A particular matrix applicable to the specific example consists of relevance estimates for advances in the areas of specific descriptors stemming from research activities in known specialties. Figure 7.4 illustrates the relevance estimates for some of the descriptors of Figure 7.3 and three specialties, multiple processors, information retrieval, and molectronics.

7.5 APPLICATION OF MATRIX DATA

To apply the information from the matrices describing state of the art and forces being applied, the laws of change are required. These laws are necessarily determined by the specific technology and forces; one of the goals of a study to mechanize forecasting should be to classify these laws into classes applicable to sets of technological specialties and types of forces. A conventional approach is the use of straight-line prediction. This is effective for short range forecasting but becomes progressively less accurate for longer range forecasts.

Three examples of straight line forecasting from the matrices of Figures 7.3 and 7.4 are shown in Figure 7.5. One observes that the larger computers are aiming toward 400 instructions while the small computers are stabilizing at about 40. There is a continuing tendency for computers to be designed with an intermediate number of instructions.

On the other hand, memory access times for large and small computers seem to be aiming toward one and ten microseconds, respectively, with perhaps a group of intermediate computers having four microsecond access time.

Weight for all computers seems to be headed for the 3000 to 5000 pound range.

These forecasts have in fact been borne out by recent developments but new forces have been brought into play, such as thin film memories and micro-electronics, which are affecting the accuracy of continued straight-line prediction. Moreover, as stated above, the illustrative example is simpler than the general forecasting problem for several reasons. Presumably the matrix approach can be used in the more intricate situations using the full information network (as discussed in section 6); this can be determined only by further study of the utilization of the more general information file.

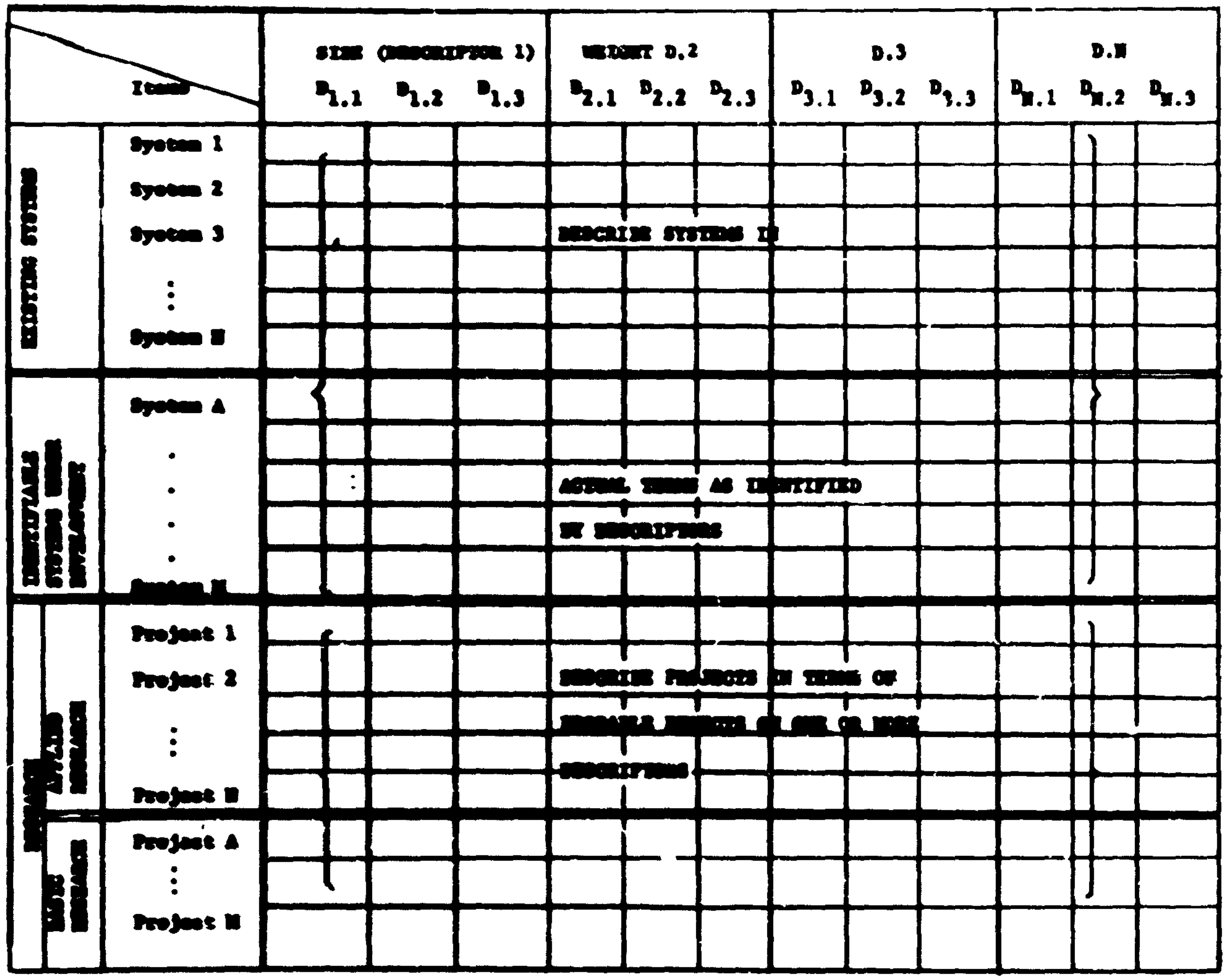

Figure 7.1. A General Information Matrix S_t

			DESCRIPTORS							
			D_1 General	D_2 Techno-logy	D_3 Processing	D_4 Storage	D_5 Input	D_6 Communi-cations	D_7 Output	D_8 Physical
			Cost Initial Inst. Date No. of Units	Logic Type Expandibility Modular Type	Clock Rate Word Size Add Time Multiply Time	Type Size Access Speed	Types Channels Rate ([illegible]/SEC)	Number Types	Number Types	Power Size Weight
EQUIPMENT	(1) Line Items Available	Univac 1 RR 1103 B 205 B 220 IBM 709 IBM 7090								
EQUIPMENT	(2) Under Develop-ment	IBM 7080 RCA 601								
RESEARCH	(3) Systems	Multiple Processors Information Retrieval Self-Organizing Systems Language Translation								
RESEARCH	(4) Components and Devices	Molectronics Cryogenics Tunnel Diodes, Etc.								

Figure 7.2 Information Matrix S_t

D_1 General

Line Item / Descriptors	Available: R.R. Univac I	Available: RRU 1103A	Available: Philco 2000	Available: IBM 709	Available: IBM 7090	Under Development: IBM 7080	Under Development: RCA 601
Basic System Purchase Price	$ 768,000	$ 760,000	$ 540,000		$2,191,600		$ 894,800
Average System Purchase Price	1,132,500	1,500,000	2,000,000	$3,000,000	3,500,000	$2,300,000	1,700,000
Basic System Rental (Annual)	164,520	215,760	144,000	279,600	588,000		240,600
Average System Rental (Annual)	238,200						425,000
Date of Initial Installation	March 1951	October 1956	1958	March 1959	September 1959	1961	September 1961

D_2 System Technology

Line Item / Descriptors	R.R. Univac I	RRU 1103A	Philco 2000	IBM 709	IBM 7090	IBM 7080	RCA 601
Logic Type	Vacuum Tube	Vacuum Tube	Transistor	Vacuum Tube	Transistor	Transistor	Transistor
Ability to Modules	None	None	Yes	None	Yes		Yes

Figure 7.3a. Typical Information Matrix

LARGE SCALE COMPUTERS

D_3 Processing

Item Description	R.R. Univac I	RRU 1103A	Philco 2000	IBM 709	IBM 7090	RCA 601
Basic Pulse Rate MC/sec.	2.25	0.5				
Operation	Sequential	Sequential	Sequential	Sequential	Sequential	
Addresses/ Instruction	1	2	1	1	1	
Word Size Bits		36	48	36	36	56
Add Time With Access	525	44	15	24	4.8	
Multiply Time With Access	2150	239	49	190	38	72
Number of Instructions	45	50	225	208	220	
Special Feature	Duplicate Circuitry	Floating Point	Floating Point	Indirect Addressing	Indirect Addressing	Multi-level Indexing

Figure 7.3b. Typical Information Matrix

LARGE SCALE COMPUTERS
D_4 Storage

Item Description	R.R. Univac I	RRU 1103A	Philco 2000	IBM 709	IBM 7090	IBM 7080	RCA 601
Internal Storage Main	Acoustic Delay Line	Core	Core	Core	Core	Core	Core
Average Access Time Microseconds	222	8	10	12	2.4	2.18	1.5
Minimum Capacity	1000 words 12,000 char.	4096 words 147,456 bits	4096 48-bit words	4096 36-bit words	32,768 36-bit words	80,000 char.	8192 56-bit words
Maximum Capacity	1000 words 12,000 char.	12,288 words 442,368 bits	32,768 48-bit words	32,768 36-bit words	32,768 36-bit words	160,000 char.	32,768 56-bit words
Magnetic Tape Storage							
Maximum Transfer Rate	12,800 char./sec.	76,800 bits/sec.	90,000 char./sec.	15,000 char./sec.	62,500 char./sec.		120,000 10-bit char./sec.
Maximum Packing Density	128 char./inch	768 bits/inch	750 char./inch	200 char./inch	555 char./inch		800 char./inch
Speed	100 inches/sec.	100 inches/sec.	120 inches/sec.	75 inches/sec.	112 inches/sec.		
Start-Stop Time Microseconds	[illegible]		8600	10,800	7300		6000
Maximum Number of Units	10	10	256	48	80		768 8-concurrent
Maximum Capacity/Reel	1,440,000 char.	8,640,000 bits	17,000,[illegible] char.	5,760,000 char.	14,000,000 char.		

Figure 7.3c. Typical Information Matrix

FIELD OF RESEARCH

Line Item / Descriptor	Multiple Processors	Information Retrieval	Molectronics
Basic System Purchase Price	.2	0	.4
Average System Purchase Price	.2	0	.4
D_1 Basic System Rental (Annual)	.2	0	.4
Average System Rental (Annual)	.2	0	.4
Date of Initial Installation	(1966)	(1964)	(1964)
Logic Type	0	0	0
D_2 Ability to Add Modules	.9	.2	0
Basic Pulse Rate MC/sec.	0	0	.3
Operation	.9	0	0
Addresses/Instruction	.7	.2	0
D_3 Word Size Bits	.2	.3	0
Add Time With Access	.5	0	0
Multiply Time With Access	.6	0	0
Number of Instructions	0	0	0
Special Feature	.7	.9	0

Figure 7.4. Typical Relevance Matrix

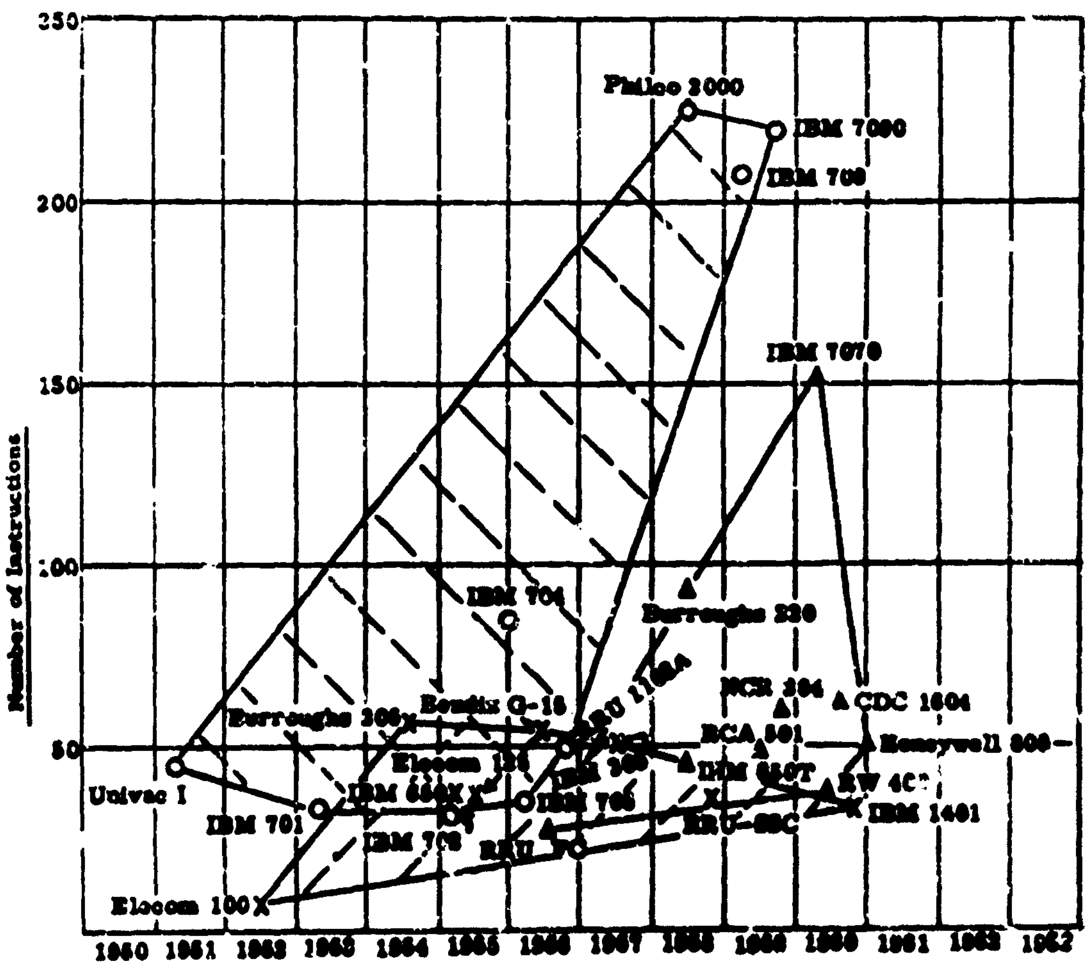

Figure 7.5a. Forecast of Number of Instructions in a Computer

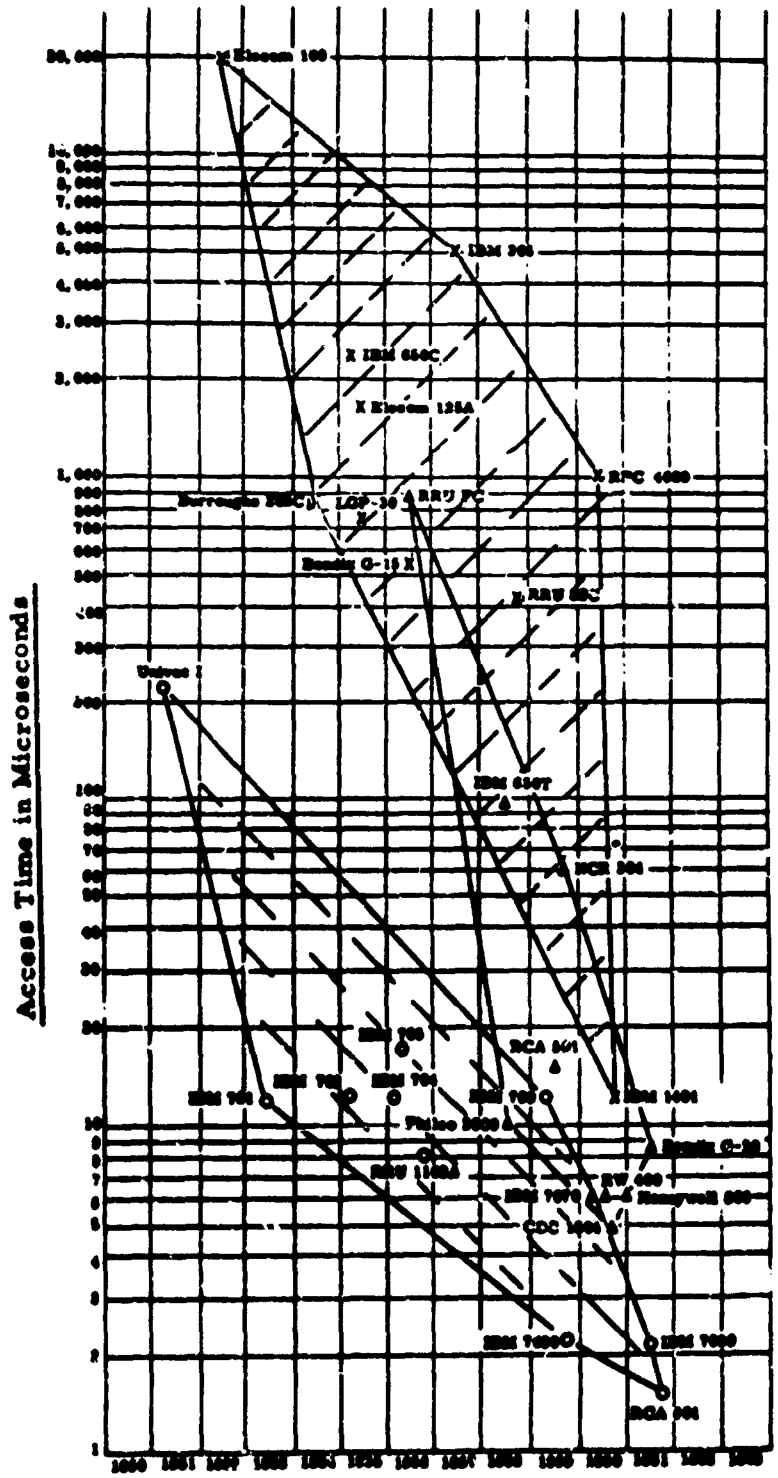

Figure 7.5b. Forecast of Internal Storage Access Time

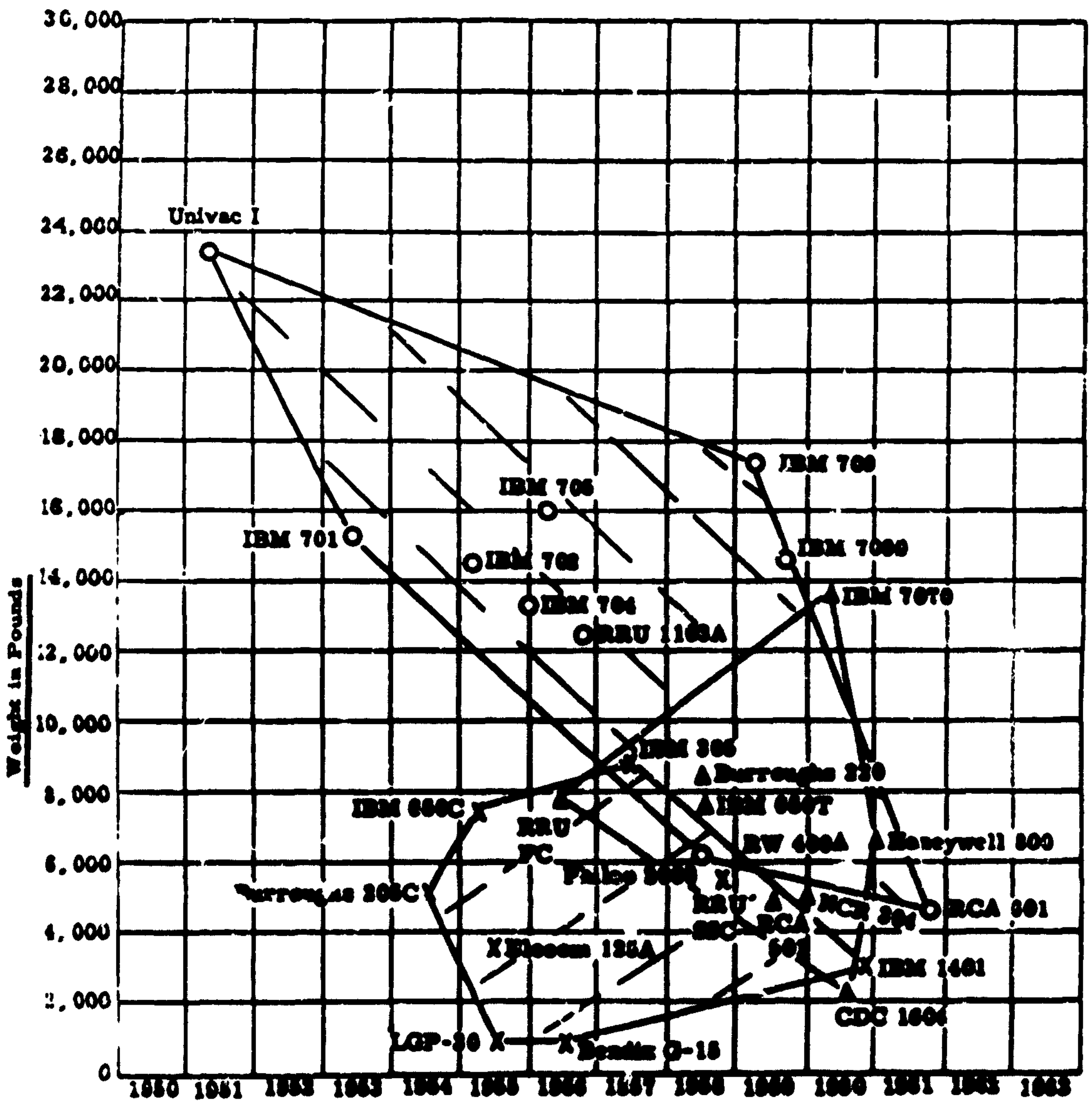

Figure 7.5c. Forecast Weight of Basic System

8. RESEARCH IN PREDICTION THEORY THROUGH GAMING

One of the purposes of this study was to plan and describe a program aimed at developing methods which will be useful in technological analysis and prediction. This section formulates an experimental game for studying human forecasting strategies and describes several tasks which would be appropriate as components of such a program.

8.1 GENERAL OUTLINE OF A FORECASTING GAME

This section describes a particular experimental game which can be used for obtaining greater insight into forecasting strategies implemented by analysts. The game requires descriptions of a universe of both technological and supporting information; derivation of a model should prove of itself to be a contribution to mathematical modeling of the forecasting process. The actual play should expose forecasting strategies which can be evaluated by statistical techniques Specific games and specific experiments for gaining insight into the forecasting process should be specified as results from earlier games are attained.

The general model will now be described. The universe is a process $y(t)$, $t = 0, 1, 2, \ldots$, where t represents time and where the process is dependent on certain parameters $\lambda_1, \ldots, \lambda_n$. At a later stage it will be desirable to consider the λ_i as varying in time, but for the present time we consider them as fixed. We assume an additive process $y(t) = f_1 (t; \lambda_1, \ldots, \lambda_k) + \ldots + f_m (t; \lambda_\ell, \ldots, \lambda_n) + \epsilon$. Note that ϵ is a random variable subsuming the effects of factors other than the f_j, and that $\epsilon = \epsilon(t)$.

The universe also contains certain other functions of the parameters λ_i. Although this might well be generalized, we will state each as a function of a single parameter:

$$L_1 = L_1(\lambda_1, t) \; \ldots \; ; \; L_n = L_n(\lambda_n, t)$$

The player is given a set of observations on y

$$y_o, \ldots, y_a$$

and also observations on the functions L

$$L_{10}, \ldots, L_{1,a-b} \; ; \; \ldots ; \; L_{no}, \ldots, L_{n,a-b}$$

The object of the game is the "forecasting" of y_{a+1}.

The game is played as follows. The player must pay \$B to play the game. The player is given the universe information and a fixed sum of money, \$C. He may either make his forecast of y_{a+1} immediately, or he may purchase additional information and then forecast. The additional information consists of the data

$$L_{1,a-b+1}, \ldots, L_{1a} \; ; \ldots ; \; L_{n,a-b+1}, \ldots, L_{na}$$

We assume here that the item L_{1q} may be purchased at a cost of $\$d_{1q}$ in a sequential fashion; other arrangements may be considered.

Let δ_1, δ_2, δ_3, δ_4 be positive quantities and let $y_{a=1}$ be the player's forecast. The following payoffs hold for the stated intervals:

Interval	Payoff
$\hat{y}_{a+1} < y_{a+1} - \delta_1 - \delta_2$	X_1
$y_{a+1} - \delta_1 - \delta_2 \leq \hat{y}_{a+1} < y_{a+1} - \delta_2$	X_2 [say $X_3\ X_4\ X_2\ X_5\ X_1$]
$y_{a+1} - \delta_2 \leq \hat{y}_{a+1} < y_{a+1} + \delta_3$	X_3
$y_{a+1} + \delta_3 \leq \hat{y}_{a+1} < y_{a+1} + \delta_3 + \delta_4$	X_4
$y_{a+1} + \delta_3 + \delta_4 \leq \hat{y}_{a+1}$	X_5

Information relevant to this play is recorded. This includes the number of additional items purchased, the types of items purchased, the universe parameter values, the observed values $y_0, \ldots, y_a$; $L_{10}, \ldots, L_{1,a-b}$; .. $L_{n0}, \ldots, L_{n,a-b}$, the forecast $\hat{y}_{a+1}$, and the payoff X obtained.

Furthermore, the player will be classified according to a number of variables such as age, educational background, forecasting experience, etc.

The same person will play the game several times; each play should involve a parameter change. Finally

(1) his overall performance will be evaluated in terms of payoff achieved, and

(2) an attempt will be made to characterize his strategy in terms of various possible strategies.

Consider for example a particular case of the general game:

4 parameters $\lambda_1, \lambda_2, \lambda_3, \lambda_4$:

2 additive functions

$$f_1(t_i \lambda_1, \lambda_2) = \lambda_1 + \lambda_2 t$$

$$f_2(t_i \lambda_3, \lambda_4) = \lambda_3 \sin \lambda_4 t$$

$$y(t) = \lambda_1 + \lambda_2 t + \lambda_3 \sin \lambda_4 t + \epsilon \qquad (*)$$

$$L_1 = 2\lambda_1, \; L_2 = 1/2\,\lambda_2 t, \; L_3 = \lambda_3 + t, \; L_4 = 1/2\,\lambda_4$$

ϵ = N(0, 16), a random number between 0 and 16, inclusive

$$\lambda_1 = 50, \; \lambda_2 = -2, \; \lambda_3 = 5, \; \lambda_4 = 1$$

Give the player 10 items $y_0, \ldots, y_9$. The value y_{10} is determined by (*) above. Give the player also

$$L_{1,0}, \ldots, L_{1,7}; \; \ldots; \; L_{4,01} \ldots, \; L_{4,7}.$$

Give him $1000 play money. Charge him $500 to play the game. Make available the following information at the cost shown.

Item	Cost to Player
$L_{1,8}, L_{1,9}$	$ 25
$L_{1,10}$	50
$L_{2,8}, L_{2,9}$	25
$L_{2,10}$	50
$L_{3,8}, L_{3,9}$	25

Item	Cost to Player
$L_{3,10}$	\$ 50
$L_{4,8}$, $L_{4,9}$	25
$L_{4,10}$	50

Let him purchase any items he wishes. Then he forecasts y_{10}. The payoff function might be

$y_{10} + 5 < \hat{y}_{10}$	\$1,000
$y_{10} + 1 \le \hat{y}_{10} < y_{10} + 5$	100
$y_{10} - 2 \le \hat{y}_{10} < y_{10} + 1$	2,000
$y_{10} - 8 \le \hat{y}_{10} < y_{10} - 2$	500
$\hat{y}_{10} < y_{10} - 8$	200

Characterize the player and then attempt to characterize his strategy. Vary parameters and repeat.

To approach the sort of games that would be closest to the problem of prediction of technical innovation, one should first vary the parameters during a game and then arrange a threshold situation for one of them.

RULES OF AN ILLUSTRATIVE GAME:

1. Given premises, alternate actions are authorized.

   (a) all possible sets of premises are accounted for – fully determinate game.

   (b) some sets of premises are omitted, i.e., completely free choice to player.

2. Premises will occasionally refer to history during the game as well as present circumstances.

3. Rewards are given proportional to success in second-guessing what the game-manufacturer manufactured.

4. Purchases of additional information on the universe can be made.

8.2 SPECIFIC TASK DESCRIPTIONS

The tasks are all empirical in nature. While a very important part of the proposed program deals with basic psychological research into human decision processes, another segment uses modeling and gaming in an attempt to simulate such processes in environments of differing artificialty. As part of this latter segment, the following games are proposed.

Task I: Preliminary Game Simulating Technological Change in Terms of Parameter Change.

The point of view adopted is simply this. A forecasting system can be described in terms of people, objects, and relationships between these. The description is thus a set of relations involving many parameters. Technological change is associated with parameter change and technological innovation and breakthrough with rapid parameter change. Hence in this first preliminary game, the problem to be studied is one of differences in speed of recognition of parameter change by a single individual who has no control over technological developments, i.e., a passive one-party game. It will be necessary to

I. a: Decide upon the functional form of the process, i.e., choose y(t), f_j, L_1, ..., L_n: in particular the innovation parameter.

I. b: Determine the cost of playing and the cost of additional information.

I. c: Determine what additional information is to be available and at what time.

I. d: Specify the rules of play and the game format.

I. e: Decide what information should be recorded about the player and about his play.

I. f: Decide upon the prescriptive decision models with which the empirical results are to be compared.

I. g: Play the game and compare results with models.

If such a one-party game is played using many different players with one play for each, several different results should be obtainable, each of interest within the context of predicting technological change.

(1) Based on I.e. above, it should be possible to characterize players by attributes and to correlate these with degree of success in playing. "Degree of success" can be measured by the players bankroll after the last payoff of the game. Thus, a first step could be taken towards identifying characteristics of individuals which are associated with recognition of parameter change (in this limited sense) and with adaption to the new situation.

(2) Based on I.f. above, it should be possible to determine which individuals or sets of individuals tend to follow a given prescriptive model. Of course, it is possible that no person or group will follow any model; however, that is an unlikely eventuality, in our opinion. And as a by-product, it should be possible to compare the accuracy of prediction of those groups using the prescriptive models.

(3) Experience in predictive gaming would be gained. This would be very useful in implementing later, more complicated games.

Task II: Breakthrough Recognition in Intelligence Context.

In terms of technological change, the analysts' job consists of two parts. He must first identify changes which are in the making. Then he must come up with a time estimate, i.e., an estimate of the time when that need at which the change is aimed will be satisfied. Tasks II and III attack the first problem.

Design a sequence of experiments in which subjects are presented with bits of information relevant to the introduction of a technological innovation in an observed system. After each bit has been digested, the subject is asked to identify the innovation, if any. It will be necessary to:

II.a: Select the situations to be studied. Decide between actual current situations, actual historical situations, and hypothetical situations.

II.b: Choose and organize the informational input to the subject.

II.c: Decide upon the scope of the subject's reference in each situation.

II.d: Choose the individual subjects. (Probably some actual analysts should be brought into the picture at a late stage.)

II. e: Set up a rating system for comparing the performance of the several subjects.

II. f: Conduct the experiment.

If such a one-party game is played using many different players with one play for each, results should be obtainable similar to (1) above. Successful and unsuccessful players should be characterized; also information should be obtained on normative models which actually approximate human decision behavior. In addition other valuable results should arise.

(4) In studying the form of the input, results should be obtained which bear on desirable ways of organizing intelligence data relative to the prediction of technological change.

(5) In playing the game, further evidence of effective systematic procedures for detecting technological change should be found.

Task III: Breakthrough Recognition in a Competitive Industrial Context.

This task repeats II, but now the specific environment has shifted as indicated to an active two-party game, i.e., a competitive game in which two players have knowledge of the technology, each knows a few things unknown to the other, and each can influence technological developments by causing certain research or development activity to take place. Steps a-f are identical for II and III.

Task IV: Revision of Prior Probability Distribution in a Military Intelligence Context.

This task and the following one speak to the second part of the analysts' job, namely, the time estimate.

In this task the subject is told what innovation is in question. After each bit of information, he is asked to estimate the probability distribution of the time of need satisfaction. The study would concentrate on comparative changes in this distribution. Subtasks are as in Task II with an additional one involving a decision as to the form in which the subject will estimate the probability distribution.

From this game, in addition to results of the forms (1) and (2), analogs of (4) and (5) should be available in a time-prediction context. The matrix format of Section 7, although presented in a two-party situation, would probably be suitable for organizing input data in this one-party situation also.

Task V: Revision of Prior Probability Distribution in a Competitive Industrial Context.

This task repeats IV with the indicated shift in environment. It could be played as a two-party game and provide an environment changing in "real time."

8.3 ONE-PARTY GAMING BASED ON AN INFORMATION MATRIX

This section discusses how input information organized in matrix form might be used in one-party gaming. The discussion is necessarily preliminary in nature.

We begin with the definition: a new product-device line-item is called a technological breakthrough if its appearance at time t + 1 evokes at least one new descriptor not needed at time t. The player is given $D and filled information matrices corresponding to time $t_0, \ldots, t_m$. He is also given an opportunity to purchase documents. For this purpose, documents are brief summaries presenting information about research line-items. He purchases as many of these as he wishes at time t_m, identifies research line-items, adds these to his matrix together with any relevant data and time estimates, and scans the documents for hints at possible forthcoming breakthroughs. He may then either predict a breakthrough and give a time estimate or he may not do so.

In this game there is no penalty for failing to make a prediction. The only penalty is one of $Z if a breakthrough occurs at time t_{m+k} which has not been predicted. And a payoff of $Y occurs if the breakthrough is predicted properly both as to type and as to timing.

Let us translate this game into specific terms. The player is given $D and filled information matrices for the times January 1, 1953 to January 1, 1960. The object is prediction of breakthroughs by IBM in the "large" computer area. Hence the matrices have large IBM computers as line-items and appropriate descriptors as column heads. The documents which can be purchased are summaries of actual reports, articles, etc. appearing during 1960 and relating (or purporting to relate) to IBM large computer research. These are purchasable in random order. The player must identify new large IBM computers on the way, list their attributes, and keep alert for new developments that might lead to a new descriptor at a future time. He must predict this innovation and its time of appearance correctly to achieve a payoff. If he fails to predict, he is penalized.

Although it is possible to play games of this nature, it may not be desirable to do so. The preparation of the needed documents would be a very considerable job and would have to be done in a most painstaking manner if this game were to be a useful one. It is not too much to say that the value of the game depends almost wholly on the job of document preparation. It may be that the time involved could be better spent in using the information network in real time to predict breakthroughs in a few areas by actual literature monitoring. At the moment, the value of this gaming situation lies with actual real-time situations which already use information networks for human forecasting, where the game can be prepared inexpensively and the results (and techniques) of the gaming can be compared and contrasted with the analysts' use of the information files.

8.4 THE STRUCTURE OF A FORECASTING GAME

The environment is assumed to follow the formula:

$$y(t) = f_1(t) + f_2(t) + f_3(t) + f_4(t) + \varepsilon$$

where

$$f_1(t) = 10 \sin \lambda_1 t \qquad f_3(t) = 30 + \lambda_3 t$$

$$f_2(t) = \lambda_2 \sin (t + \frac{\pi}{2}) \qquad f_4(t) = 10 \lambda_4$$

$\lambda_1 = 1,\ 0 \le t' \le 8$	$\lambda_3 = 0$,	$0 \le t' \le 4$
$\lambda_1 = 2,\ 9 \le t' \le 16$	$\lambda_3 = .20$,	$5 \le t' \le 8$
$\lambda_1 = 3,\ 17 \le t' \le 24$	$\lambda_3 = .60$,	$9 \le t' \le 12$
$\lambda_1 = 4,\ 25 \le t' \le 32$	$\lambda_3 = .80$,	$13 \le t' \le 16$
	$\lambda_3 = .90$,	$17 \le t' \le 20$
	$\lambda_3 = .95$,	$21 \le t' \le 24$
$\lambda_2 = 1,\ 0 \le t' \le 16$	$\lambda_3 = .98$,	$25 \le t' \le 28$
$\lambda_2 = 0.5, 17 \le t' \le 32$	$\lambda_3 = 1.00$,	$29 \le t' \le 32$

$$\lambda_4 = .1 \quad , \quad 0 \leq t' \leq 9$$

$$\epsilon : N(0, 4) \qquad \lambda_4 = 1.00 \quad , \quad 10 \leq t' \leq 25$$

$$\lambda_4 = 10 \quad , \quad 26 \leq t' \leq 32$$

$y(t)$ is computed for $0 \leq t' \leq 32$

In addition we have the functions $j_i(\lambda_i)$, $i = 1, 2, 3, 4$, as follows

$$j_1(\lambda_1) = 1 + \sqrt{\lambda_1} \quad , \quad j_3(\lambda_3) = -\lambda_3$$

$$j_2(\lambda_2) = 10 - \lambda_2 \quad , \quad j_4(\lambda_4) = 8\lambda_4$$

The $j_i(\lambda_i)$ are also computed for $0 \leq t' \leq 32$.

The player is given $y(t)$ from $t' = 0$ to $t' = 16$. He may purchase information on the $j_i(\lambda_i)$ before each prediction. Prices should be low relative to the player's initial bankroll. Suppose that he starts with $400 and that information costs $1.00 per bit. Suppose also that he receives $50 for each prediction which misses by less than 3 units, zero dollars for those between 3 and 5, and loses $10 if his prediction misses by more than 5 units.

This game entails a very rudimentary attempt to simulate a breakthrough when this phenomenon is viewed as an abrupt change in one of the parameters of an observed system. For example, the parameter λ_4 is varied in a stepwise fashion, and the intent of the game is to identify players who adjust their predictions rapidly to the change. There are clearly many variations possible. Later gaming would consider a breakthrough as a continuous process.

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) The Moore School of Electrical Engineering University of Pennsylvania Philadelphia 4, Pennsylvania	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE
Evaluation of Techniques and Devices as Applied to Problem Solving

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final Report

5. AUTHOR(S) (Last name, first name, initial)
Rubinoff, Morris
White, J. F., Jr.
Loev, David
Blumberg, Donald F.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
March 1965	103	30

8a. CONTRACT OR GRANT NO. AF30(602)-3065 b. PROJECT NO. 4594 c. 459404 d.	9a. ORIGINATOR'S REPORT NUMBER(S) 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) RADC-TDR-64-402

10. AVAILABILITY/LIMITATION NOTICES
Qualified requestors may obtain copies of this report from DDC. This report may be released to OTS.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Rome Air Development Center Griffiss AFB, NY 13442

13. ABSTRACT

The problem of forecasting technological change in investigated. Machines and computer programs having "problem solving" capabilities are examined to determine their usefulness in aiding or replacing the human forecaster. The literature on human problem solving was also reviewed. The following conclusions were reached:

1. The nature of the forecasting problem precludes the use of computer-type problem solvers developed to date.

2. The application of information science techniques, namely; descriptors representing technological concepts, the forces acting to change the technology and the laws governing the change, appear to offer the most promise in assisting the human forecaster

Accordingly, a quasimathematical model was developed using math notation to describe a technology. An example of a forecast of computer technology made several years ago is included.

DD FORM 1 JAN 64 1473

UNCLASSIFIED
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK	
	ROLE	WT	ROLE	WT	ROLE	
Technological Intelligence Information Retrieval Problem Solving Gaming Creativity Insight						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statem such as:

(1) "Qualified requesters may obtain copies of th report from DDC."

(2) "Foreign announcement and dissemination of t report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies this report directly from DDC. Other qualified users shall request through

____

(4) "U. S. military agencies may obtain copies o report directly from DDC. Other qualified user shall request through

____

(5) "All distribution of this report is controlled. Q ified DDC users shall request through

____

If the report has been furnished to the Office of Tech Services, Department of Commerce, for sale to the public cate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional exp tory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the nam the departmental project office or laboratory sponsoring (*ing for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and fa summary of the document indicative of the report, even th it may also appear elsewhere in the body of the technica port. If additional space is required, a continuation she be attached.

It is highly desirable that the abstract of classified be unclassified. Each paragraph of the abstract shall en an indication of the military security classification of the formation in the paragraph, represented as *(TS), (S), (C),*

There is no limitation on the length of the abstract. ever, the suggested length is from 150 to 225 words

14. KEY WORDS: Key words are technically meaningful or short phrases that characterize a report and may be us index entries for cataloging the report. Key words must b selected so that no security classification is required. I fiers, such as equipment model designation, trade name, project code name, geographic location, may be used as k words but will be followed by an indication of technical c text. The assignment of links, rules, and weights is opti