DIAGNOSTIC PROBLEM SOLVING BY COMPUTER

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The elements of a theory of diagnostic problem solving were presented in this paper. Specifically the focus was on the diagnostic processes of clinical neurologists, but the implications for clinical judgments in general were discussed.

Clinical intuition, it is often said, is an art and as such it cannot be subjected to the rigors of the scientific study. It is commonly believed among clinicians that patients communicate with them in numerous non-verbal modes; and that the particular way in which a patient expresses himself conveys certain special types of information. Some clinicians, especially in the psychiatric areas, report that they "resonate" to patients with their unconscious and claim to be able to understand the patient's motivations and dynamics in this way. It is probably true that a certain amount of this nonverbal or even motional communication takes place, but we have been collecting an increasing amount of information that leads us to believe that diagnostic judgments are predominantly cognitive in nature (Kleinmuntz, 1963). We have already discovered enough about the cognitive activities of a personality test interpreter to enable us to translate his cognitions into a computer language. Tested on many cross validation samples this set of computer programmed decision rules was demonstrated to be more accurate than the best among many human test interpreters.

In this paper we propose to demonstrate that clinical intuition can be subjected to scientific study, and we will argue that unless diagnosis is accepted as a cognitive activity it is not possible to transmit it to aspiring clinicians. Some preliminary definitions are in order. Up to this point the terms diagnosis, clinical intuition and cognitive clinical activities have been used interchangeably. We are concerned in this paper only with formal diagnosis and shall consider diagnosis to be a special instance of problem solving in which the clinician is confronted by an array of data, and in which he searches and sifts through this array, rejecting some aspects of the available information and calling for more information to supplement existing data. The problem to be solved by the diagnostician is usually in the form of a patient about whom certain biographical data, symptoms, signs, laboratory test results and other observable or elicited cues are available. The solution to the problem consists of an etiologic formulation, a classification of the patient into a taxonomic category, and the prescription of some treatment recommendations. The fact that different clinical specialties deal with different symptoms, signs, and tests, and use different tools does not alter the fact that similar problem solving behaviors may underlie them all. Also it is recognized that the diagnostic problem solving that intervenes between the beginning and end may be for each diagnostician a highly idiosyncratic process.

The problem of how the clinician pro-
cesses information is clearly within the domain of psychological studies that concern themselves with thinking, judgment and problem solving. However, as a reaction to the influence of the introspectionists and with the advent of behaviorism, psychologists have for many years been unwilling to concern themselves with phenomena that had about them an aura of the mentalistic. These subject matters seemed not to lend themselves to objective study in the laboratory; and only recently has there been a resurgence of concern within psychology with the central topic of thinking. With the appearance of the electronic digital computer and the emergence of the concept of a computer program, there has occurred a revived interest in such complex human behavior as thinking. The significance of the computer for diagnostic decision making does not lie in its ability to process clinical data in a mechanical way; but rather it lies in the fact that this machine has forced us to specify with complete rigor the processes that are involved in thinking. Instructions can be given to the computer, i.e., programs can be written, that combine these processes in such a way so that the machine could execute each of the instructions in order to solve the most complicated problems. Obviously, if we can be precise enough about a process to describe it in terms which can be programmed for machine operations, then we know quite a bit about that process.

As an example par excellence of diagnostic problem solving we chose to focus on the cognitive activities of diagnosticians within the clinical specialty of neurology. This particular specialty was selected because of the highly structured nature of clinical data within it and because of the importance among neurologists of arriving at a correct diagnosis. The emphasis in our work has been on one particular diagnostician in a specific class of problem situations; and we intend the computer program to be an information processing theory of his diagnostic behavior. We are not yet at the point in our work where we can say that our computer program is a predictor of \( n+1 \) diagnostic behavior situations, but in principle this is certainly possible. At the present time our computer program is a theory that explains the diagnostic problem solving behavior of individual clinical neurologists in a given set of \( n \) situations.

An important distinction must be made at this point between various problem solving computer programs that could possibly be written to represent the neurologist's cognitive processes. Such a distinction would be helpful in highlighting the essential differences between the information processing point of view and the artificial intelligence approach to similar problem solving tasks. The artificial intelligence computer program might consist of an information storage and retrieval scheme that would resemble the ordinary dictionary look-up approach to this medical problem. In other words, the computer would have stored in its memory core all the known symptoms, signs, demographic variables, laboratory tests and treatments, and then when a particular set of symptoms or signs are presented to it, the computer would proceed very much like a beginning medical student who might consult a diagnostic manual or textbook. Although the search time of the computer could be designed to be considerably more speedy than that of the human diagnostician, this particular approach would be most primitive and cumbersome. Certainly it would teach us nothing about the human diagnostician.

A more elegant approach to this diagnostic problem, although still one of artificial intelligence, would consist of a computer program that incorporates all of the above information, but additionally, one which uses probability notions, weighting schemes, and takes into consideration the relative frequency of a set of symptoms for a particular disease and the frequency of occurrence of a particular disease in a par-
ticular geographic region. This approach is best represented in the pioneering work that has been suggested by Ledley and Lusted (1959) in which symptoms and diseases are formalized in terms of the propositional calculus, probability theory and the theory of games, so that a computer can be programmed to represent this formal process and to carry it through step by step. These artificial intelligence approaches are probably potentially operational, but the choice of these approaches is largely dependent on the goals one has in mind. For example, if one is interested in constructing computer programs that solve problems in the most efficient manner in order to get a job done then the goal can be best achieved by an artificial intelligence approach. Often such programs rely considerably on the brute force arithmetic speed of the computer and solve these problems by performing systematic routine calculations. On the other hand, if the intent is to focus on human problem solving methods, and if the goal is to parallel closely the consistencies, inconsistencies, errors and all the strategies of the human problem solver, then we should use an information processing approach that attempts to simulate the human's thinking. Our goals consist of discovering as much about the diagnostician's cognitive activities as possible and therefore we are interested in simulating the human diagnostician. Specifically, the questions we would like to answer are: 1) How does the diagnostician store or represent information in his memory; and 2) how does he process this information during his diagnostic problem solving? Answers to both these questions should aid us in the education of aspiring diagnosticians and should enable us to modify existing diagnostic search strategies.

In order to discover the neurologist's search strategies we have devised a scheme which allows him to "think aloud" during his diagnostic problem solving sessions. Similar schemes have been used successfully in our other computer simulation studies (Kleinmuntz, 1963), and in this neurology problem we found that a variant of the childhood game of Twenty Questions was a useful technique that lends itself readily to the systematic study of a number of variables. The game is played by having one player, called the experimenter, think of a disease, while the other player, or subject, tries to diagnose the disease the experimenter has in mind. The experimenter can play any of a number of roles: he can pretend, for example, that he is a patient suffering from symptoms x, y and z; or he could assume the role of the neurologist who is thinking of a particular disorder which is characterized by symptoms x, y and z. The diagnostician's job in either case is to inquire about the presence of certain symptoms, signs or biographical data and he may, if he chooses, ask for certain laboratory test results. It is necessary that the experimenter be an experienced neurologist in order to answer the subject's questions, because he must be able to recognize the appropriateness of many symptoms, signs and laboratory tests that might possibly be relevant for a particular disease.

These games are tape-recorded, and the end product, after appropriate editing resembles a tree structure. The way the game was described above a binary tree is obtained in which each point, or node, in the tree has exactly one connection to a point closer to the root of the tree. The starting point, or the root of the tree, is the subject's first question. All subsequent questions are the tests that are performed at the various nodes of the tree. Unless a diagnosis has been reached, each node is connected to exactly two lower nodes and through them to any number of still lower nodes. A path is a collection of lines from the root of the tree to a terminal node and is the schematic representation of the search strategy used by the neurologist to arrive at a diagnosis. In other words, the tree structure, or as it is sometimes called, the
FIG. 1. A tree structure of a neurologist’s diagnostic game in which the information given was: Sudden left central scotoma and right hemiparesis in a 55 year old.

discrimination net represents the diagnostician’s solution path from a certain set of givens to the diagnosis.

For illustrative purposes consider the game in Fig. 1 in which the subject was given the information that he is to diagnose the case of a 55 year old patient who suffered from a sudden left central scotoma and a right hemiparesis. From the point at which the diagnostician asked the first question (i.e., “Is this the first episode?”) until a diagnosis was reached, there were exactly nine test nodes and eight binary branchings. Of the latter, five were positive and the others were negative branchings.

From inspection of this binary tree structure we can readily see the types and the number of questions that were asked by the diagnostician as he worked his way toward a diagnostic solution. An additional refinement was made of this procedure in that several diagnosticians were called back and instructed to diagnose the same set of problems. During the second session the diagnostician was expected to state his reasons for asking each of his questions, in order to enable us to obtain not only the test node questions but additionally to allow us a glimpse of what the diagnostician thought was his reasoning procedure. Also it permitted us to run a test-retest reliability estimate on the size and structure of each diagnostician’s discrimination net. The reliabilities were remarkably high but the effects of practice are readily recognized in this task.

More important for our theory of diagnostic problem solving were our analyses of such protocols as are represented in Fig. 1. These analyses have suggested a number of hypotheses about the diagnostic process of a clinical neurologist and these will be listed below. It should be kept in mind that these hypotheses do not constitute statements of fact and in their present form are testable and therefore subject to revisions and modifications:

1. The neurologist has stored, in his memory core, symptoms and associated diseases that have been learned by a rote memorization process. It has been observed in our diagnostic games that a certain stimulus class such as a symptom or a set of symptoms and signs consistently evoked an identical set of responses within a particular diagnostician. These responses were either in the form of a chain of symptoms or they could be specific diseases that seem to have been stored alongside one another in the neurologist’s memory. Such a storage scheme lends itself readily to a representational format designed by Feigenbaum (1961), to simulate human verbal learning experiments. His computer program, known as EPAM (Elementary Perceiver and Memorizer), takes as inputs nonsense syllables, learns these in a paired associate manner and then reproduces the response side of the pairs much like the human experimental subject. In our neurology situation we might assert that the clinician’s memory contains cross-reference tables or lists of symptoms and their associated diseases. However, there is much about the diagnostic strategies of experienced neu-
rologists to suggest that the rote memorization technique represents only a portion of their learning process and that it seems to play a larger part among beginners whose clinical experience on the ward is limited.

2. The neurologist has an internal visual representation of the central nervous system and much of his information processing involves a shuttling back and forth between symptoms, test findings, and neuroanatomical locus. This assertion implies a rather active information processing system and suggests that the neurologist's diagnostic reasoning includes an active hypothesis formulation process that is subject to momentary confirmation and disconfirmation. Moreover, this hypothesis asserts that the neurologist's diagnostic reasoning is considerably more complex than mere rote memorization and recitation. It suggests that he has stored in memory and uses a pictorial image of neuroanatomic structures.

3. The neurologist has learned to search his problem environment for those symptoms and signs that yield the greatest amount of information. This is more true about the experienced diagnostician than the beginner. The more experienced neurologist's overall search strategy seems to be guided by a maximization principle in which he radically reduces his problem environment with each question until he has zeroed-in on a differential diagnostic judgment. In order to illustrate this point we will digress for a moment from the field of neurology and consider the game of Twenty Questions as it might be played in geography. If an experimenter asserts that he is thinking of a City in the U.S.A., a poor diagnostician might ask several specific, but low yield questions such as "Is it City X?", "Is it City Y?", "Is it North?", and so forth, before arriving at an incorrect or correct solution. The experienced diagnostician, who would be the counterpart of our diagnostician, might ask whether the city was east or west of the Mississippi River, and thus with one question cut his problem environment in half. The next high yield question about U.S.A. geography might be whether the city is north or south of the Mason-Dixon line. Again his problem space is cut in half, and then he might continue in this manner until a diagnosis is reached. Also in our neurology tree structures we have observed that this type of optimization leads to solution paths that tend to be shorter than those of the inexperienced neurologists.

4. The neurologist elicits data and calls for tests that conform to a pattern that moves from general to specific questioning. This pattern of diagnostic problem solving is highly contingent on our third hypothesis above which states that a maximization principle is followed. However, we can add here that the neurologist's pattern of moving from a general to a specific search strategy is true only when he encounters confirming instances of his differential diagnostic hypothesis, and that the pattern is disrupted by infirming instances. That is to say, when the neurologist runs into a cul de sac or a number of infirming instances, he often reverts from very specific to more general types of questions.

5. The neurologist's search strategies involve the use of both short-term and long-term memory storage. When diagnosticians have proceeded about one-half way down a particular diagnostic tree and are asked at that point to recall or recite all information that they have accumulated prior to that point, they seem not to be able to remember those data that did not substantiate a particular differential diagnostic hypothesis. In other words, they can recall only information that is relevant to a particular diagnosis and seem to forget selectively irrelevant data. Therefore, it may be assumed that their short-term memories undergo moment to moment modifications and revisions, and we may postulate that their long-term memories are much less subject to such modifications.

These hypotheses constitute the beginnings of a theory of neurological diagnostic
problem solving. The theory is testable because its components can be stated in terms of a computer program. It is a good theory only to the extent that it processes neurological information in a manner indistinguishable from that of the human diagnostician. Moreover it is a good theory only to the extent that it could predict a particular diagnostician's problem solving behavior for a set of new diagnostic situations. At this point in our work we are not ready to judge whether or not it is a good explanatory or predictive system because these are empirical problems that are still subject to verification. Whether or not we do emerge with a good theory of diagnostic problem solving in general or neurological problem solving in particular, we have attained an important subgoal:

We have succeeded in convincing some clinicians that diagnostic problem solving is a cognitive activity and that it can be studied under rigorous laboratory conditions.

REFERENCES


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