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# Analysis of Synthetic Students as a Model of Human Behavior

by
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## Abstract

The research described in this report is an attempt to evaluate the educational effects of a computer game known as Wumpus. A set of five synthetic computer students was taken as a model of the progress of real students playing a sequence of twenty Wumpus "warrens". Using a combination of observations made of the students, representations drawn by the students and protocols kept by the computer of each session, it was found that the synthetic students are a reasonable static model of real students, but miss completely many of the important dynamic factors which affect a student's play. In spite of this, the Wumpus game was found to be an effective educational tool.


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# INTRODUCTION

One of the more interesting and exciting developments in computer science in recent years has been the application of computers and computer technology to the field of education. Through the use of computerized math drills, programs which teach specific subjects such as reading or chemistry, interactive use of computer languages, and computer games the concepts of CAI (computer-assisted instruction) have helped to create successful learning experiences for students of many ages and backgrounds. To better understand the effects of computers in education, extensive evaluations of these efforts are necessary. The research described herein represents one phase in the evaluation of a computer game known as Wumpus[1]. To more clearly define the focus of this evaluation, it is necessary to first understand some of the history of CAI research in general and the evolution of the relevant version of Wumpus in particular.

The development of CAI programs may be split into three stages for descriptive purposes[2].The programs of the "first generation" are perhaps best typified by the mathematical drill. In this environment, the computer is programmed with a list of questions, and the corresponding answers . A student is asked each question in order and must respond with an answer which is then compared to the computer's answer to determine whether or not it is correct. More advanced versions include some simple branching in order to be more sensitive to the students actual ability.

The "second generation" of CAI programs were able to more fully utilize the power of computers through the use of domain-specific knowledge. In programs such as Sophie[3] (Brown, Burton & Bell, 1975) or Wumpus, the reasoning skills which are being taught are imbedded in the structure of the program itself, and are acquired by the student through direct interaction with the computer in the course of a session. This kind of program has several advantages over those of the "first generation": they are designed to be inherently interesting to use, they allow the student to make decisions which influence the course of a session, and they are able to teach new skills instead of simply providing practice in already learned ones.

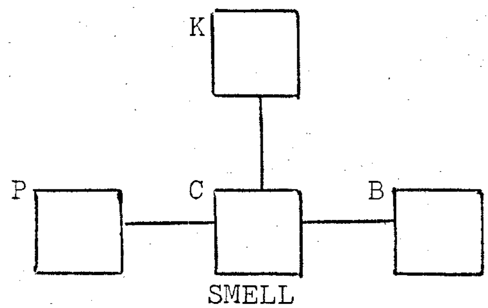
Recently, a "third generation" of CAI programs has come into existence. This third group is characterized by the ability of the program to actively select circumstances in a given domain where advice to a student seems to be necessary, and then to provide advice which is appropriate to the situation. Examples of this kind of program include West[4] (Burton & Brown, 1976) and the Wumpus Advisor I[5] (Stansfield, Carr & Goldstein, 1976) at M.I.T. The sophistication of these programs and others like them holds great promise for the future of computers in education. The current Wumpus/Wusor II system is also a part of this "third generation", and this is the system on which attention will now be focused.

## WUMPUS/WUSOR II

The central portion of the Wumpus/Wusor II package at M.I.T. is the game of Wumpus itself, a maze-search game which requires simple deductive and probabilistic reasoning skills. It was found that an important part of a persons ability to acquire these skills was the way in which the person represented the knowledge about the wumpus-warren encountered during the game; a poor representation could be a significant impediment to further learning. To minimize this effect, a graphics capability was added to the game to allow the computer to maintain a standard representation for each player. Finally, the Wumpus advisor Wusor II[6] (Carr, 1977) was added to provide advice on strategy and other playing skills. These modules interact to create a rich learning environment which can be carefully controlled and monitored.

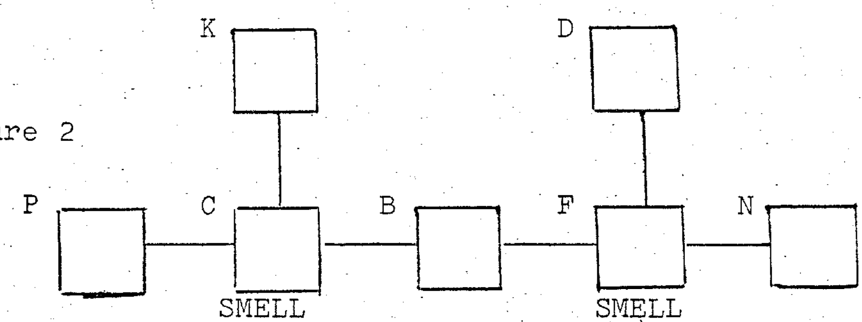
In the actual game of Wumpus, a player is placed in a group of interconnected caves collectively known as a "warren", and given the task of hunting down and shooting the wumpus which is hidden somewhere in the warren. The player searches for the wumpus by moving from a cave to any other cave which is connected to it. When a new cave is entered, the player is told the identifying letters of the adjoining caves, and these become the candidates for the next move. The wumpus is located by its horrible stench which can be smelled in any of the caves connected to the cave in which the wumpus is hiding. Thus after a move, the player might be informed: "We are now in cave C. The neighboring caves are P, K and B. What a stench! The wumpus must be in one of the neighboring caves". The player might then draw a partial map of the warren like this:

Figure 1




Notice that the player does not know in which of the neighboring caves the wumpus is lurking, and this is where deductive ability becomes important. If the player moves into one of the three neighboring caves and the wumpus is in that cave, the wumpus eats the unwary player and the game is lost. If, on the other hand, the player can combine the evidence with evidence from other caves and deduce where the wumpus is, it is possible to shoot the wumpus and win the game. Thus in the following scenario, if the player has visited cave F and is now in cave C it is possible to deduce that the wumpus is in cave B (since there is only one wumpus):

Figure 2



In this case instead of moving from cave C into another cave, the player could type "SHOOT", subsequently telling the computer into which cave it should shoot, and winning the game.

The game as described so far would be easy and somewhat boring were it not for the fact that two other types of danger exist in the warren: pits and bats. Accidently moving into a cave containing a pit is fatal and loses the game, whereas bats, although not directly fatal, carry the player to some other cave in the warren- possibly a cave containing a pit or the wumpus. Thus both pits and bats are dangerous, and by using reasoning similar to that used for locating the wumpus the player can avoid moving to caves containing these dangers.

These are the basic rules for Wumpus, although certain subtleties do arise. A very large number of warrens are possible, varying in the number and interconnectedness of the caves, the number of pits and bats, the locations of the various dangers and even how far away the wumpus can be smelled. By creating a sequence of warrens of increasing complexity, it is possible to teach the strategy and hopefully the assosciated reasoning processes necessary to master the game.

## EXPERIMENTAL DESIGN

The evaluation of a system such as Wumpus/Wusor II can proceed in a variety of ways. The computer tutor can be compared with a human teacher to see if similar results are achieved as far as increased ability of students to play the game. A Turing test can be conducted to see if an observer can distinguish the computer's advice from that of another person. Another possibility, described in Carr's thesis (1977), is to create a synthetic rule-based student and watch the interaction of the computer tutor with this synthetic student. The synthetic student "Syndie" was constructed specifically to test the functioning of the Wusor II part of the system and made no claim to being an accurate model of a real student. Subsequently however, a series of synthetic students of increasing complexity were programmed into the machine, and these taken together do form an initial hypothesis as to what the progress of a real student learning the game might look like. It is the goal of this evaluation to test this model against actual students to see how they compare.

In order to accomplish this task, a group of elementary school students ranging from third to sixth grade were selected as subjects. This age group was settled upon as being mature enough to handle the necessary reasoning skills, yet young enough to possess a range of representational and logical misconceptions vast enough to challenge any teacher, human or machine. It was hoped that this would avoid one of the main problems to date: the older students who have comprised most of the experimental subjects so far are generally so well trained in scientific and logical reasoning that they simply may not make a large number of the mistakes which the tutor would come across in a real teaching situation.

Since the goal here is to compare the synthetic students to real students, the decision was made to put as few restrictions on the students as possible. As a result, the Wusor II module was turned off for the experiment so as not to influence the students reasoning or progress in learning the game. Consequently, it was possible to ask students to explain their reasoning at each step of the process, and these explanations formed the first part of the data to be evaluated.

The second part of the data was the result of turning off the graphics capability of the Wumpus package and asking students to maintain their own representations of the game. Unlike the verbal explanations, these drawings are very informative as to the extent of the knowledge which is taken into account in the reasoning, rather than the process itself.

The third and final part of the data used in the evaluation was the protocols kept by the computer of each session. These are an accurate record of the sequence of moves in each game, and combined with the students drawings may provide insights into the students thought processes which are not available to the students themselves.

One of the more illuminating aspects of Wumpus is the development of a students ability as experience with the game increases. Each student therefore was asked to play a predetermined sequence of twenty warrens. These warrens were designed to increase in complexity as well as expose the student to a wide variety of game situations. Each warren has between sixteen and twenty-one caves, one wumpus and two or fewer dangers (pits or bats). The twenty warrens as well as the rationale behind their ordering may be found in Appendix A.

To summarize then, the procedure used in this experiment is as follows: subjects were asked to play a sequence of twenty warrens unaided by any tutoring either human or computer. Each student was given a piece of paper to keep track of each game and instructions to use it to put down whatever they thought might help them. During the course of the games, students were solicited to explain their reasons for making particular moves. These explanations, the representations kept by each student and the protocols of each session were then examined and compared to the behavior of synthetic students on the same warren sequence.

## THE SYNTHETIC STUDENTS

As mentioned previously, the synthetic students are rule-based; that is, the action of a synthetic student in a given situation is determined by the collection of rules which make up that particular student. Two main types of rules are used to define the synthetic students, antecedent rules (A-rules), and consequent rules (C-rules).

The A-rules are used by the student to maintain variables pertaining to the state of the game such as the list of caves which have been visited or the list of caves which may contain dangers. Any A-rules which are part of a given student are automatically run after each move the student makes, and each one either succeeds, or else fails because the variable it maintains is not relevant to the situation at hand.

The C-rules embody the playing strategy of the student, and use the information given by the A-rule variables to select the next move. A C-rule consists of a condition followed by an action to be taken if that condition is met. The ordering of C-rules is also important since, in general, the first C-rule in a sequence whose condition is satisfied is the one which gets activated while the others in that sequence are ignored. A synthetic student may have several such sequences, with the sequences themselves also being ordered.

A list of the A-rules may be found in Table I, with the C-rules being listed in Table II.

## TABLE I: A-RULES

In this table, the numbering is the same as that used in constructing the synthetic students. "Current cave" is the cave you are presently in. "Neighbors" are the caves connected to the current cave. "Warning" is either a smell, draft or squeak. Variables are indicated by capitals. DANGER+ indicates possibly dangerous caves, DANGER- is the group of safe caves, DANGER= is caves which are definitely dangerous, DANGER1 is caves for which there is single evidence of danger, DANGER2 is caves for which there is multiple evidence of danger.

a0: Current cave is VISITED.

a1: Neighbors which are UNVISITED are FRINGE.

a1-1: Neighbors are FRINGE.

a1-2: VISITED neighbors are not FRINGE.

a2: Current cave is not UNVISITED.

a4: Warning implies neighbors are DANGER+.

a5: No warning implies neighbors are DANGER-.

a6: VISITED are not DANGER-.

a7: Neighbors which are not already DANGER1 become DANGER1 if there is a warning.

a8: Neighbors which are DANGER1 become DANGER2 if there is a warning.

a10: Current cave is not evidence.

a11-4: VISITED caves are not DANGER+.

a15: No warning implies neighbors are not DANGER+.

(TABLE I continued on next page)

TABLE I: A-RULES (CONTINUED)

a16: No warnings implies neighbors are neither DANGER1 nor DANGER2.

a17: If current cave is dangerous, this implies that the current cave is DANGER=.

a18: If a cave is DANGER=, then that cave is not DANGER1 or DANGER2.

a19: Multiple evidence implies DANGER= if only one danger.

## TABLE II: C-RULES

Numbering used in this table is the same as that used for synthetic students. Variables are indicated by capitals. MOVES is the list of caves which are candidates for the next move. BAT-, PIT-, WUM-, and DANGER- are the lists of caves which are safe from bats, pits, the wumpus and all dangers, respectively. "Intersects" is used in the normal manner; thus rule c3 for instance may be read as: "make the set of potential moves be those caves which are safe from both pits and the wumpus." Rule c0 is the final strategy of all players, namely to select one of the remaining candidates at random.

c0: Select first of MOVES to visit.

c1: Set MOVES to FRINGE.

c2: Set MOVES to DANGER-.

c3: Set MOVES to PIT- intersects WUM-.

c3-1: If bats must be risked, select from those caves for which there is only single evidence.

c4: Set MOVES to WUM-.

c5: Set MOVES to BAT- intersects WUM-.

c5-1: If pits must be risked, select from those caves for which there is only single evidence.

c6: Set MOVES to BAT- intersects PIT-.

c6-1: If the wumpus must be risked, select from those caves for which there is only single evidence.

c7: Set MOVES to PIT-.

(TABLE II continued on next page)

TABLE II: C-RULES (CONTINUED)

c8: Set MOVES to BAT-.

c10: If trapped by pits and bats, choose bats.

c11: If trapped by pits, bats and the wumpus, choose bats.

c12: If you know where the wumpus is, shoot it.

Table III correlates the synthetic students with the rules which make up each one, and although formally this is sufficient to specify the synthetic students, it provides only a limited understanding of the actual behavior of these students. Therefore a brief description of the five synthetic students, Playr0 through Playr4 inclusive, is given below. First however, an explanation of Table III is in order.

In Table III, the synthetic students are listed down the left-hand column, with the A-rules and C-rules listed by number across the top of their respective sections of the table. For the A-rules, an X indicates that a rule is part of the specifications of the player in question. Since ordering is important for the C-rules, this part of the table is more complicated. Entries consist of either a number or a number and a letter. The numbers indicate which sequence the rule is part of, and the letter indicates position in that sequence. Thus for Playr1, rules c2, c3, c4 and c1 are tried in that order; as soon as one succeeds the rest of the sequence is ignored and rule c0 is run. For both the A-rules and C-rules, a blank space indicates that a rule is not part of that student.

Playr0 is by far the simplest of the synthetic students. It moves randomly to caves on the fringe without regard for warnings of any kind. Playr0 makes legal moves, and because it keeps track of visited and unvisited caves does not go around in circles, but it makes no deductions whatsoever. Thus it is doomed to fail in any warren which has a wumpus or a pit.

Playr1 is somewhat more sophisticated, keeping track of safe

| A-rules: | a0 | a1 | a1-1 | a1-2 | a2 | a4 | a5 | a6 | a7 | a8 | a10 | a11-4 | a15 | a16 | a17 | a18 | a19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Synthetic Students | | | | | | | | | | | | | | | | | |
| Playr0 | X | | X | X | X | | | | | | | | | | | | |
| Playr1 | X | X | | | X | X | X | X | | | | | | | | | |
| Playr2 | X | | X | X | X | X | X | X | | | | X | X | | | | |
| Playr3 | X | X | | | X | | X | X | X | X | X | | | X | | X | X |
| Playr4 | X | | X | X | X | | X | X | X | X | X | | | X | X | X | |

| C-rules: | c0 | c1 | c2 | c3 | c3-1 | c4 | c5 | c5-1 | c6 | c6-1 | c7 | c8 | c10 | c11 | c12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Synthetic Students | | | | | | | | | | | | | | | |
| Playr0 | 1b | 1a | | | | | | | | | | | | | |
| Playr1 | 2 | 1d | 1a | 1b | | 1c | | | | | | | | | |
| Playr2 | 2 | 1h | 1a | 1b | | 1e | 1c | | 1d | | 1f | 1g | | | |
| Playr3 | 3b | 1h | 1a | 1b | 2a | 1e | 1c | 2b | 1d | 2c | 1f | 1g | 2d | 2e | 3a |
| Playr4 | 3b | 1h | 1a | 1b | 2a | 1e | 1c | 2b | 1d | 2c | 1f | 1g | 2d | 2e | 3a |

TABLE III: THE SYNTHETIC STUDENTS

caves and warnings in addition to the information maintained by Playr0. Playr1 does not make deductions about the actual location of dangers however, so its competence is limited. As far as strategy is concerned, Playr1 will always choose to move to safe caves if there are any; if not, it will choose caves which risk only bats, and if none of those remain, caves which risk both bats and pits but not the wumpus. If all else fails of course, it moves at random. This player then moves about the warren avoiding possible dangers as long as possible, and is particularly careful not to be eaten by the wumpus.

Playr2 is very similar to Playr1. Although it has several rules which Playr1 does not, the difference amounts to the fact that Playr2 can distinguish more types of strategic situations such as caves which are safe from bats and pits but not from the wumpus, or caves which risk only pits. In the end its fate is the same as that of Playr1 though since Playr2 also does not deduce the location of dangers.

Playr3 is the first really competent player. Not only does it deduce where the dangers are when possible, it also differentiates between caves for which there is single or double evidence of a danger. Thus if it is forced to guess, Playr3 is capable of making the best possible choice. This is also the first synthetic student which knows how to shoot the wumpus when it has been found.

Playr4 uses the same strategy as Playr3, but in addition uses something known as possibility sets. Like the name implies, these are sets of caves which could possibly contain a given danger. The size of a possibility set is reduced as new evidence is discovered, and when the set becomes unary, that cave is the one which contains the danger. There is a third kind of rule known as a P-rule which is used to manipulate possibility sets. The P-rules used by Playr4 are listed in Table IV below; to this point, Playr4 is the only synthetic student which employs these rules. The combination of possibility sets with the strategic rules of Playr3 allow Playr4 to play optimally in virtually every situation.

<u>TABLE IV</u>

In this table, DANGER= is the cave which contains a danger, and DANGER? is the possibility set.

p3: If there is a warning and no neighbors are DANGER=, add neighbors to DANGER?

p4: If there is no warning, delete neighbors from DANGER?

p5: Safe, visited caves are not DANGER?

p6: If there is only one danger and two possibility sets intersect, the intersection is DANGER=.

# DATA AND ANALYSIS

Once the data, consisting of protocols, representations made by the students and observations made during the course of each session was collected, extensive analysis was necessary. Three different types of analysis were done. The first was a rule analysis, which attempted to use all three kinds of data to represent each students progress in terms of the A-rules, C-rules and P-rules of the synthetic students. Once this analysis was done, it was possible to do a direct comparison of the real and synthetic students to see how well the synthetic students modeled the actual behavior of real students. The second part of the analysis concentrated on the representations each student was asked to make. Understanding the ways in which students represent their knowledge is an important part of being able to provide advice or tutor the different skills involved. The fact that the conclusions reached by this part of the analysis contradict some of the assumptions which have been made to date raises many questions about the design of the Wumpus/Wusor II system which merit further investigation. The final third of the analysis used almost exclusively the observations which were made, and attempted to focus on larger issues involved in the learning process. In general, these issues fall outside the scope of the present system, but they are nonetheless things which affect the efficacy of the system in imparting the desired skills. The three parts of this analysis and their results are discussed at length below with samples of data from different students included wherever necessary.

a. Rule Analysis

The task of determining which students know which rules is necessarily complex and imprecise. Even with the assumption that a students play is determined by a set of rules the task is not easy, since these rules are never directly observable and often not consistently applied by a real student even if they are known. Behavioral clues allow one to make reasonable guesses however, and the analysis was further aided by the fact that virtually every student talked out loud to herself during the entire session. This analysis was conducted as follows: first, the sequence of warrens was examined to determine for each rule (see Tables I, II, and IV) the earliest possible warren in which a situation exists where the rule could be applied. This was used as a base line against which both the real and synthetic students could be compared. Next, using the kinds of evidence described below, it was determined in which warren each student first showed behavior indicative of knowledge of each rule. Finally the synthetic students were each placed at some point in the warren sequence, corresponding roughly to the most complex warren that that synthetic student is capable of mastering.

The evidence used to determine C-rule knowledge is the most straightforward and can be drawn simply from the sequence of moves contained in the protocols. If, for instance, a student will move only into completely safe caves, then rule c2 can be assumed to be known. Sometimes even a person who uses this strategy will take chances on possibly dangerous caves, but people who for the most part used this strategy were given credit for using the rule. Rules c3 through c8 could be deduced directly from the kinds of risks taken in different situations. Rule c10 was specifically relevant only in warren 118, but if people had reactions such as "I hate pits. I like bats much better", this was taken as evidence for this rule. Rule c5-1 was only useful in warrens 117 and 120, and rules c3-1, c6-1 and c11 were never applicable in this sequence of warrens.

The A-rules were much more nebulous, and it was necessary to rely on the students maps and the observations which were made as well as the protocols to determine when a student had mastered these. Rule a0 was considered known if the student made some distinction between visited and unvisited caves. This could consist of some notation on the students diagram, expressions such as "Oh, I didn't want to go there- I've already been there before", or even consistently choosing only unvisited caves to go to even though there was no observable method or basis for doing so. On the other hand, a students going in circles was considered evidence that a0 was not known. Rule a11-4 is the rule which permits backtracking, so anyone who hit a warning and then backed up through already visited caves was given credit for knowing this rule. Once a student had backtracked in order to reach an unvisited cave in a different place in the warren, the student was told that instead of going back through all those caves they had visited, it was possible to jump directly to the desired cave. Students who proceeded to use this capability were considered to have the notion of a "fringe", and thus to know rule a1. Maintaining a list of the unvisited caves was the only evidence allowed as showing knowledge of a2. Rules a4 and p3 are very similar, and hard to distinguish behaviorally. The evidence used for a4 was comments to the effect of "The wumpus is in either I or G" whereas some idea of finding the intersection of the two lists of neighbors in caves where warnings were received was required before p3 was accepted. Rules a5 and p4 are even harder to distinguish, but again comments such as "It can't be B. I've been in cave B before." was sufficient for a5 to be considered known while some indication of looking for intersections of reduced sets of neighbors was required in the case of p4. Rule a17 was applicable only in warrens with bats, and only then if the student fell into the bat-cave. In these cases, any evidence that the student knew where the bats were was enough to include this rule in the students repertoire. Finally rule a19 (which behaviorally is indistinguishable from rule p6) was credited to the student if deductions as to the exact locations of dangers were made. The rest of the A-rules as well as p5 were not considered, either because they served primarily as bookkeeping rules for the synthetic students or because they were not applicable to the sequence of warrens.

The results of this analysis are shown in Table V. The warren numbers are listed across the top, the names of the students down the left side. In cases where two students worked together, both names are listed and the data was treated as if it came from a single student. The row marked "Optimal" shows the first warren in the sequence in which each rule could have been applied. An entry in the table which is empty means that no new rules were evidenced by the student in that warren. An entry which is X-ed out means that the student did not play the warren in question (a detailed explanation of why each student did not play all twenty warrens may be found in a later section). The remaining entries indicate the first warren in which a particular rule was used, as determined by the evidence given above. Finally, the row labeled "Synthetic Students" indicates the most complex warren in the sequence which each student can successfully complete.

Although Table V gives a reasonably good indication of different students knowledge of the different rules, it misses altogether the fact that a large part of the problem which many students had was not in knowing the rules so much as in not being able to apply rules in a consistent manner. In the synthetic students, rules either succeed or fail, and their success or failure depends only on the game situation. Real students however often end up with rules only partially succeeding, or failing because a vital piece of information has been forgotten or is not noticed on the students diagram. This problem needs more extensive investigation if the computer tutor is to be able to model students with more precision than it is presently capable of. In order to shed some light on

TABLE V

| WARRENS: | 101 | 102 | 103 | 104 | 105 |
|---|---|---|---|---|---|
| OPTIMAL | c0 c1 c4 c12<br>a0 a1 a2 a11-4<br>p3 p4 p5 | a19<br>a4<br>a5 | p6 | | c5 c8 c10<br>a17 |
| Wendy G. | c0 c12 a0 | | | c4<br>a4 a11-4 | c1 c5 c8<br>a1 a5 a19<br>p3 p4 p5 |
| David W. | | | | a0<br>c0 c12 | c4 a4 a17 |
| Steven D.<br>Chris B. | c0 c12<br>a0 a1 | | | a4 | c8 a11-4 |
| Jr F. | c0 c12 a0 | | | | a2 a5 a17<br>c2 p4 p5 |
| Andy S.<br>Stacy W. | c0 c12 a0 | | | a4 | c8 a11-4 |
| Cathy S.<br>Tony C. | c0 c12 a0 | | | a4 a5 | c8 a11-4 |
| Richard M.<br>David W. | c0 c12 a0 | | | a4 a5 | c8 a19<br>p3 p4 p5 |
| Kurt<br>Erik | c0 c12 a0 | | | | a4 a11-4 a19 |
| Marjorie G.<br>Miles B. | c0 c12 a0 | | | a4 | a17 |
| Joel O. | a0 a1<br>c0 c12 | a4<br>a5 | a11-4 | | p3 p5 p6<br>c5 c8 a19 |
| Danny R. | | | | a0 a19<br>c0 c12 | |
| Austin R. | c0 c12 | | | a19 | c8 a4 a11-4 |
| Synthetic<br>Students | Playr0 | | | Playr1<br>Playr2 | |

TABLE V (CONTINUED)

| 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 |
|---|---|---|---|---|---|---|---|---|
| c3 c7 | | | | | | | c2 c6 | |
| c7 | X | X | | | | c3 | c2 | |
| | X | X | | | | | a19 | |
| a5 c7 c10 | X | X | | | p3 p5 p6 a19 | c1 p4 | | |
| a4 p6 | | a11-4 | c1 a1 | | | | | |
| | X | X | a5 | a19 | | | | |
| p3 p4 p5 c4 a19 p6 | X | X | | a1 c1 c7 | | | c2 | c3 |
| p6 a1 a11-4 c1 c4 c7 | X | X | | | | | c2 | |
| | X | X | | a1 a5 c1 | | | | |
| | X | X | | | a11-4 a19 | a5 | | |
| c1 c4 | | p4 | | c3 c7 | | | c2 | |
| a4 a5 a11-4 c7 | X | X | | | | | | |
| | X | X | a5 | | | | | |
| | | | | | | | | |

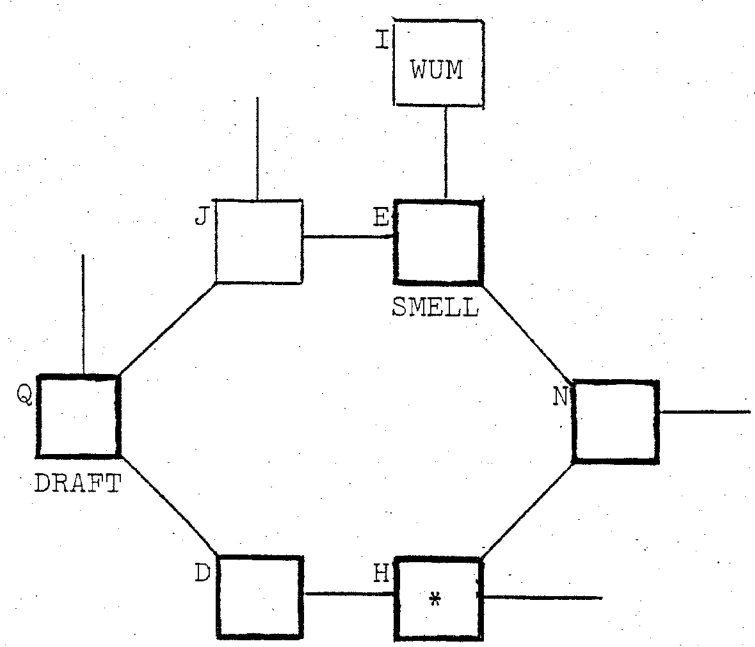
TABLE V (CONTINUED)

| 115 | 116 | 117 | 118 | 119 | 120 |
|---|---|---|---|---|---|
| | | | | | c5-1 |
| | c6 | c10 | | | c5-1 |
| | | | a11-4<br>c10 | p3 | |
| c3 | | | | | |
| | | | | | c5-1 |
| | a17 | | c10 | | |
| | | | | c6 | |
| | | | a17<br>c10 | c6 | |
| | a17 | | c10 | | |
| | | | c10 | | |
| | | | c10 | a17 | c5-1 |
| | | | a17<br>c10 | | |
| | | | a17 | | |
| | | | | | Playr3<br>Playr4 |

this problem and to give more concrete examples of what it means for a student to "know" the rules in Table V, the rest of this section will be devoted to examples taken from different sessions of students applying and misapplying various of the rules.

The first example is taken from a session with Wendy G., and shows the application of rule a5 which says that "No warning implies that the neighbors are DANGER-." In warren 109 Wendy had reached the following situation by making the moves shown below the diagram:

Figure 3

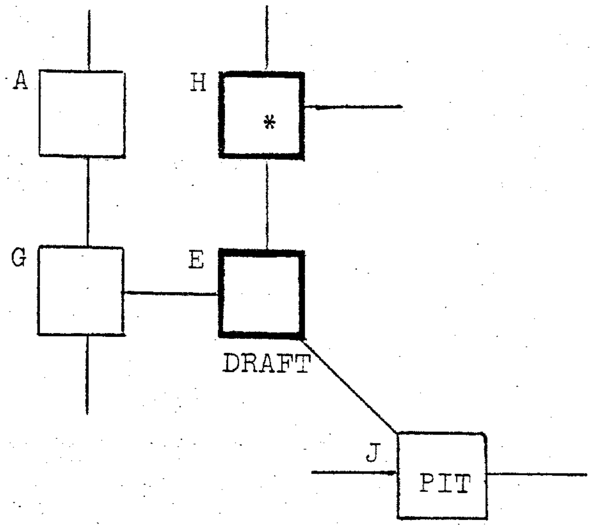



VISITED: HDQDNE

At this point Wendy says to herself "J and I...When I was in Q, there was J, and no warning for a wumpus." She then proceeds to shoot into cave I and kill the wumpus, obviously deducing that cave J was DANGER- (or more specifically, WUM-) since there was no wumpus warning in cave Q.

The second example shows Richard M. and David W. using the concept of possibility sets described in rule p3 as DANGER?. Our intrepid wumpus hunters had moved from cave H to cave E in warren 106 and were confronted with the following situation:

Figure 4



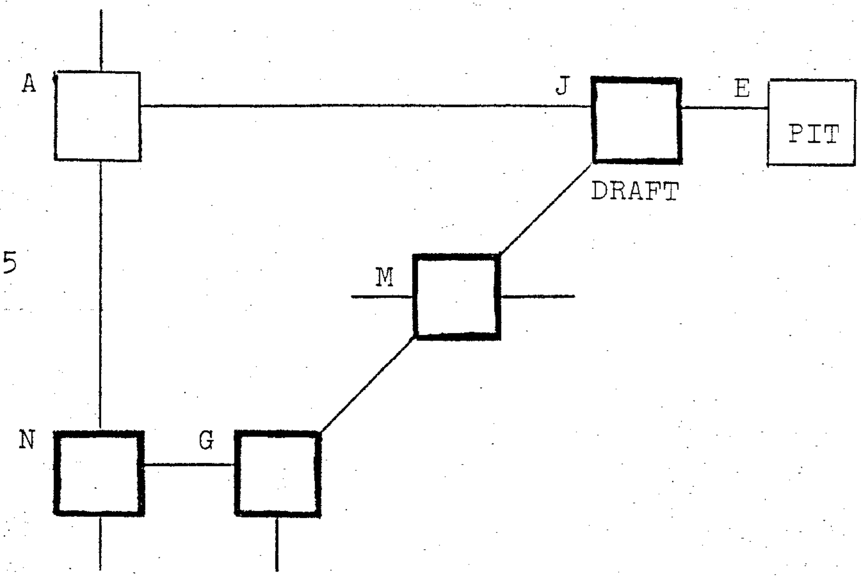

David proceeded to remark "We're already next to a pit. Terrific. Make lightly a circle around G and J but not H. The pit is in either G or J." After reaching cave A from another direction, the power of the possibility sets was exploited: "Go into G. That proves it's in J."

Steven D. and Chris B. were one of two groups to explicitly use the word "backtrack", the evidence needed for rule all-4. In warren 105 after moving from P to M, Steven exclaimed "We want to avoid the bats! Want to backtrack?" The two then returned to cave P.

The final example of students successfully applying a rule is when Kurt and Erik used rule a19 to help them solve warren 110.

After traveling through N,G,M and J to reach the situation shown below, Kurt declared "It's not in A. It's in E. How many pits are there? One. It's in E."

Figure 5

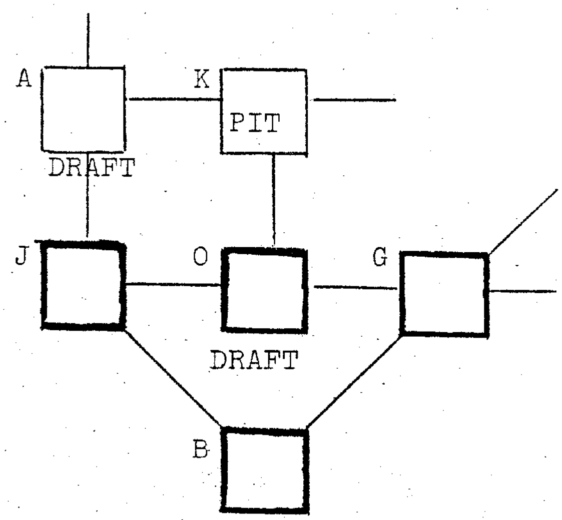



Clearly he wanted to make sure that only one pit could be responsible for the warning, and thus the condition for rule a19 was satisfied.

Two examples of the misapplication of rules may also be instructive. Marjorie G. and Miles B. found themselves in exactly the same situation as described in the second example above (see Figure 4). Miles' response however was "It's in G or J. I don't want to go back though." Unfortunately they chose J, and the game ended. Notice that the comment indicates that Miles had both limited the location of the pit to two caves and was aware that he could backtrack. He simply chose not to apply his knowledge.

The second example comes from David W.'s wanderings through warren 114. David moved from B through G and O to cave J. While still in cave J and knowing that a pit was somewhere in the vicinity, the comment was made "It's in O. No, it's not in O. It's in J." After moving to cave A and receiving another warning, David assumed that his hypothesis had been verified: "It's J alright."

Figure 6

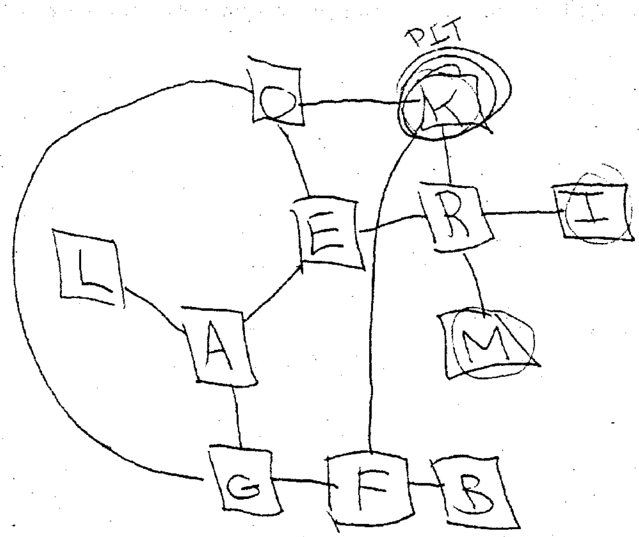



Since the pit was actually in cave K, David's successful completion of this warren was merely good fortune, not the result of good logic.

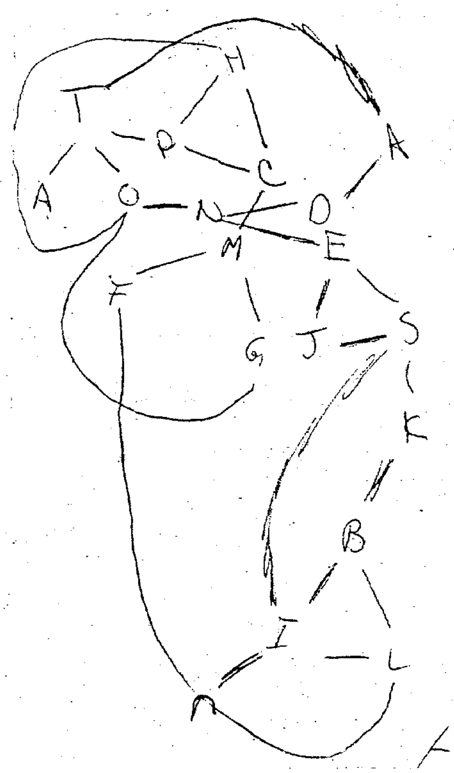
b. Representations

A limiting factor on the kind and number of rules which can be learned is the representation of the game which the student uses. In her Wumpus Protocol Analysis[7] (White, 1977), Barbara White discusses three general classes of representation: graphs, tables and list structures with some of the properties of graphs. These three types were also predominant in the representations done by the subjects of this experiment. To convey some idea of what is meant by these three varieties of representation, examples of each type may be found in Figures 7, 8 and 9 respectively.

An interesting difference between the findings made by White and those presented here involves the distribution of the different representation types. Five of White's ten college age subjects used graphs alone to represent the information, with the remainder using various combinations of the three types. Of the seventeen different elementary students who made representations for this experiment, only four started using graphs as their representation and by the end, two of those had switched to some other type. Eight people began by using tables, three began with list structures, and two started without any representation at all. A fair amount of switching between representation types occured, mostly among partners who would start with two different kinds of representation and then settle on one after several games. The net result however was that at the end eight people were

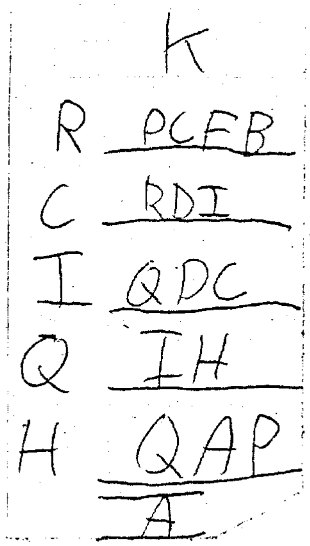



WARREN 117

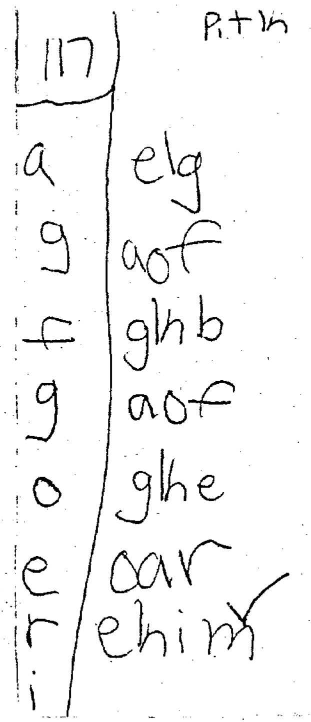


WARREN 112

FIGURE 7: GRAPHS

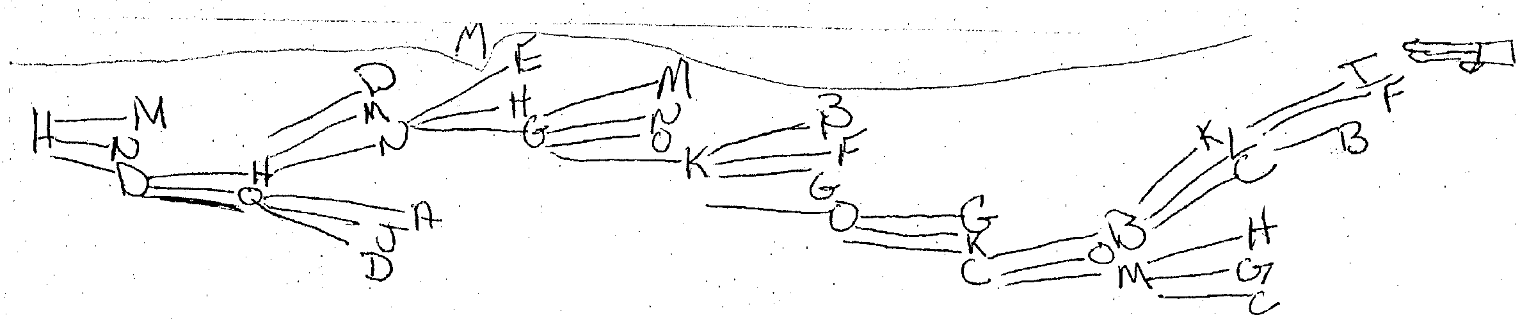



WARREN 104

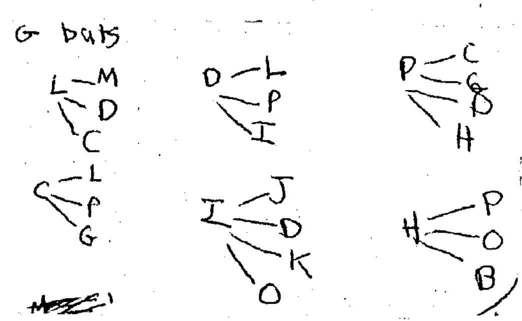



WARREN 117

FIGURE 8: TABLES



WARREN 109



WARREN 116

FIGURE 9: LIST-TYPE REPRESENTATIONS

still using tables, three still used list-type representations and the number of people not using any representation at all had risen to four. This result was rather unexpected, and an initial hypothesis was that the younger students had difficulty changing from the table structure presented by the computer in this experiment to a graph; observations indicate that this is actually only part of a larger problem. It is significant that two people who began using graphs stopped using them after a few games. One of these people was asked why they changed, and replied that the graph was "too complicated." One of the people who did not use a representation was shown the graphics capability of the system with the expectation that they would like the simplicity of the computer doing the representational work, but the response was that the person did not like it at all: "It's too confusing." Subsequently, a third person who had used a graphical representation throughout was shown the graphics package, but this person also responded negatively when asked if they thought it would be nice to have the computer draw the map of the warren. Two things seem clear from this: firstly, the spatial representation used in a graph is extremely difficult for most children of this age group to work with. Apparently the kinds of logical processes these students use are best aided by the information maintained in a table, and translating back and forth between tables and graphs only confuses the issue. Secondly, even in the cases where a graph was the representation of choice it was necessary for the students to make the graph. This may be because the student can only think productively about a problem if the information available has been acknowledged and internalized, processes which happen automatically in the course of making a representation. A computer representation is external to the student, may use symbols which are not meaningful to the student and certainly reqires an extra level of interpretation, and these difficulties may render the computer drawings practically useless to students of this age.

The interplay between the rules which a student applies and the representation she maintains is also quite interesting. In general, the increasing sophistication of a students play is reflected in the increased amount of information which is included in the representation. The remainder of this section will focus on several examples to illustrate some of the ways in which representations may increase in complexity. It seems that once a particular kind of representation is chosen, the number of ways in which the complexity may increase is at least partially limited by the type of information which is easy and natural to add onto the representation. Thus graphs are excellent for taking account of the connectedness of a warren but require some effort to use for possibility sets. Tables are just the opposite; the possibility sets are explicit but the connectedness is diffuse. The examples illustrate the development of three different types of representation and although more investigation is needed in this area, it seems plausible that an effective tutor would need to be able to stress different rules or strategies according to the type of representation used by the student.

The first example involves a graphical representation. Figure 10 depicts a student's drawing of warren 109, and as can be seen, it consists of nothing more than the caves which have been seen and their connections. This is in spite of the fact that a breeze had been felt in cave Q, and that information had then been combined with a stench in cave E to allow the player to shoot the wumpus.

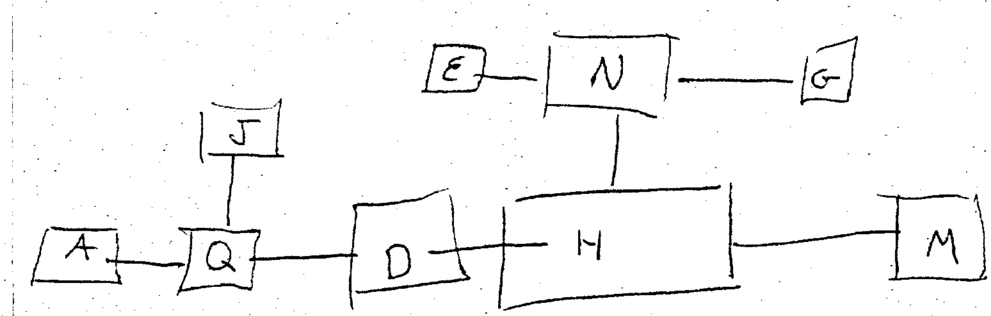



Figure 10

Clearly the player is using more information than that contained in the diagram. By the time that the drawing for warren 113 (shown in Figure 11) has been done, the student has realized that the representation can be useful for other kinds of data such as the location of pits or the number of dangers in the warren. The graph itself however is still nothing more than a picture of the caves and their connections; other information is listed separately.

Finally in Figure 12, the graph has become the primary representation for warren 114, with only the list of warren specifications being kept elsewhere. Notice that in this

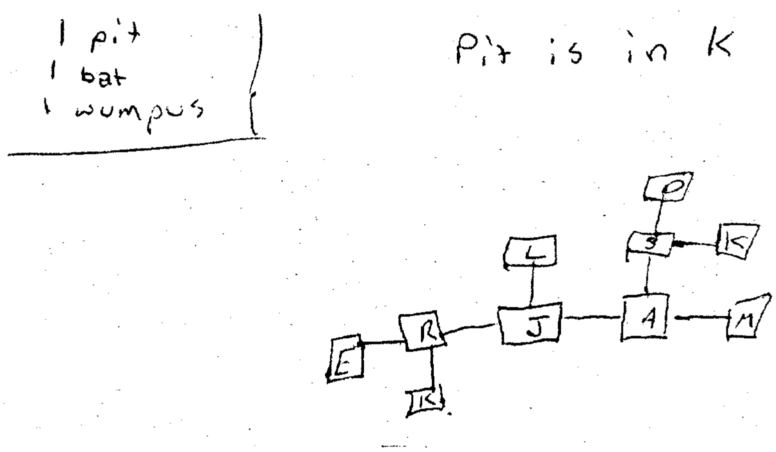



Figure 11

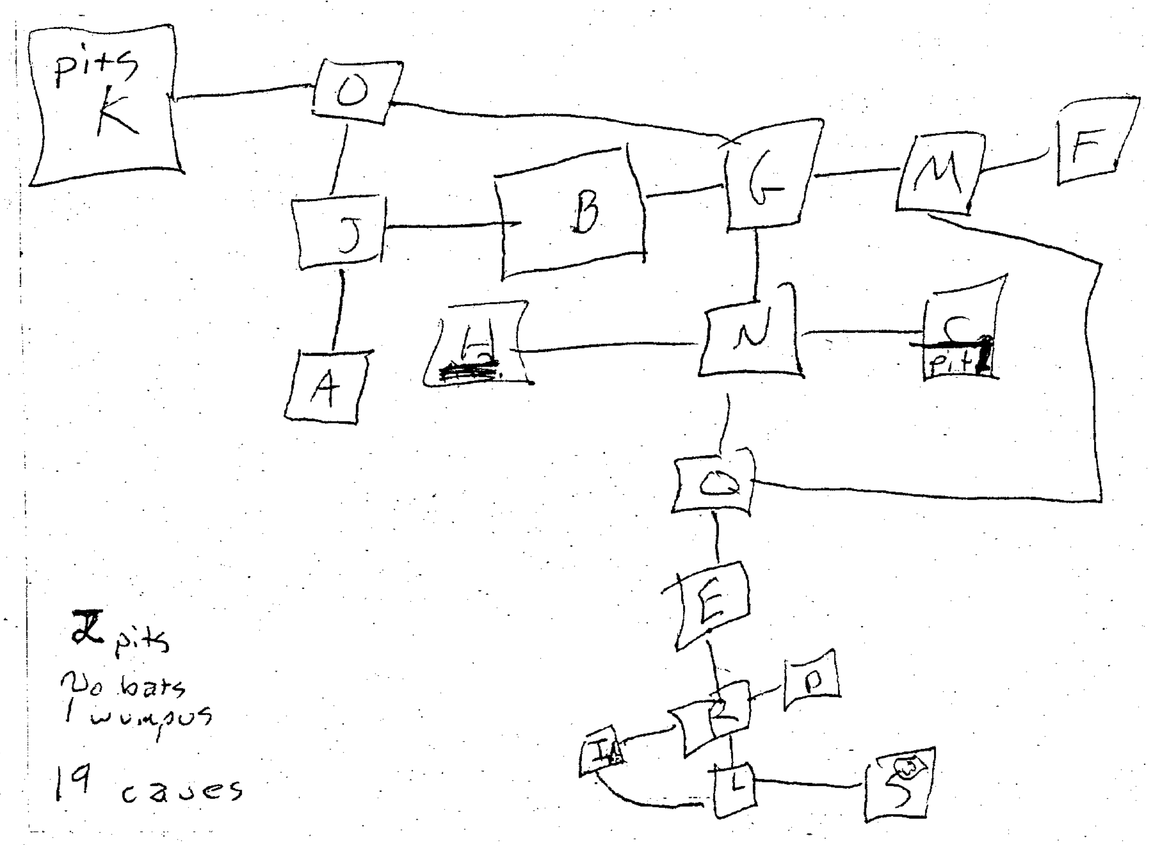



Figure 12

warren the graph has even been used as an aid in the reasoning process, with caves C and H both originally marked as PIT? and later changed to reflect the positive identification of the pit.

The second example shows the development of the most unique of all the representations. In warren 101, this representation began as simply a list of the caves which had been visited with the notation "s" for safe under each one as shown in Figure 13.

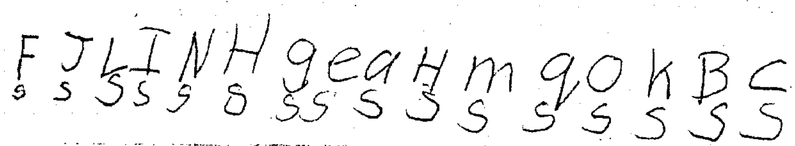


Figure 13

Starting with warren 105 however, the representation began evolving. First, the student took advantage of the fact that at the start of each warren the computer informs players of the number of caves in that warren. This allowed our student to start by listing the set of all possible caves, as is indicated by the fact that the representation in Figure 14 has the caves listed in alphabetical order instead of the order visited. Once this was accomplished, the "s" notation could be used for the

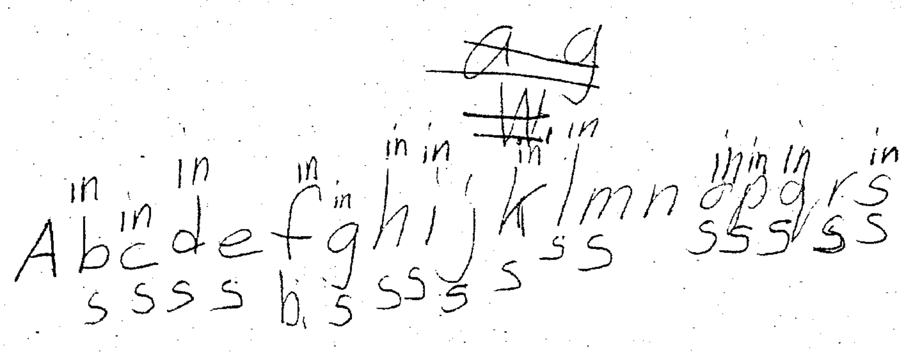


Figure 14

neighbors of caves without warnings as well as the caves which had been visited. To keep track of the latter, a new notation was added in the form of the word "in" written over the visited caves. Also in this diagram, the location of a danger is marked for the first time, with a "b" for bats under cave F. Note finally the letters a, g and w crossed out above the list. These were written as the student tried to figure out the location of the wumpus; the "w" stands for wumpus, with a and g being the members of this possibility set. They were crossed out when the student realized that the warren had started in cave G (not counting the starting cave as visited was a common mistake) and thus the wumpus was in cave A.

A final refinement to this scheme was made in warren 113 as shown in Figure 15 below. In order to emphasize the fact that the dangers should be avoided, the student began to put cross marks through the letter of the caves containing dangers.

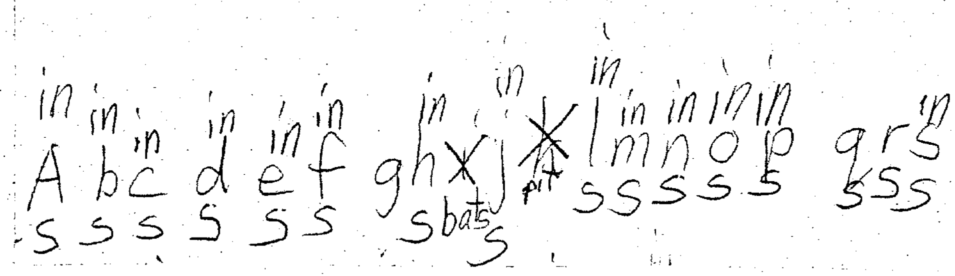
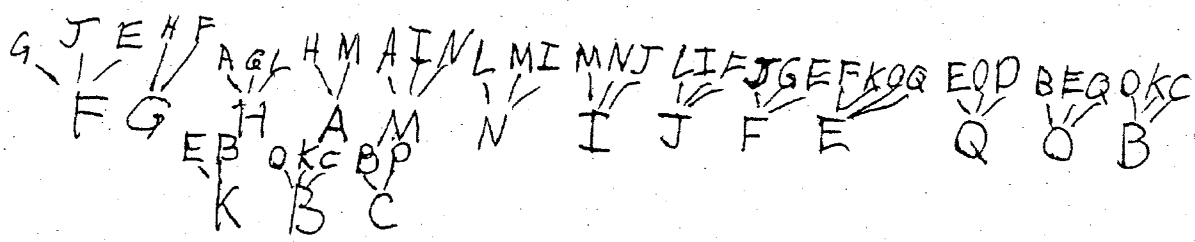



Figure 15

The third and final example of this section illustrates one of the typical results which occured when two people worked together. Figure 16 shows the two simultaneously drawn versions of warren 101, one by each person. After one more



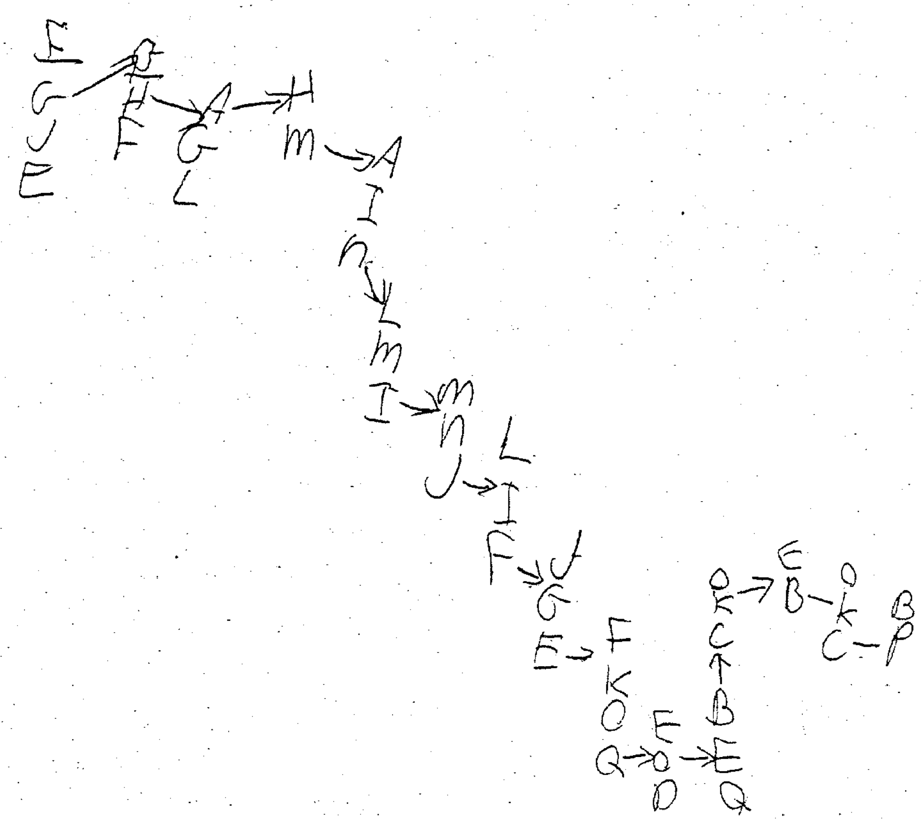


Figure 16

attempt at maintaining two distinct representations, the students decided that one was as many as they really needed, and so settled on the format shown in the top illustration of Figure 16. This representation was then refined until by warren 115 it had developed to the point shown in Figure 17. The conventions used here are that caves with warnings are included in a large circle with their neighbors (primitive possibility sets), caves in a possibility set which are safe have a check mark put over them, and the identified dangers are circled and marked.

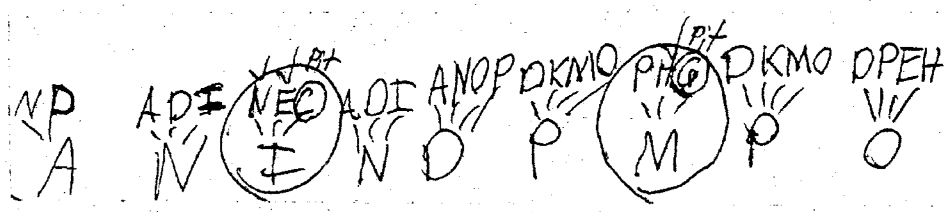


Figure 17

c. Other Factors Affecting Learning

As mentioned at the beginning of the presentation of the data and its analysis, there were several things which influenced the way in which students learned but which do not necessarily fall within the scope of the present Wumpus/Wusor II system.

The first such factor was that there was only a single sequence of warrens which all students were expected to play. This had several distinct disadvantages: first of all, the sequence was designed for complete beginners at the game. In order to give everyone a chance to learn the rules and overcome the novelty of working with a computer, the first four warrens were designed as a "warm-up", with no pits or bats in any of them. Some people made comments such as "When are we going to get some pits or bats?". This usually coincided with other signs of boredom such as wandering attention or making guesses when the student knew the necessary rules for a deduction. A few people even thought the warrens with single dangers were too easy, and persevered only when promised that the warrens would get harder. Wendy G., who won fifteen of the sixteen warrens she played made the comment "I'm sick of shooting the wumpus" after warren 110, and after shooting herself in warren 115, seemed satisfied and exclaimed "Finally!".

In other instances it was clear that a students imperfect knowledge of a rule needed to be allowed to fail in other warrens with situations using the rule in question. Finally, after a number of games some students were just physically and mentally tired and wanted to finish as quickly as possible. All of these considerations led to the situation indicated in Table V, that students were not usually forced to play the entire sequence. In these cases an effort was generally made to skip the less interesting and less informative warrens such as 102, 103, 107 and 108. Since this experiment is largely exploratory, it was not felt that this lack of rigor significantly affected the experiment, particularly since the deleterious effects of boredom or tiredness often resulted in much poorer play than the student seemed capable of.

An item which is relevant to the computer tutor Wusor II (not used in this experiment) also came to light. Wusor II has the advantage of being able to intervene between the time a player types his move and the time the computer actually moves the person to the new cave, and thus its main tutoring strategy is to ask the student if he really wants to make a questionable move, and to suggest possible alternatives[8]. Although the primary aim of this research was not to tutor students, some advice on strategy or specific moves was occasionally given. Advice was given before students decided where to move, after they decided but before the actual move, and after the move had been made. It was found that a large majority of the students to whom strategic advice was given would change their strategy only after it failed; that is, only if the old strategy caused the student to lose the game. The only kind of help which most students were receptive to either before or during the move was reminders that dangers were nearby such as "Don't forget, you can feel a breeze in that cave." If a third version of the Wumpus Advisor is to be written, this question of what advice should be given when is one which deserves more attention.

Perhaps the largest limitation on the game as far as elementary school students are concerned is the modality of the interaction itself. One of the more amazing observations to come out of this experiment is that, without fail, every student who played the game alone talked to herself during the entire session. It seems that children of this age are very verbally oriented and talk out loud to help in their thinking. In order to test this, several students played the game verbally, with the experimenter providing the information normally provided by the computer. These students seemed to play the game much more quickly at comparable levels of skill, and to have an easier time maintaining their representations. Some of the problem lies in the fact that most students of this age are not familiar with the typewriter keyboard, and many either read slowly or else skim over or read only part of what is written (comments from several parents bore out this observation). Many students even failed to understand the meaning of the word "stench" used by the computer to indicate a wumpus warning until the meaning of this word was explained to them. In short, the process of reading information off a computer display screen, transferring this information to an external representation for the reasoning processes and then being forced to put a response back into the machine via the keyboard seemed to cause problems even for the best players in this age group.

Lastly, the game was universally declared by students and parents alike to be worthwhile and extremely enjoyable. This enthusiam certainly makes the game much more effective than would otherwise be possible, but in some cases people were enjoying the game to such an extent that they did not really care whether they won or lost- an attitude which renders any tutoring almost worthless. In cases like this it seems best to abandon any efforts at tutoring and trust that the structure of the game itself combined with the students self motivation are sufficient to make a session educationally useful whether or not any of the intended ways of thinking are actually learned.

## CONCLUSIONS

A number of conclusions are evident from the data presented above. For starters, the rules used in constructing the synthetic students form a reasonably accurate description of the kinds of thinking which the students in this experiment attempted to use, and formed a solid base from which an analysis of the data could proceed.

The synthetic students themselves, although not descriptive of any particular person, do provide plausible static models of what a students behavior might look like at some point in his wumpus-playing career. Assuming that the less skilled synthetic students were given the ability to shoot at the wumpus under certain conditions, the currently existing synthetic students viewed as a sequence would form a believable model of a students progress.

On the other hand, the synthetic students are definitely not good models of the difficulties which real students have. The students in this experiment had more trouble with consistently applying rules for example, and relatively less trouble in learning new rules as might be expected. Students also had a lot of trouble remembering that they knew pieces of information, or getting lost in the middle of a train of thought; the logical processes themselves seemed well within the grasp of most of the subjects.

A large part of this last problem seemed related to the modality of the situation, with many mistakes occuring while transferring information back and forth to the computer, or as a result of misreading the screen or forgetting what the student had decided to do in the process of typing it in.

The graphics part of the present system was seriously called into question by the data gathered here. At least for students of this age group, being forced to rely on a graphical representation would have had many detrimental effects. Most students simply were not readily able to use a map and were much more comfortable with some form of tabular representation

Generally, students were only motivated to change their behavior as a result of previous behavior failing; thus strategies changed only when the student lost a game, and representations evolved only when a piece of information the student wanted was not available on his representation.

Finally, the Wumpus/Wusor II system proved in all cases to be an exceptionally good teaching device, although the skills learned by the students may not necessarily have been those envisioned by the people who designed the system. It is certainly true that many students seemed to have developed at least part of the deductive and logical reasoning skills which are modeled by the A-rules, C-rules and P-rules. But playing the game seemed extraordinarily successful from an educational standpoint whether or not the student learned any of these skills. The reason for this is that in order to play the game students were forced to rely on more general problem solving skills. These skills involved taking a real-world problem (playing the game), making up a representation for that problem, updating the representation to account for new information in an organized enough manner to be able to use it, solving the problem with the aid of the representation, and transferring the solution back to the game where immediate feedback was available. It is rare that students are challenged to use this set of skills, and even more seldom is the challenge made in an environment as interesting and exciting to children as Wumpus. Students of this age are enormously eager to learn if they are taught well, and this is the source of the comment which was almost universally made at the end of a session: "That was fun."

## SUGGESTED AREAS FOR FURTHER INVESTIGATION

The most urgent area where further work is needed is the area of variable warren sequences. Warrens can be designed to correlate fairly closely to the exercise of a specific rule or rules. If for each rule in the Wusor II curriculum a group of warrens which depended on that rule for their solution could be constructed, it would be possible to introduce the flexibility which is so desparately needed into the system. A student who readily catches on to the basic concepts of the game could be quickly advanced to the more complicated warrens while a person who had more difficulty could play several easy warrens in a row. A students file might contain some sort of boredom factor to allow the machine to tailor the length of each session to the particular students needs. The need for such a capability was repeatedly pointed out during the experiment, and this seems like a logical direction for the development of this system.

More work is also needed on the tutoring aspects of the system. At least three different questions concerned with the tutoring seem to merit further investigation. The first question is when is the optimal time to intervene with tutoring advice. Different kinds of advice may be best presented at different times; for instance, strategic advice might be most effective after a student has lost a game whereas omissions in the representation might need to be pointed out whenever they are spotted.

Another possible area of investigation is the desirability of expanding the kinds of skills the Wumpus Advisor is capable of tutoring. Perhaps the general problem solving skills discussed in the conclusions section would be suitable candidates for such an expanded tutor.

A final question related to tutoring concerns the limitations imposed by different types of representation. It simply may not make sense to attempt to tutor certain concepts if those concepts are incompatible with the representation. Little, if any, work seems to have been done in this area.

The type of representation which various groups find easiest to use is yet another area in which little work has been done. The findings of this experiment indicate that younger students may be better at using a table while older students prefer a graph. Certainly before a single representation becomes universally enforced by the machine, extensive work remains to be done on this problem.

Lastly, the limitations imposed by the modality of interaction need to be explored. This may present no problems for older students, but it is clear that the younger a student is, the more of a problem this becomes.

# APPENDIX A

# THE WUMPUS WARRENS

## EXPLANATION OF DIAGRAMS

In these diagrams of the twenty warrens, caves are represented by squares with the identifying letter of the cave immediately next to it. Connections between caves are indicated by straight lines. Dangers are marked by WUM, PIT or BAT written in the cave in which the danger is located. Warnings are written below the cave in which they are received. The starting cave for each warren is indicated by an asterisk (*) in the appropriate cave. The warren number is listed below each diagram.

## ORDERING RATIONALE

The warrens are divided into three groups by the number of dangers they contain. Warrens number 101 through 104 have only a wumpus in them, warrens 105 through 112 have a wumpus and either a pit or a bat, and warrens 113 through 120 have a wumpus and either apit and a bat, or two pits. Within each group the warrens are ordered in accordance with the reasoning explained below.

Wumpus Only:

101- This is a simple search. As soon as a smell is encountered, the location of the wumpus follows immediately.

102- Here, the warning in cave A may be caused by the wumpus being in either of two caves. Thus some slightly more complicated reasoning is required.

103- Both warnings may come from one of two caves.

104- In this warren, the warning in cave H is necessary to find the wumpus. The warnings in caves O and P, either singly or together are not sufficient.

Wumpus Plus One Danger:

105 and 106- One smell plus one bit of negative evidence are enough to locate the wumpus. The dangers may be avoided simply by backtracking when a warning is given.

107- Straightforward deduction, but must find two caves with smells to get wumpus.

108- The trick here is not to get confused by caves with two warnings.

109- By combining the lack of a smell in cave Q with the smell in cave E, this one can be solved quickly. There is also a simpler deduction which will solve this if the short solution is missed, but the search is much longer.

110 and 111- By deducing where the bat or pit is, you can safely move past the dangers to get at the wumpus.

112- Discovering the location of the pit is a necessary step before the wumpus can safely be found.

Wumpus Plus Two Dangers:

113 and 114- Once again, backtracking at warnings

is sufficient strategy to negotiate the warren.

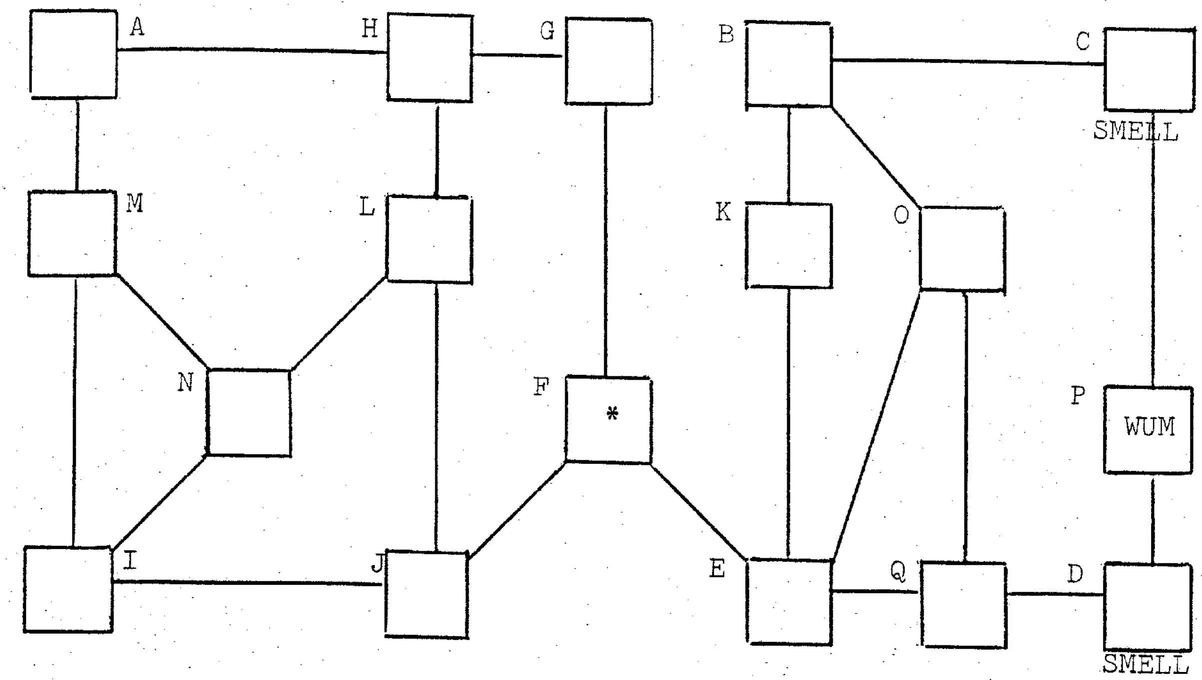
115 and 116- Each of these requires the player to deduce the location of one of the two dangers to get to the wumpus.

117- The draft in cave R is from two pits instead of one, a possibility which makes things hard for most people. The pits aren't too difficult to locate though and once they are found, the wumpus follows almost immediately.

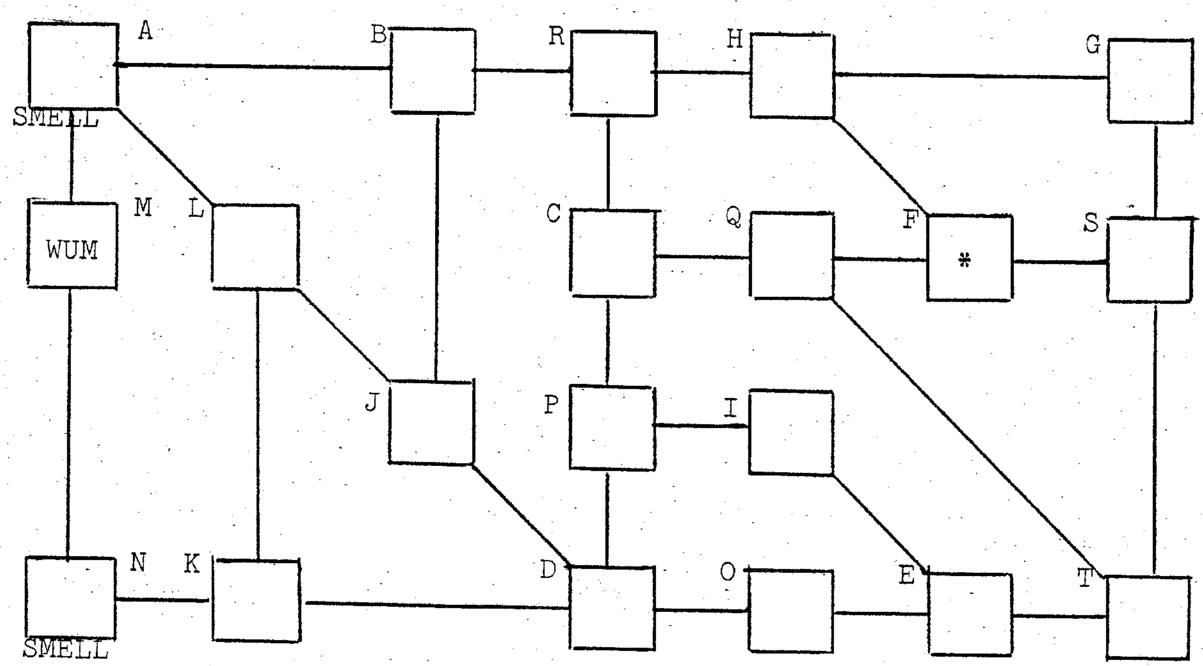
118- This one requires probability. Once you decide that the bats are a much better risk than the pit, the rest is easy.

119- You better know where both dangers are if you want to survive this warren.

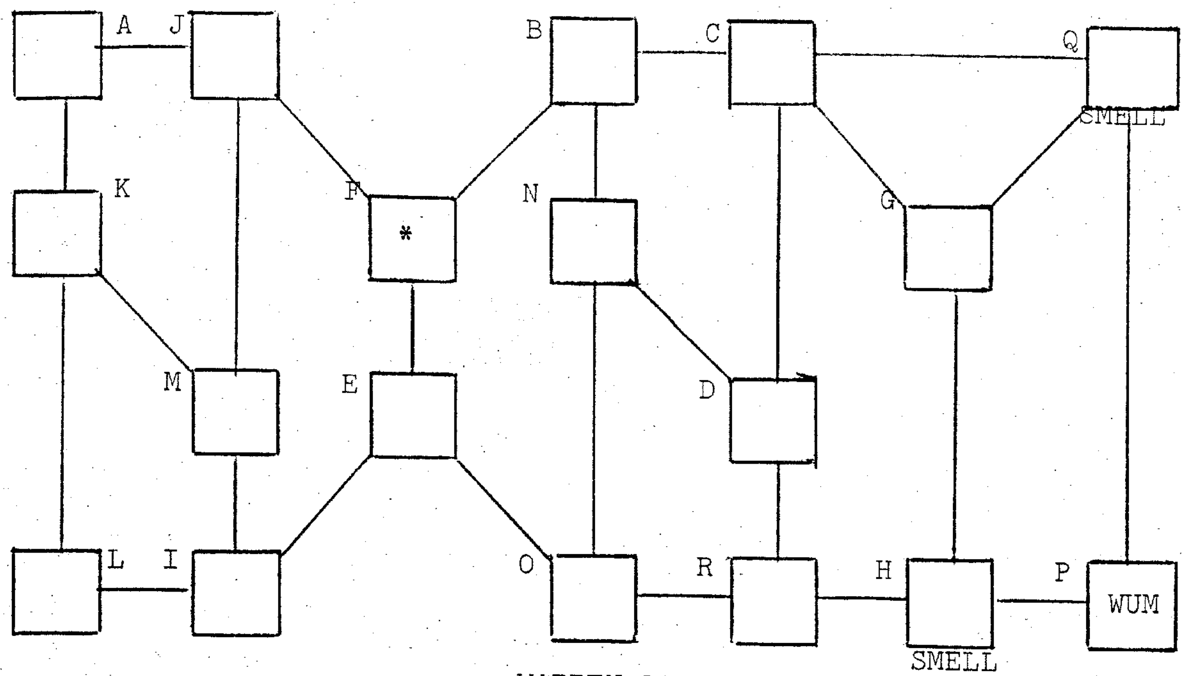
120- This is the hardest one of all. Not only is it necessary to know where both pits are, locating them is difficult since two of the warnings are for both pits. Even when the pits are found, it takes some work to get the wumpus.




WARREN 101




WARREN 102

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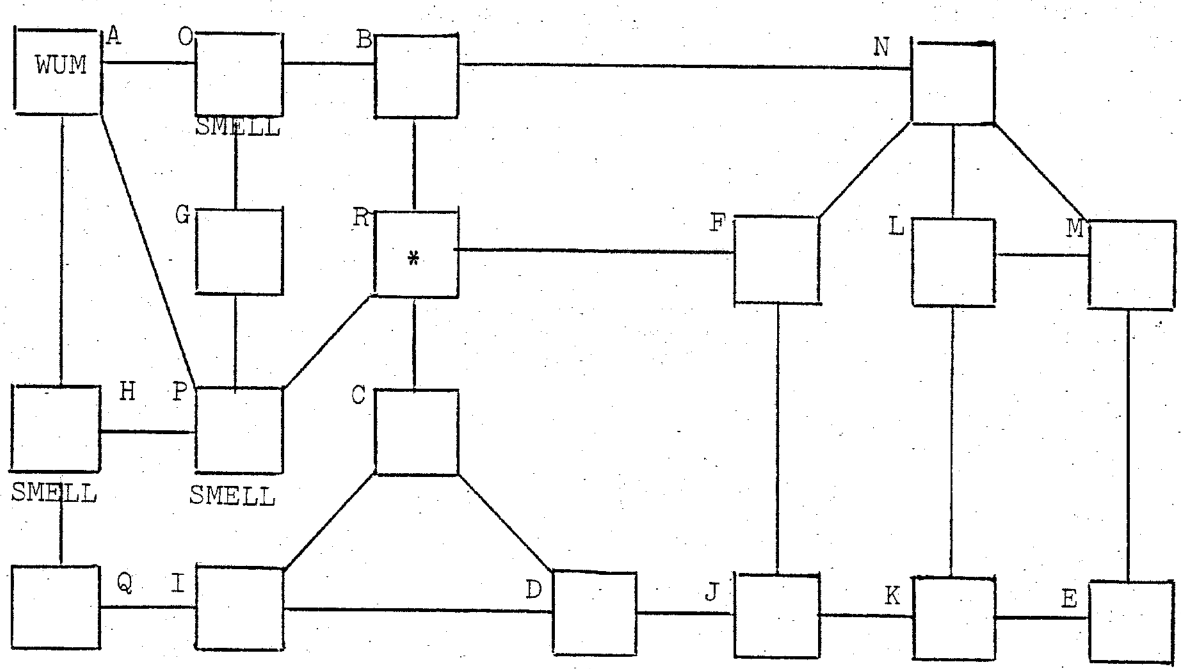


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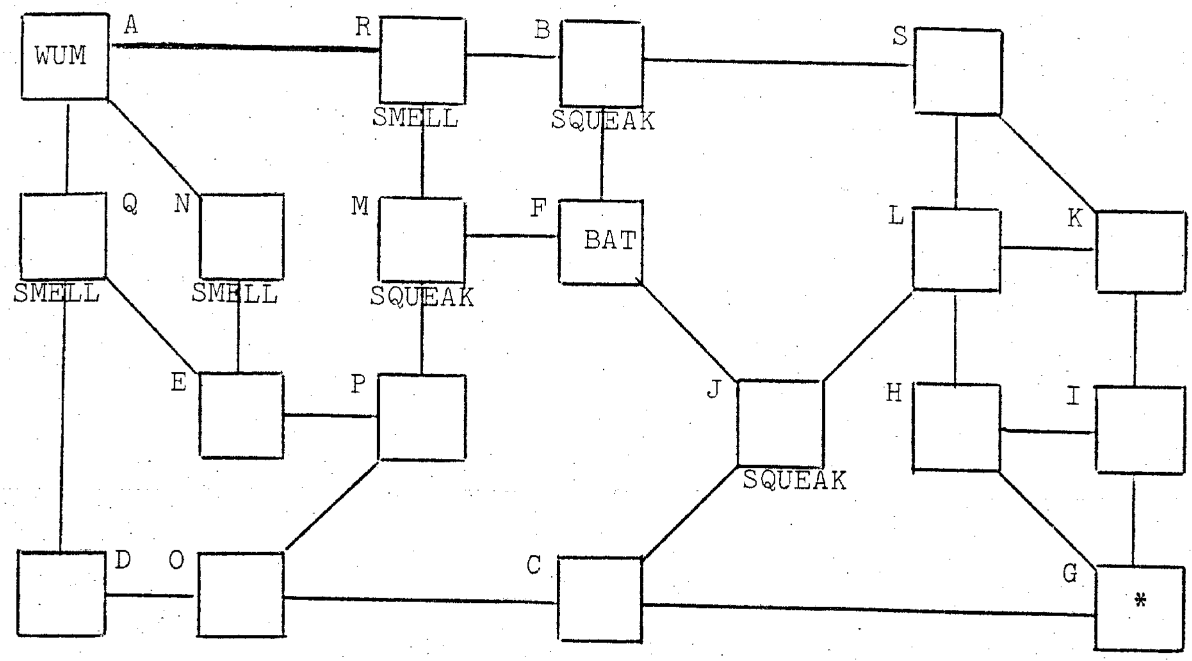
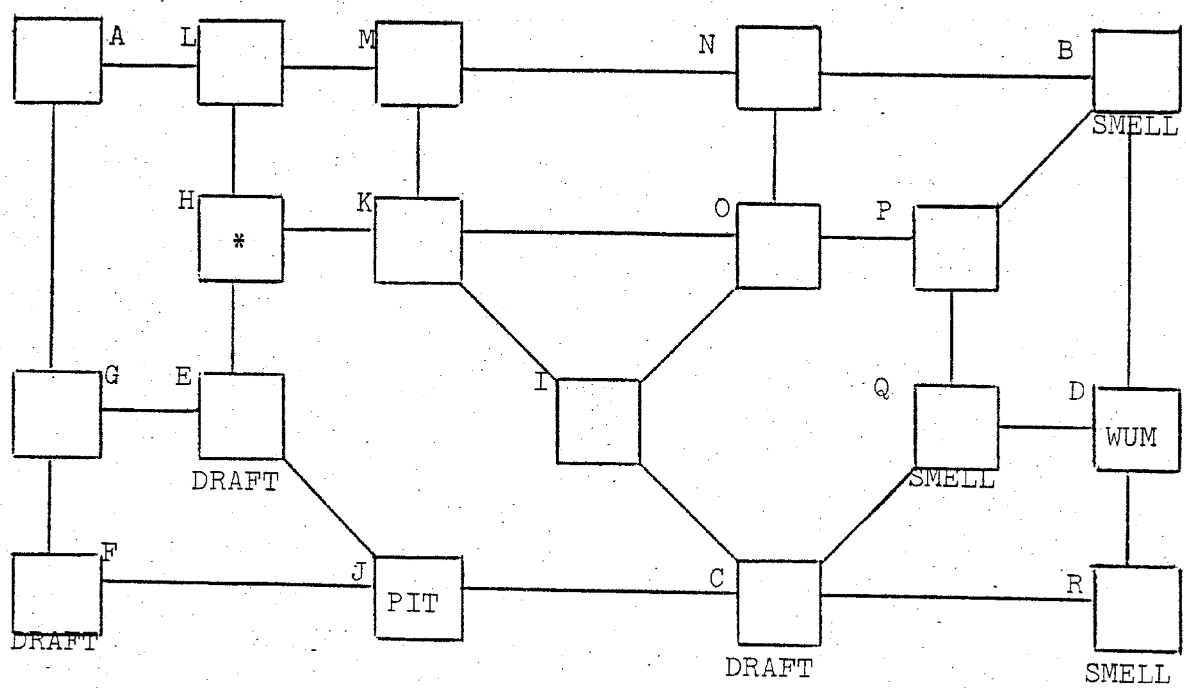



WARREN 105

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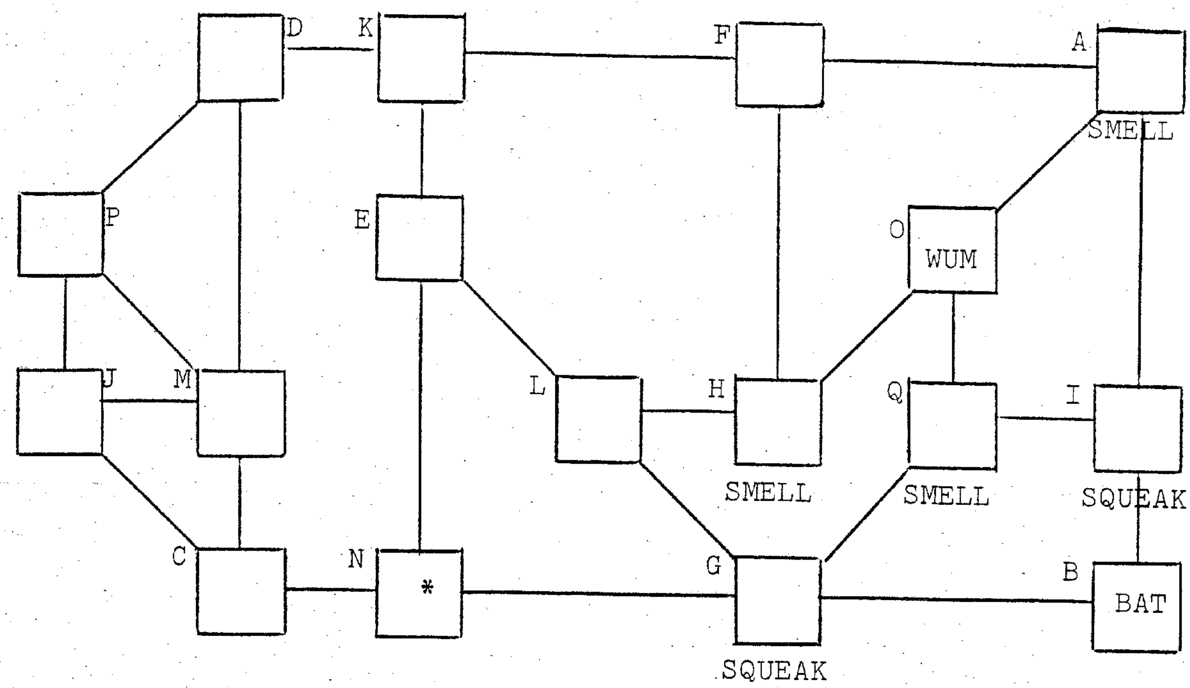
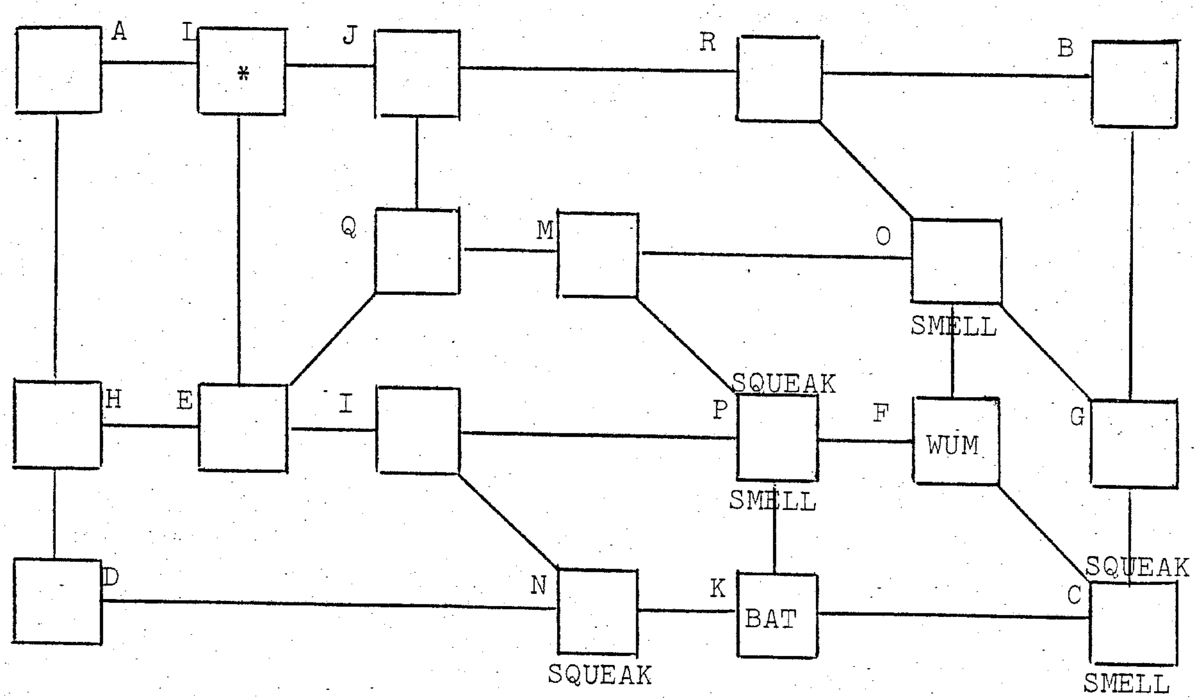



WARREN 107

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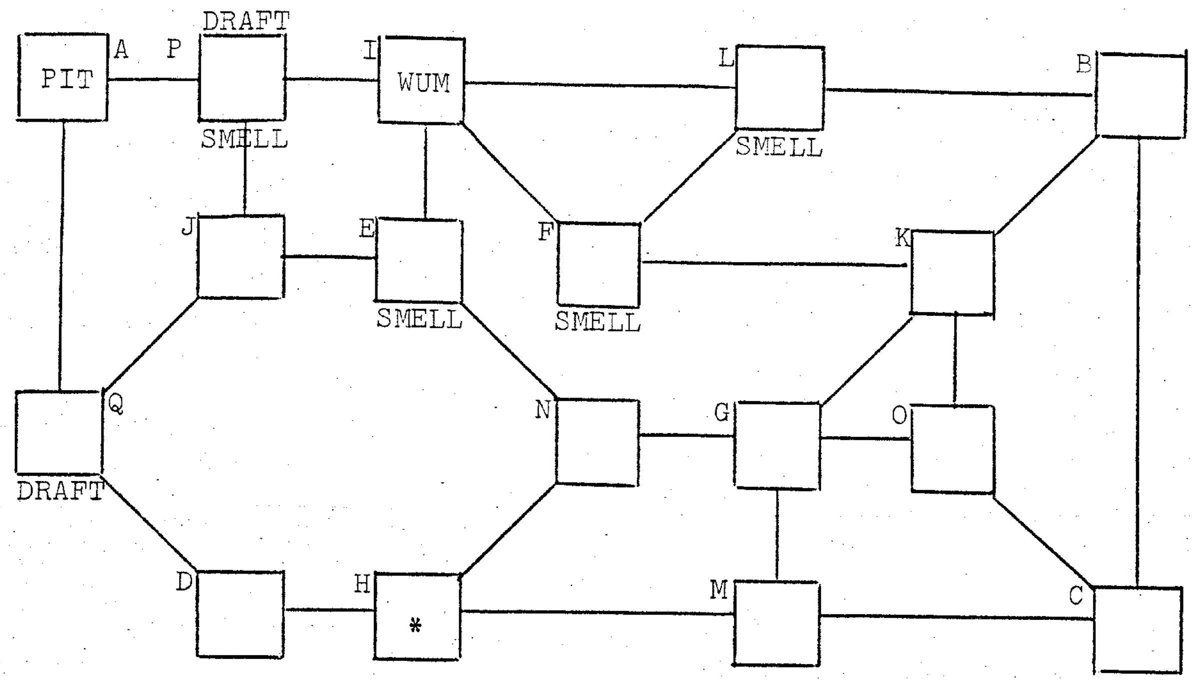
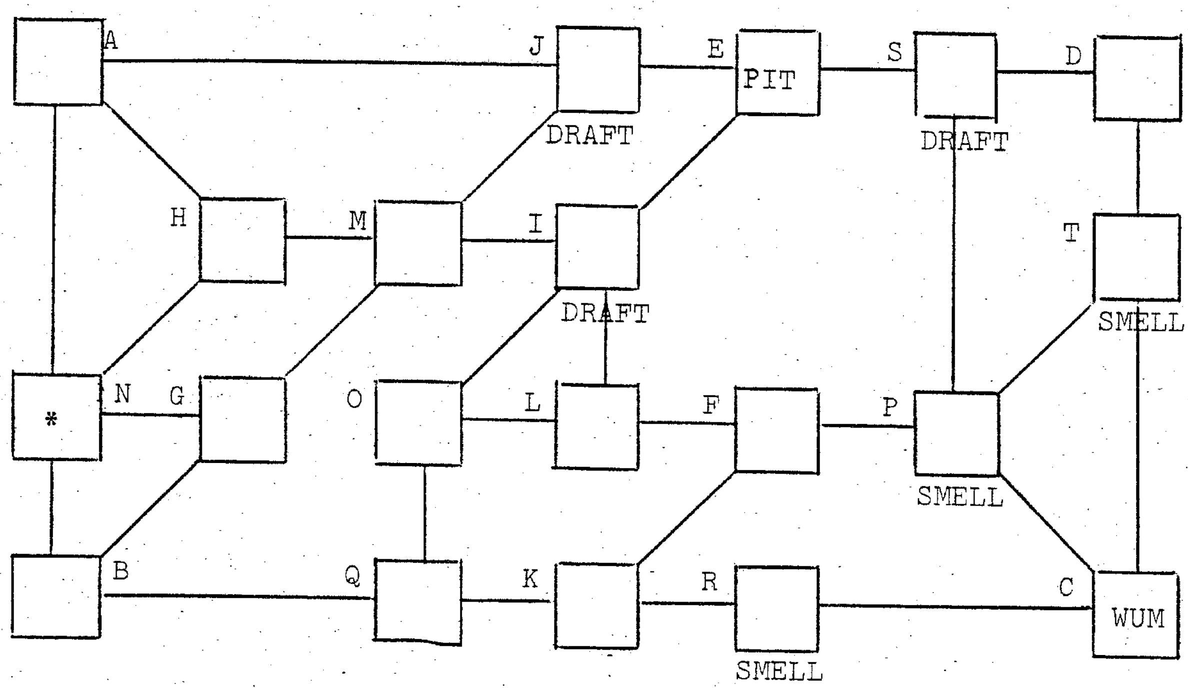
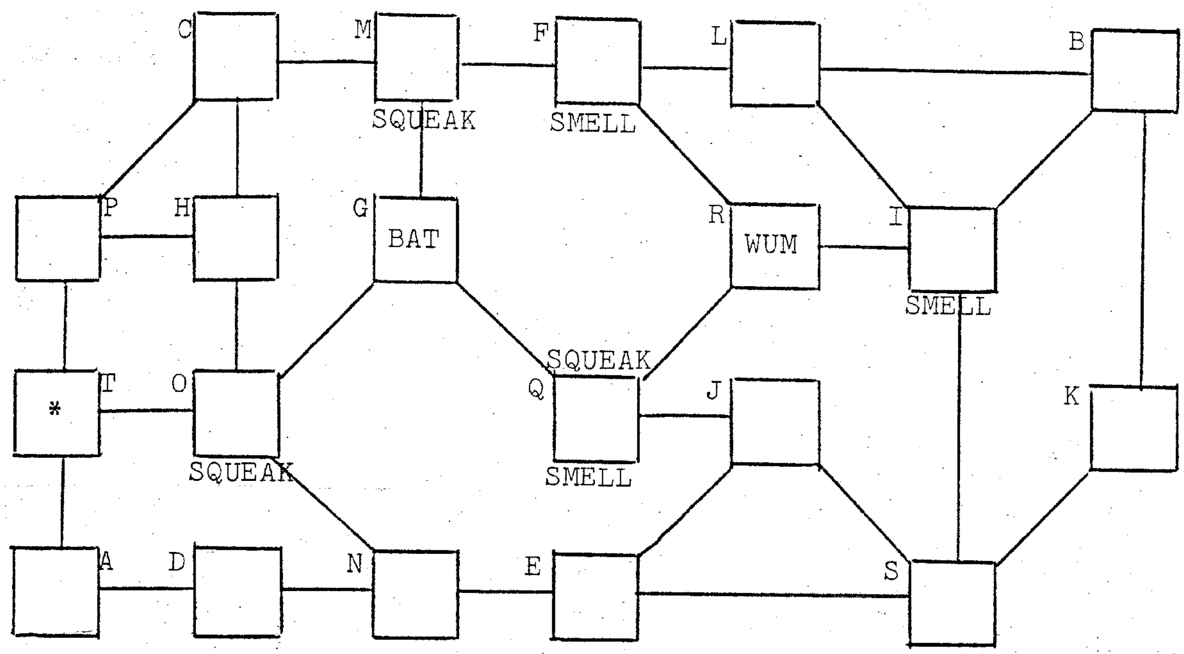



WARREN 109




WARREN 110

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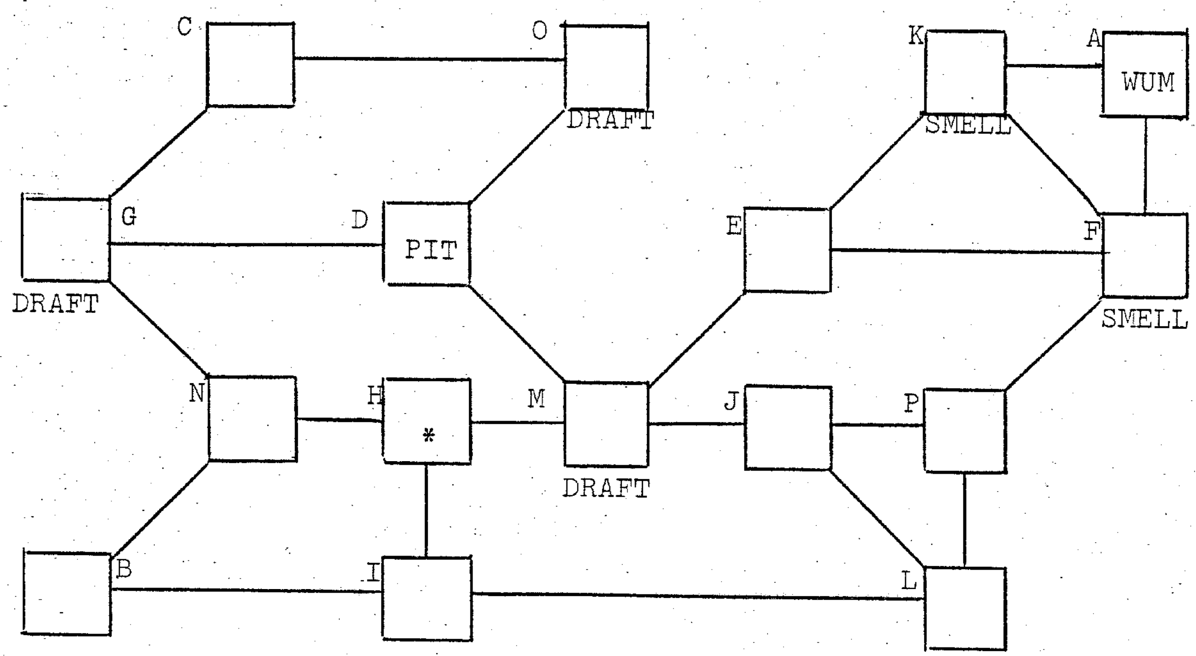


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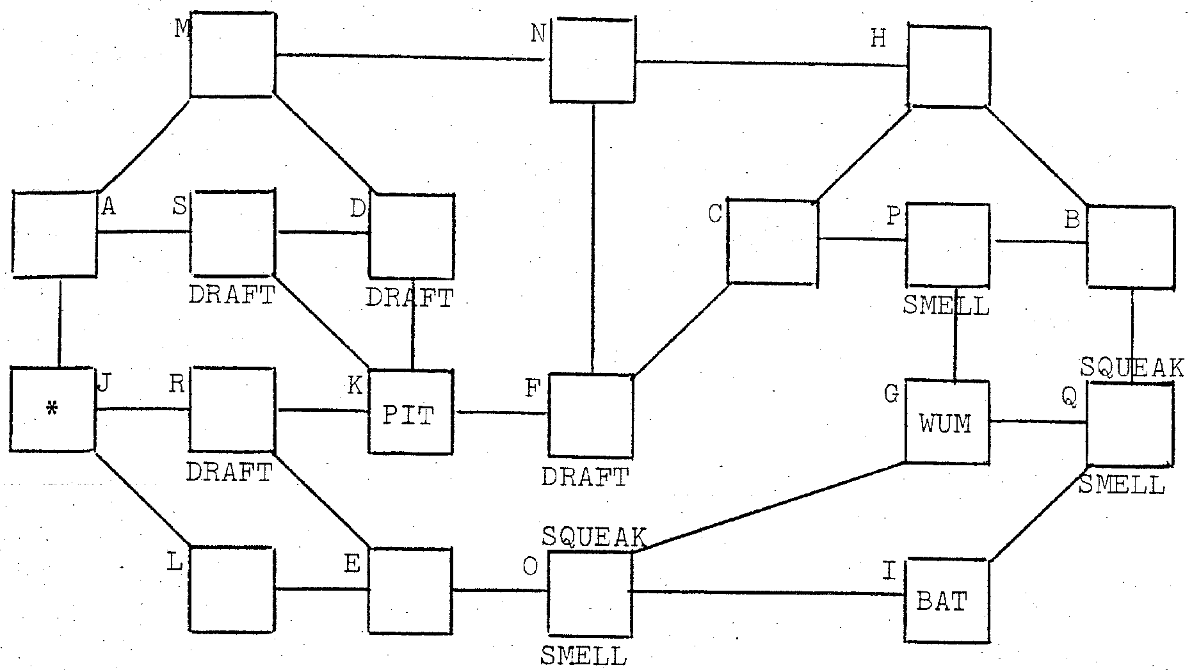
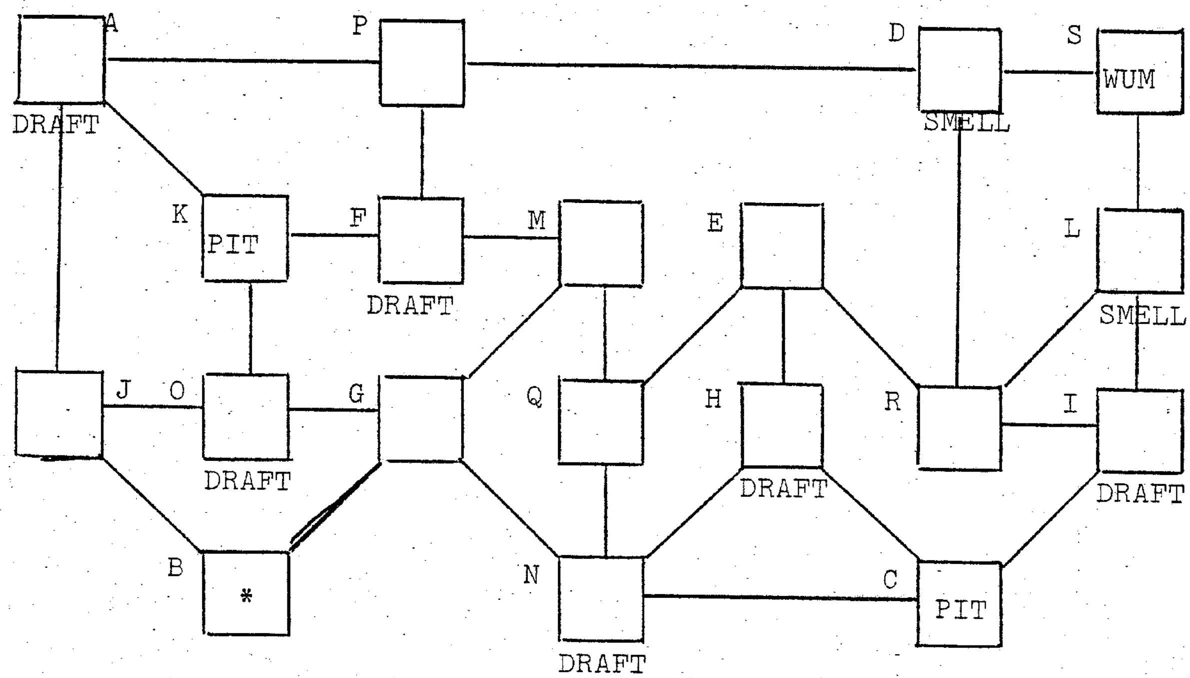
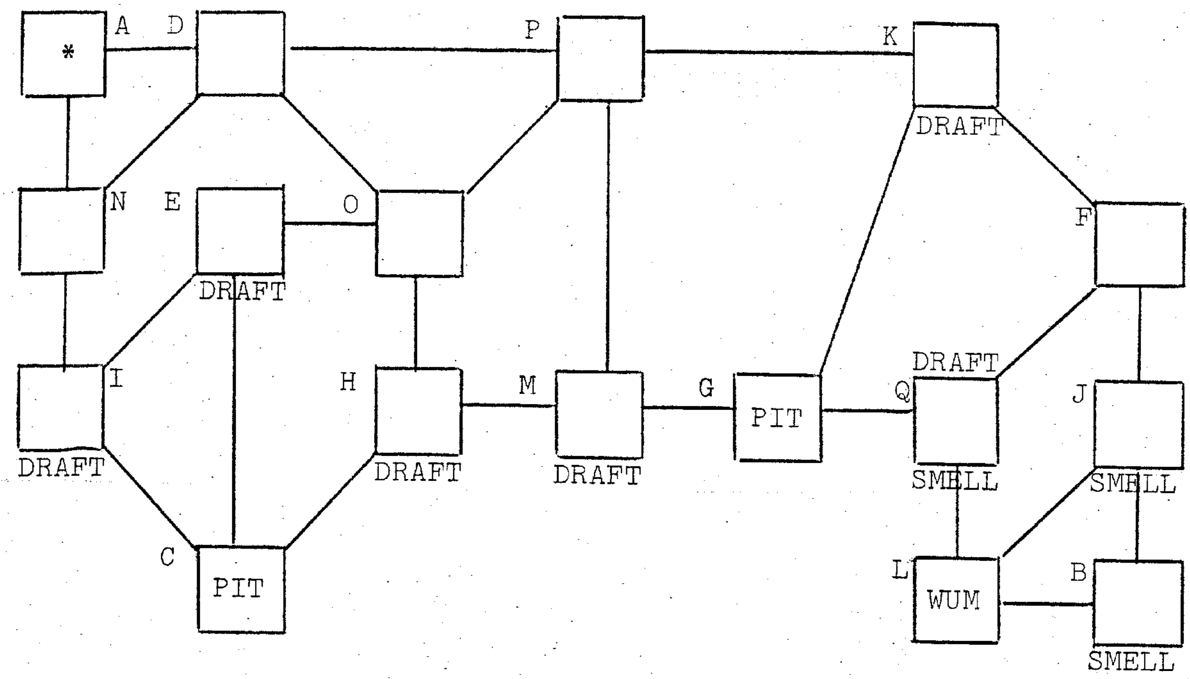


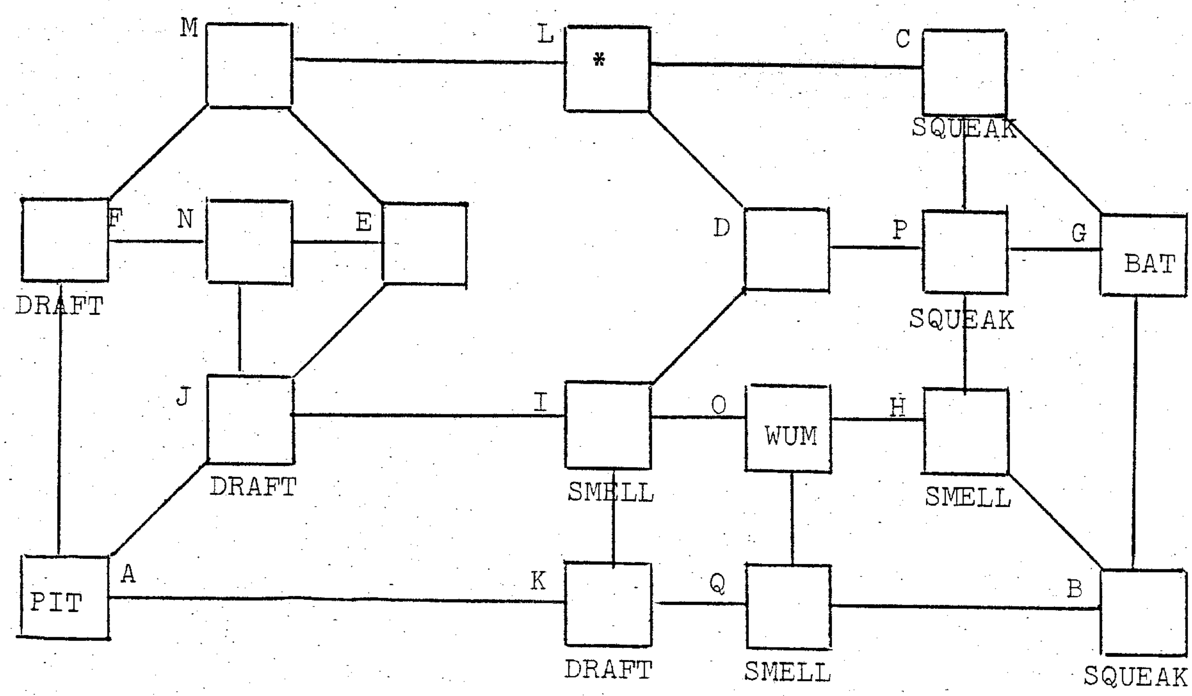
WARREN 113



WARREN 114




WARREN 115

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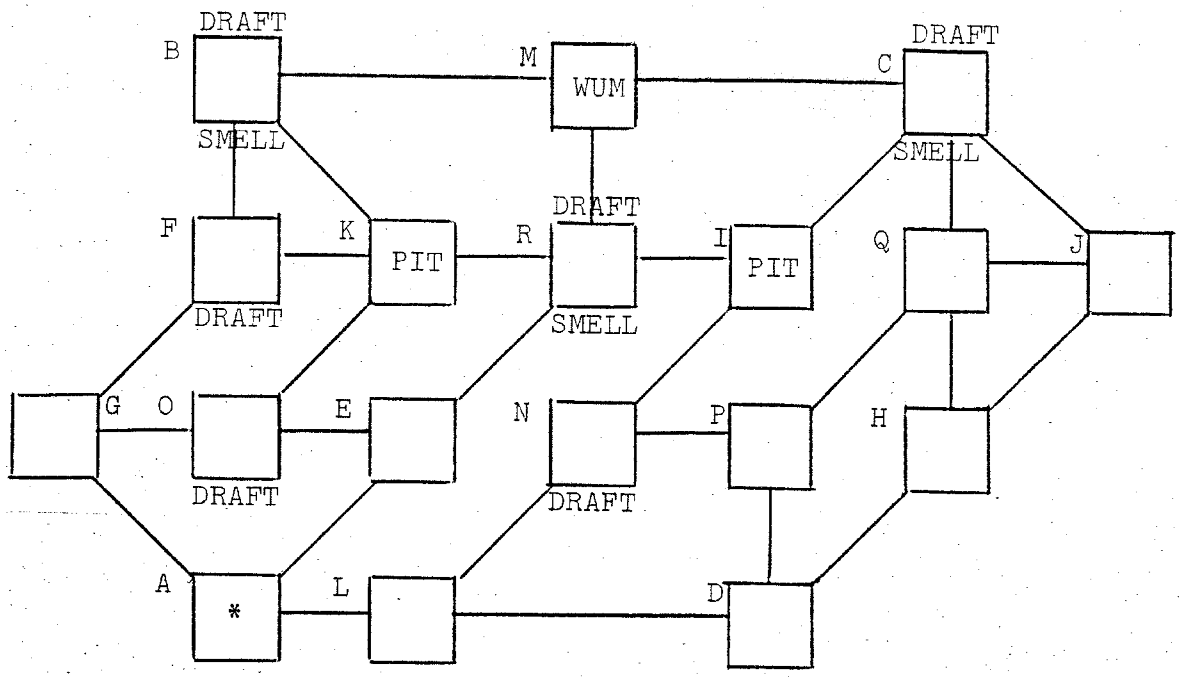
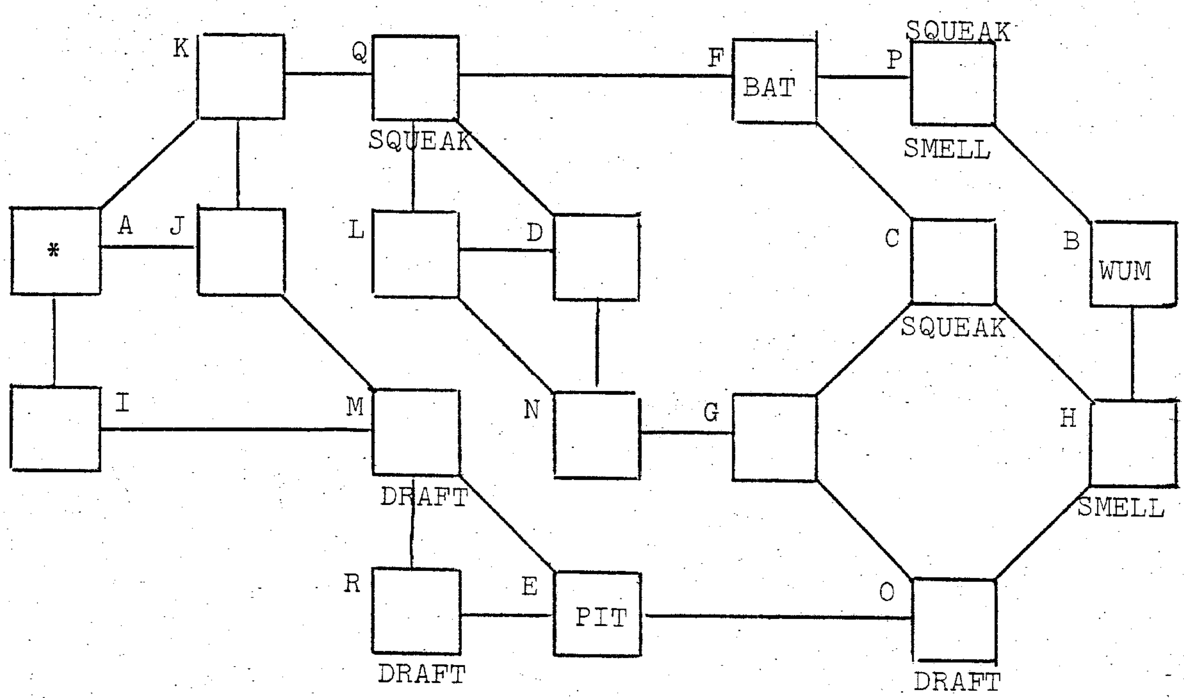
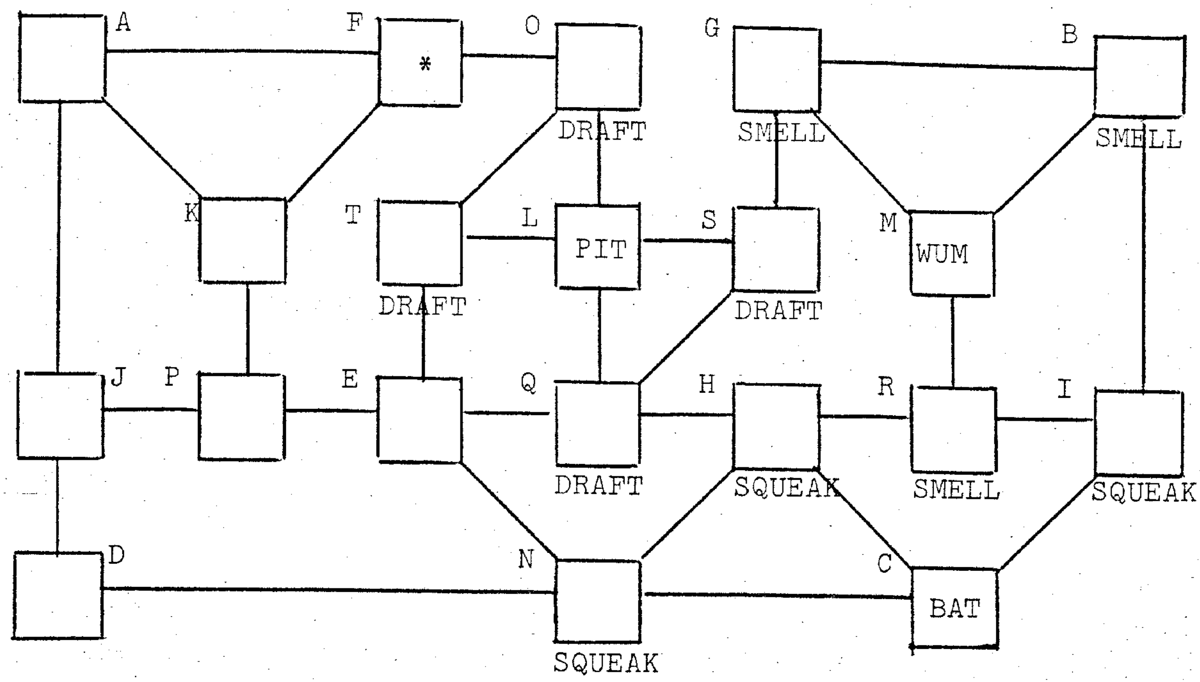


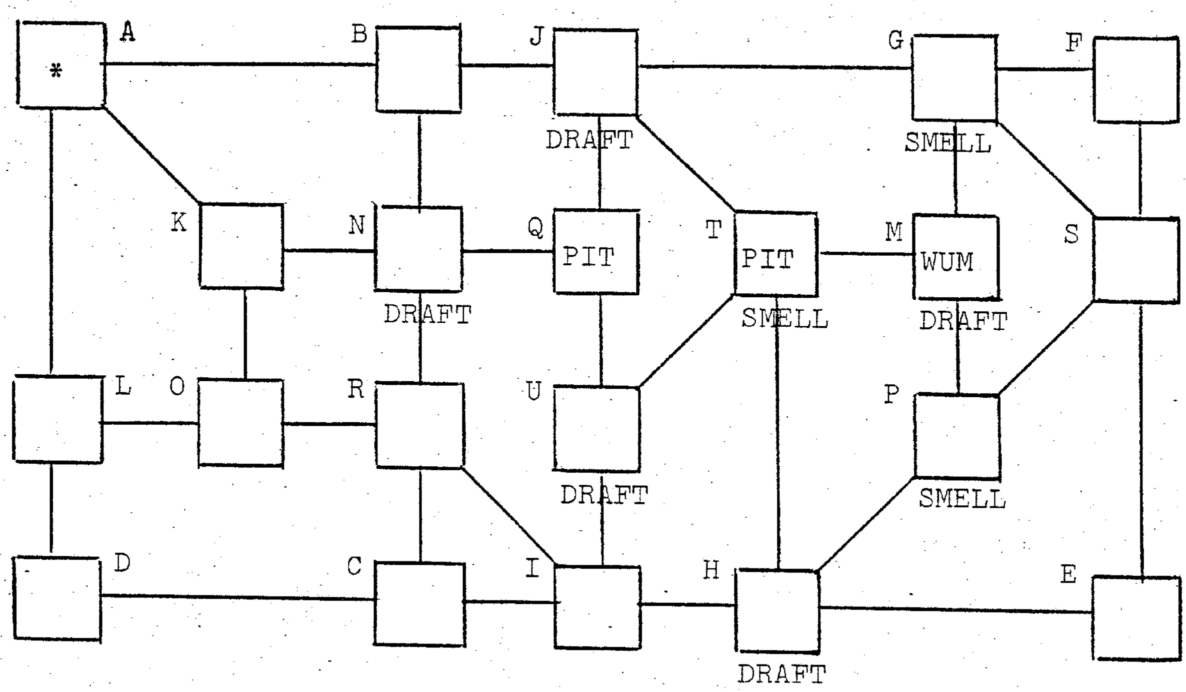

WARREN 117




WARREN 118




WARREN 119




WARREN 120

# APPENDIX B

# SAMPLE DATA

This Appendix illustrates the kinds of data gathered for each student. Joel O. played the entire sequence of twenty warrens, winning nineteen and losing only one. Included here are the twenty representations which he made, four selected protocols, observations made during the four games from which the protocols were taken and comments which were inserted later. The computer generated part of each protocol begins at the left margin; Joel's responses in this protocol are underlined. Since the observations consist exclusively of things Joel said out loud to himself while playing, these are indented and enclosed in quotation marks. Explanatory comments are indented and preceded by the symbol ***.

F JG E L I N H M A Q O K B C

| | | |
|---|---|---|
| F J G E | I L I F | L N H J |
| N M L I | M N I A | A M H |
| H L A G | G H F | H I N M J |
| E Q O K | K B E | B O K C |

WARREN #101

In this game, Joel, we will be in warren number 102. There will be 20 caves all total, no pits, and no caves with bats. NOTE: You will be able to smell the Wumpus only if it is in a neighboring cave.

"I think I'm going to do what my brother does. He draws like a map instead of writing down the safe squares."

We are now in cave F. The neighboring caves are caves H, Q, and S.

What now? S

We are now in cave S. The neighboring caves are caves G, F and T.

***Note in the diagram that Joel first connected T and G to cave Q instead of cave S. After moving into T he then crosses out the original T and makes a new one which is connected to both Q and S. The mistake in connecting cave G is never found.

What now? T

We are now in cave T. The neighboring caves are caves S,E and Q.

What now? E

We are now in cave E. The neighboring caves are caves O,I and T.

What now? O

We are now in cave O. The neighboring caves are caves D and E.

What now? D

We are now in cave D. The neighboring caves are caves K,J,P and O.

What now? J

We are now in cave J. The neighboring caves are caves B,L and D.

What now? L

We are now in cave L. The neighboring caves are caves K,J and A.

What now? A

We are now in cave A. The neighboring caves are caves M,B and L.

What a stench! The wumpus must be in one of the neighboring caves.

***At this point Joel figures out where the wumpus is hiding.

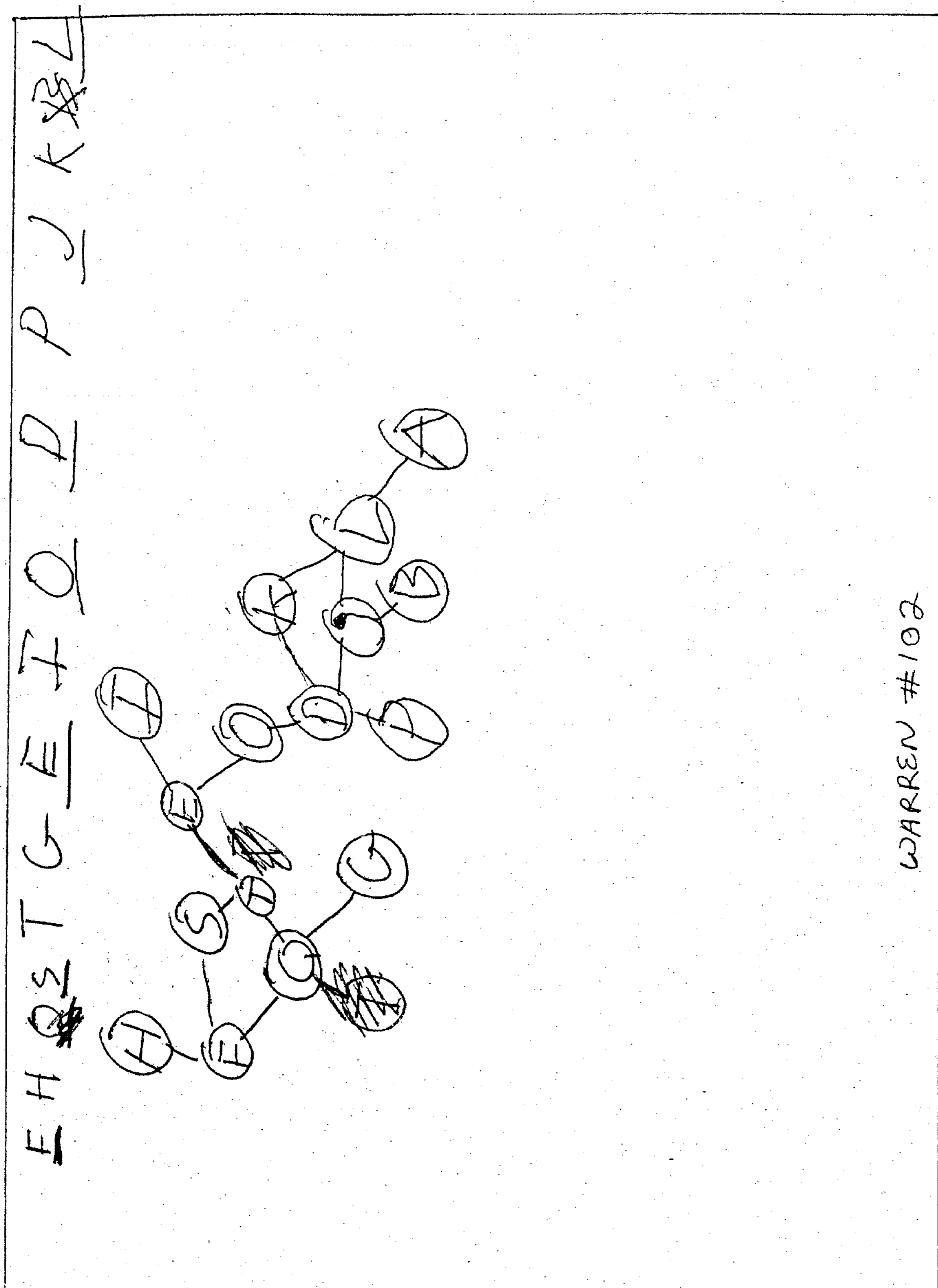
"B...No, because when I was in J, no B. I went into L actually."

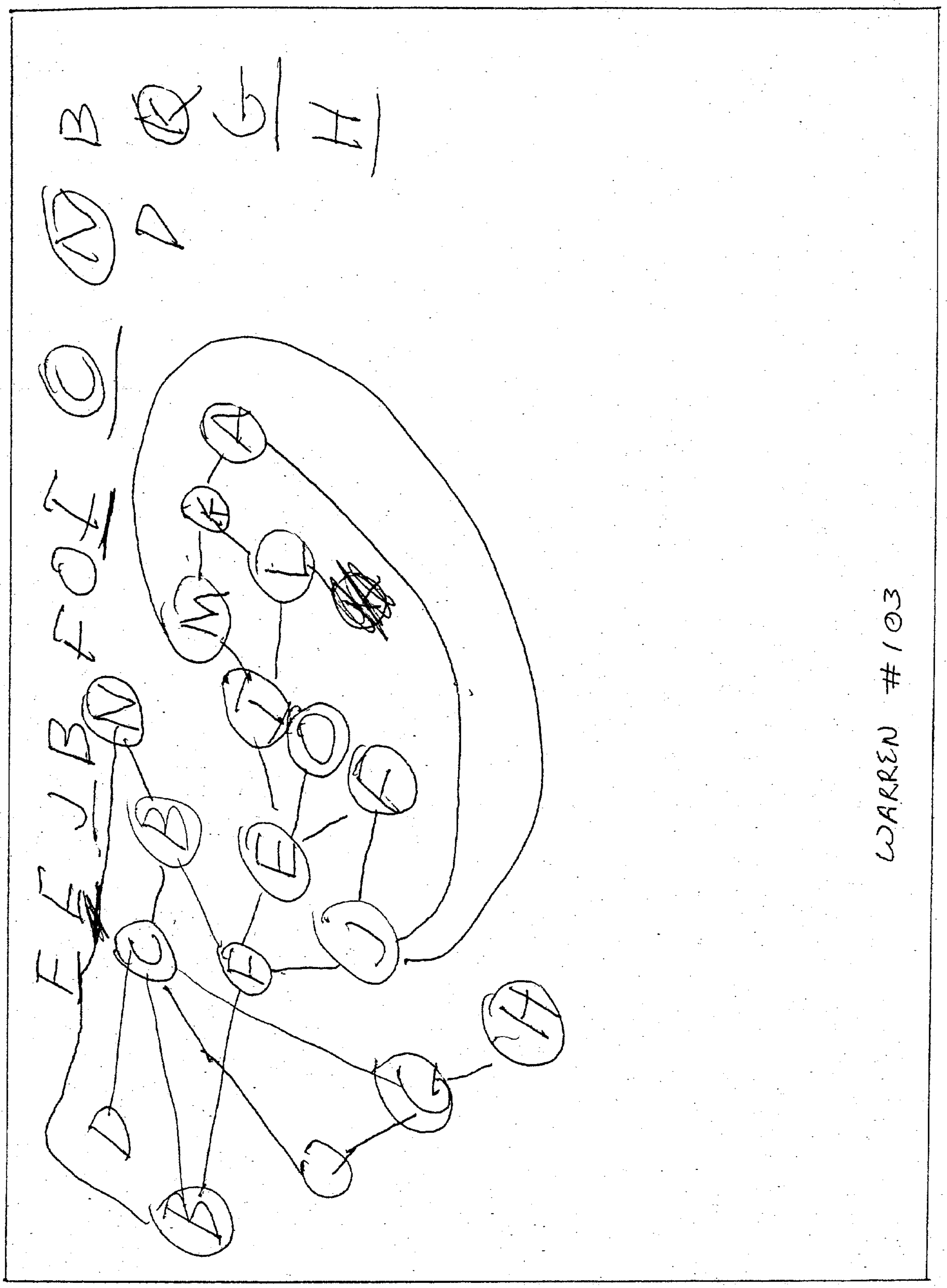
What now? SHOOT

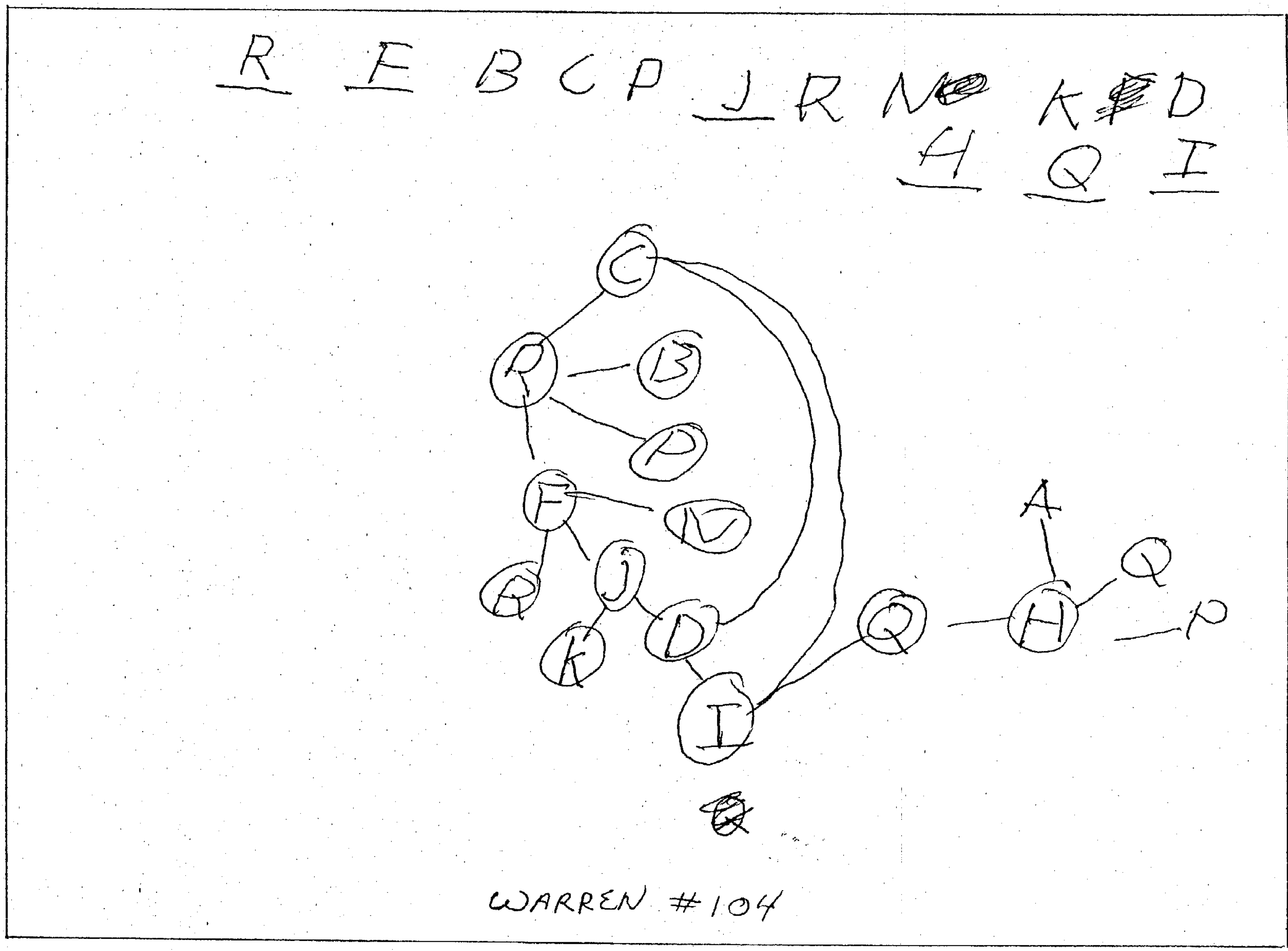
Into which cave would you like to shoot? M

Congratulations, Joel, you have shot the Wumpus!

"When we start getting bats or pits I'll go back to my conservative method [of representation]; the way I did it the first time."


WARREN #102


WARREN #103


R E B C P J R N K D
H Q I
WARREN #104

DE EA

SK G H C I G OJDPQ

G H C I I K G H BK R

G GOJ OJFC^s ODCP

D QO Q EAD HGLI

L JSK KBL R

WARREN #105

DC

H LKE MHA IO PA BQ

GLB

H LKE LMAH H RQIMH

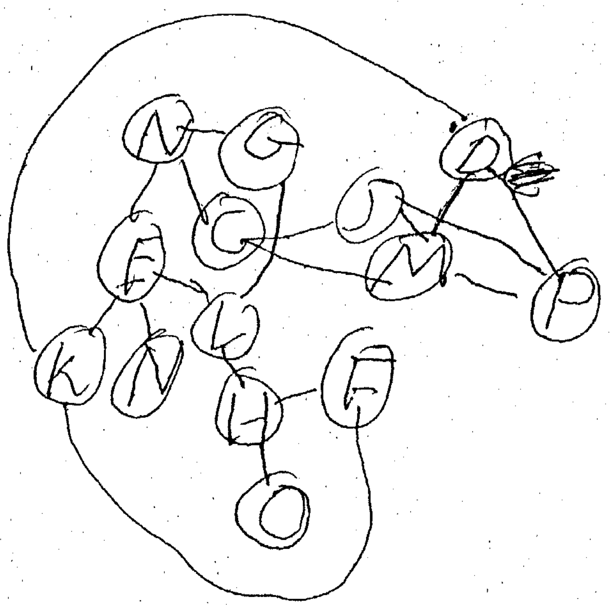
O IPKN PQBO QDCP

A GL LMAH MNKL

N BMO

WARREN #106

N G C E J K N L H D P

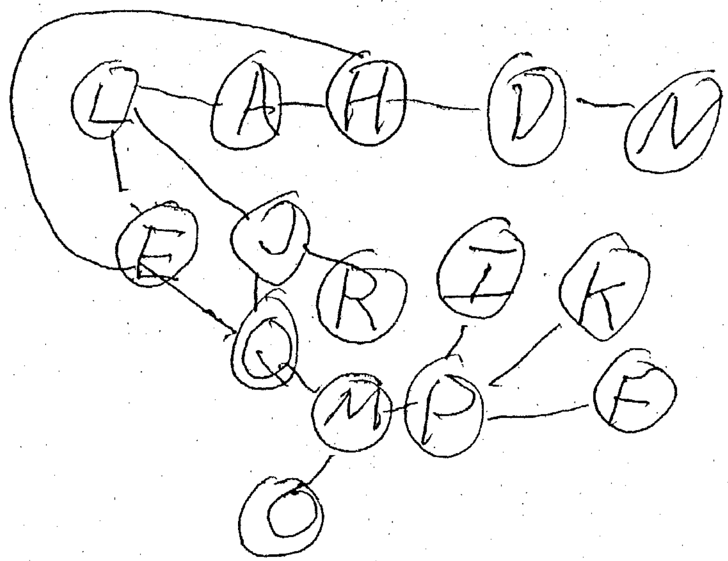



WARREN #107

Sq BQ

Stink FO

LEJA QRM PO DN




WARREN#108

IKF

***Up to this point Joel has been convinced that graphs are easier to use, but still thinks they are not as good a representation and so has switched back to a table for the first two warrens with dangers. For warrens 107 and 108 which have only bats, he has decided that he is safe enough to get away with a graph. Pits are another matter however, but after thinking a while Joel says:

"I'm going to take a chance."

and proceeds to use a graph. Even though this is the only warren he does not win, he continues to use a graph for the rest of the session but starts adding more information so as to avoid every danger from here on.

In this game, Joel, we will be in warren number 109. There will be 17 caves all total, one pit, and no caves with bats. NOTE: You will be able to smell the wumpus only if it is in a neighboring cave.

We are now in cave H. The neighboring caves are caves M,N and D.
What now? N

We are now in cave N. The neighboring caves are caves G,H and E.
What now? E

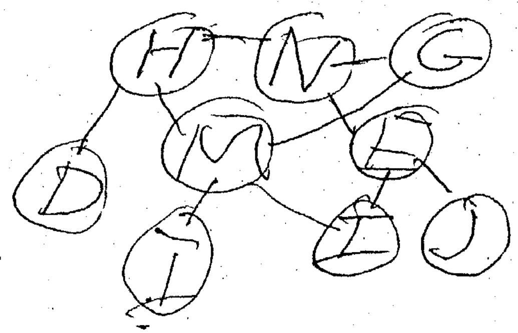
We are now in cave E. The neighboring caves are caves J,N and I.
What a stench! What now? M

We are now in cave M. The neighboring caves are caves C,G, and H.
What now? I

We are now in cave I. The neighboring caves are caves L,F,P and E.
Oh no! The wumpus is in here! Chomp. Chomp. Chomp.

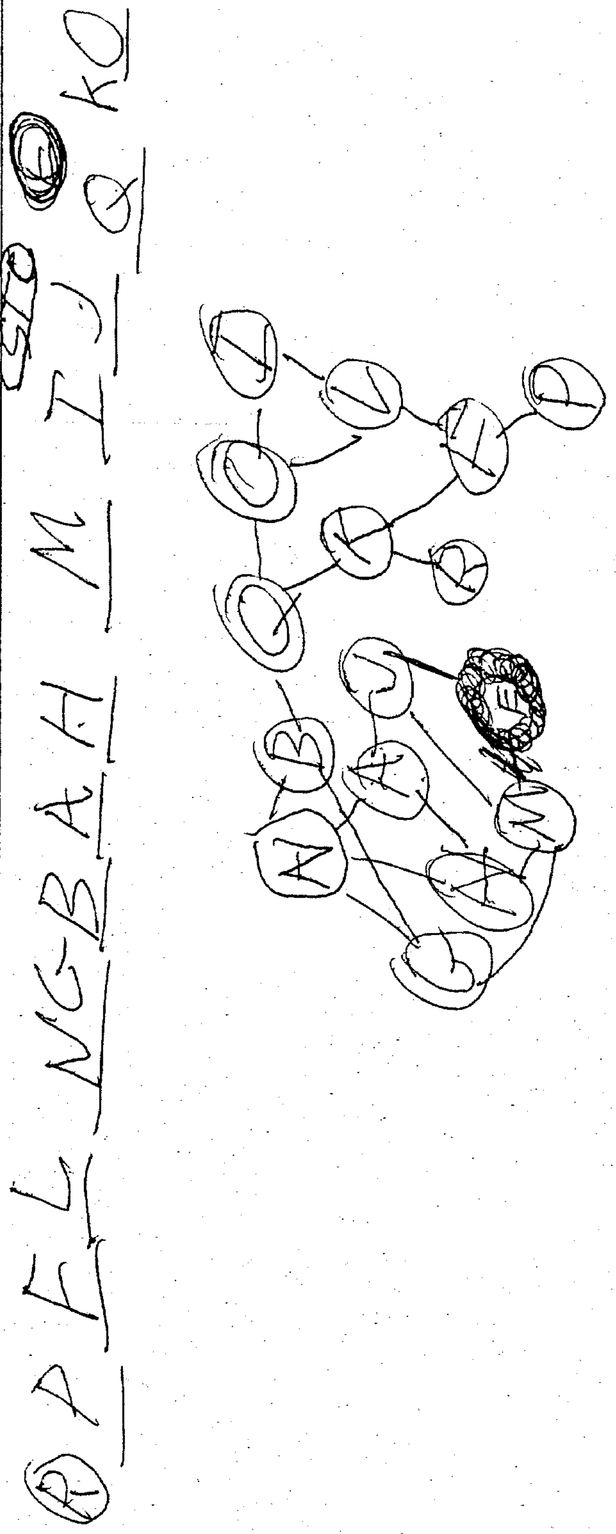
"I found cave I there as safe, but it shouldn't have been. I made a mistake."

HMND GEI



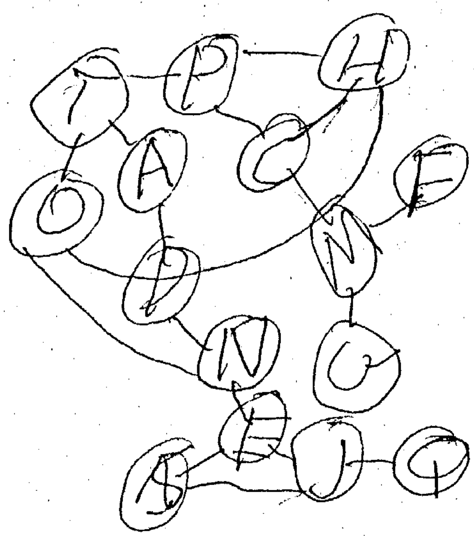
WARREN #109

IJ

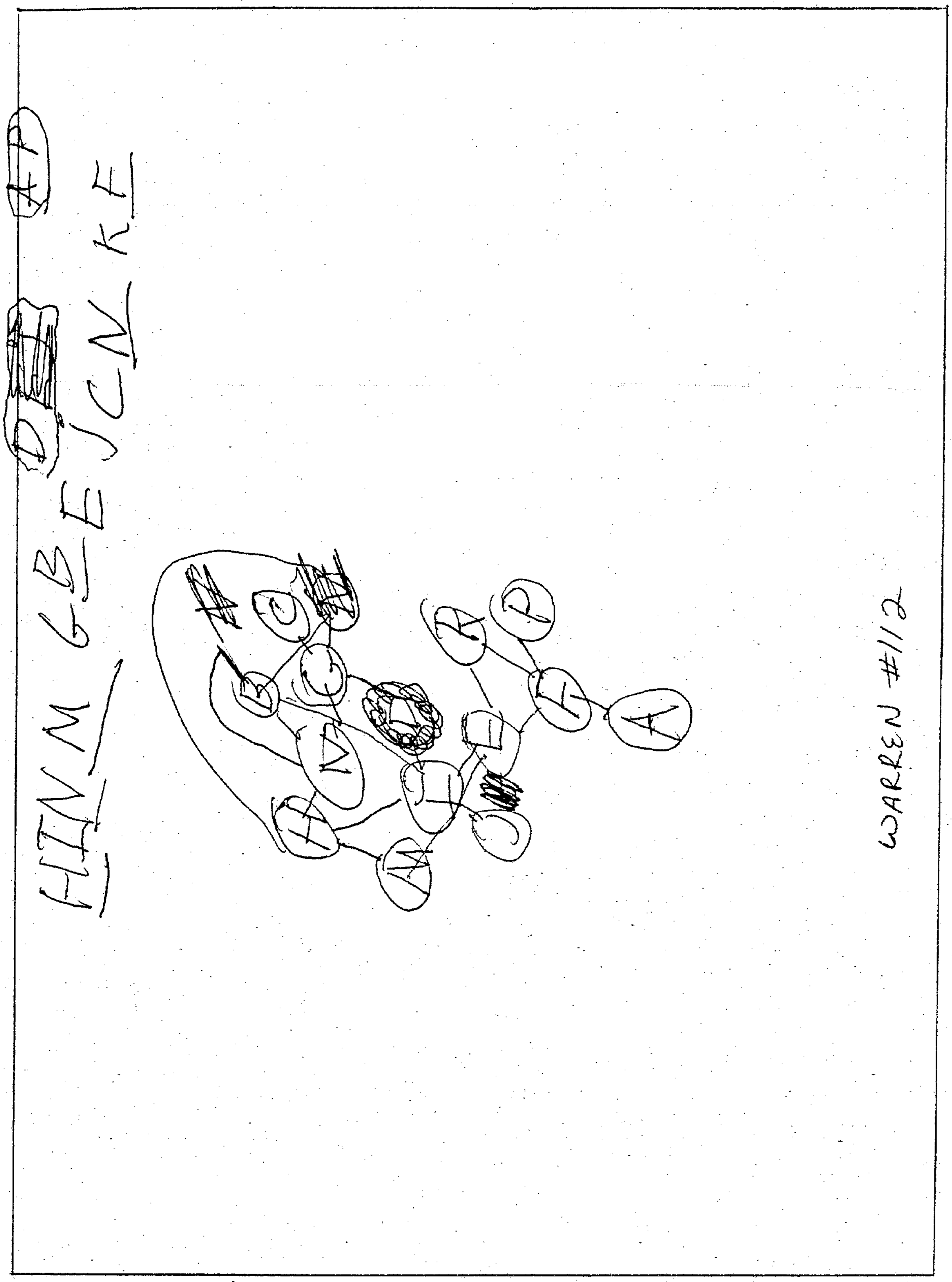


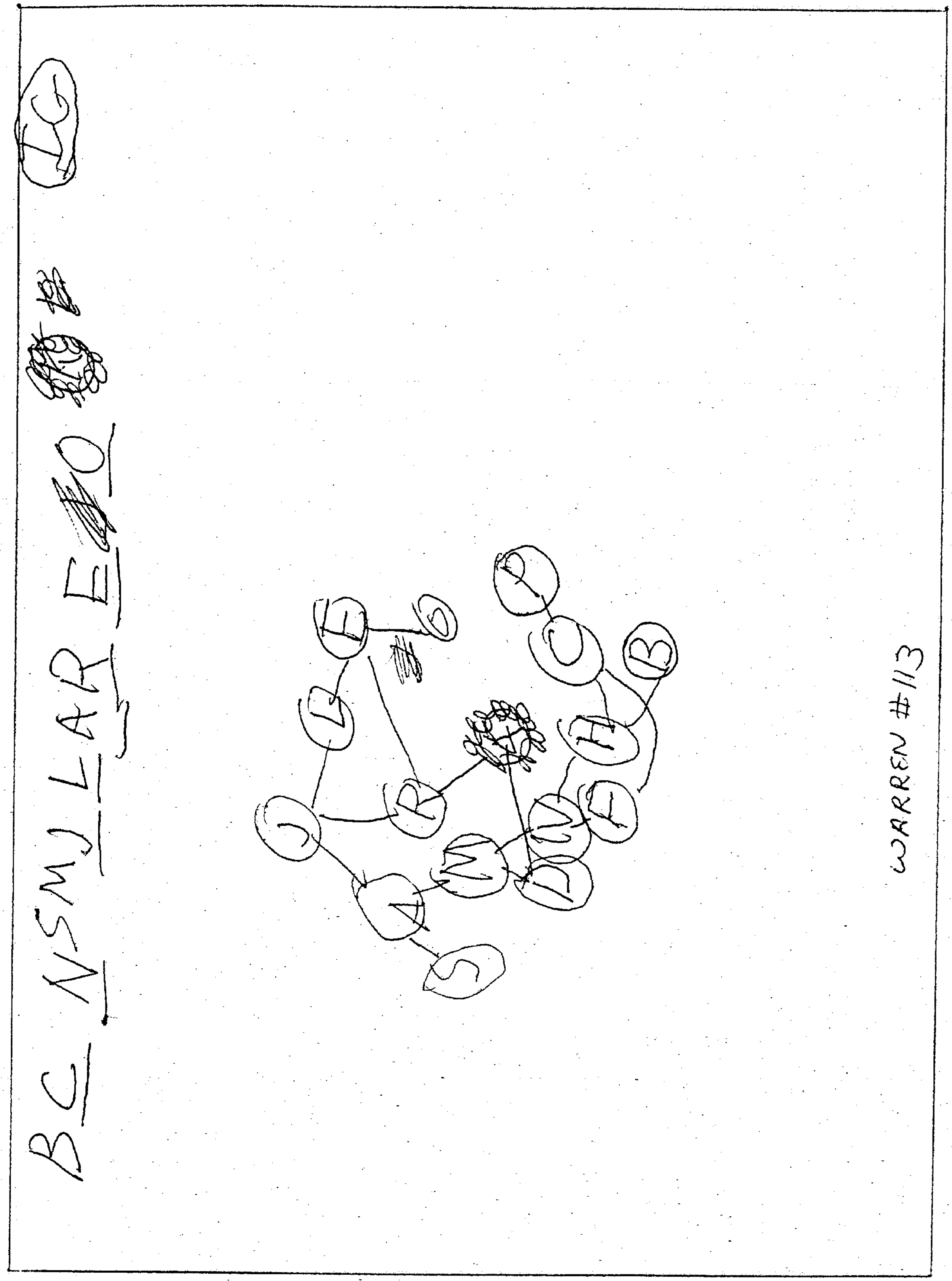
WARREN #110

TOAPCHEM DNESJ

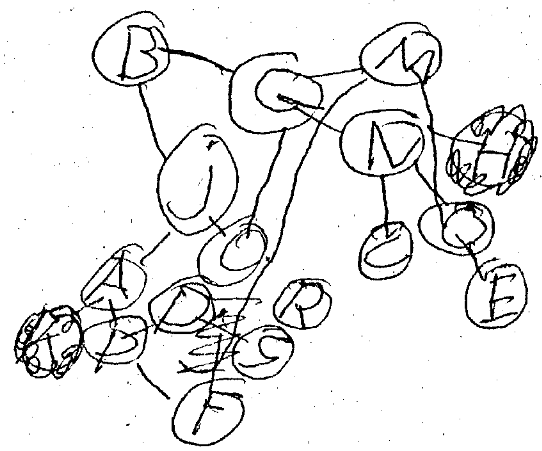


WARREN #111

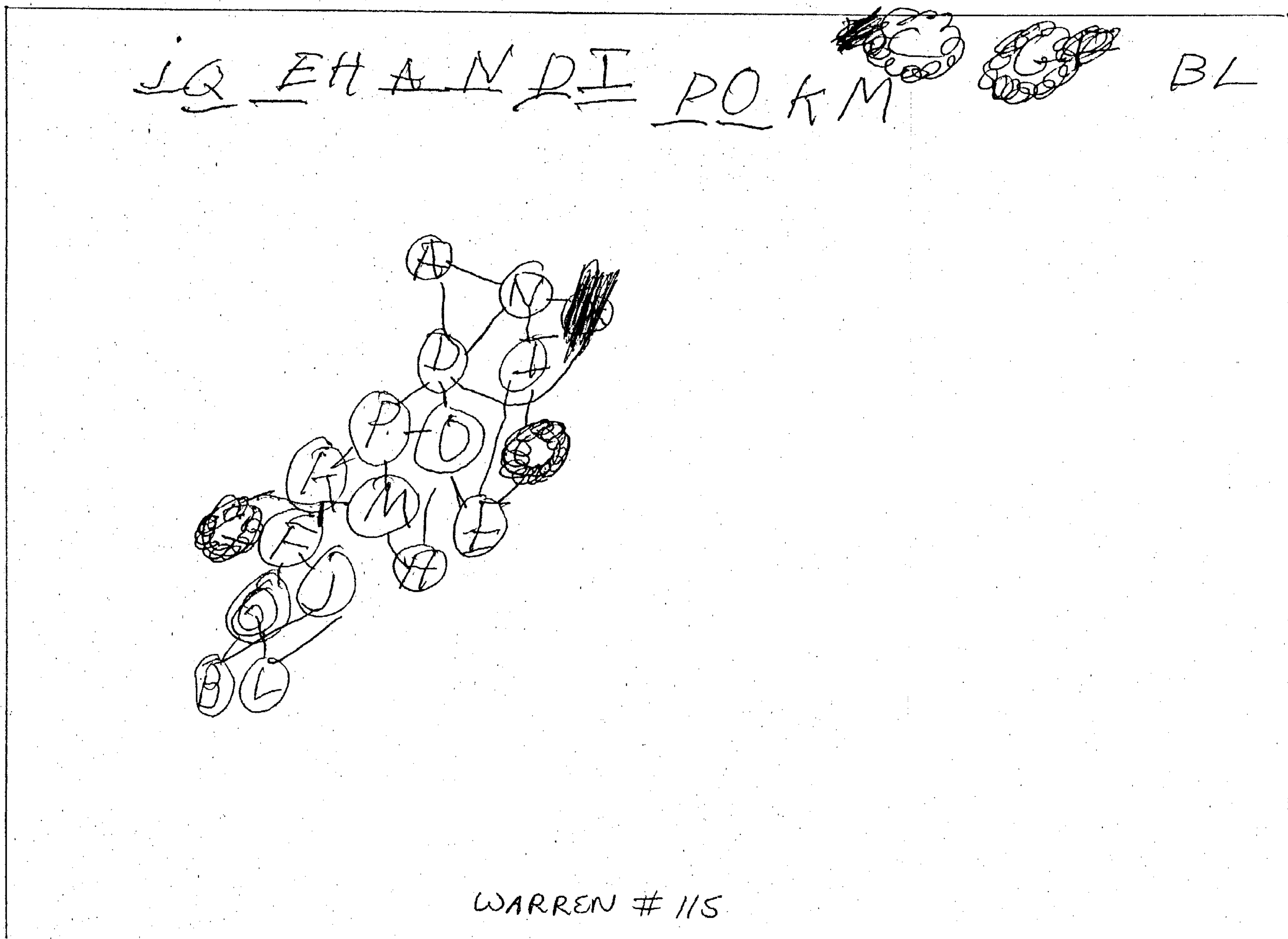

WARREN #112

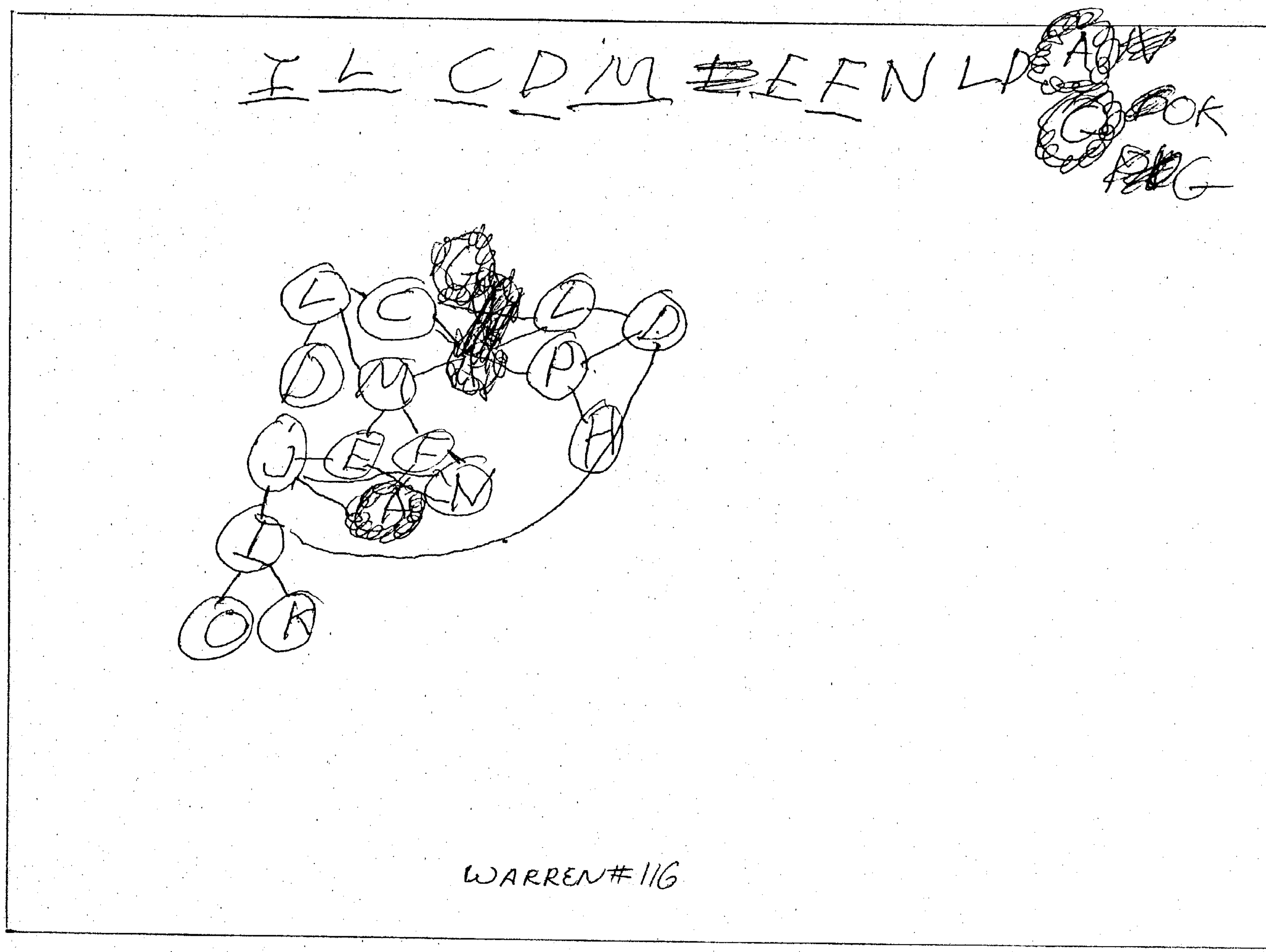

WARREN #113

MN B C J E A O G Q F P H



WARREN #114


JQ EHANDI POKM BL
WARREN # 115


WARREN#116

In this game, Joel, we will be in warren 117. There will be 18 caves all total, two pits, and no caves with bats. NOTE: You will be able to smell the wumpus only if it is in a neighboring cave.

We are now in cave A. The neighboring caves are caves E,G and L.

What now? G

We are now in cave G. The neighboring caves are caves F,O and A.

What now? F

We are now in cave F. The neighboring caves are caves B,K and G.

Brrrr. I feel a breeze. We must be next to a pit.

What now? O

We are now in cave O. The neighboring caves are caves K,E and G.

Brrrr.

"I know where at least one of them is.I'll take a chance."

What now? B

We are now in cave B. The neighboring caves are caves M,F and K.

What a stench! Brrrr.

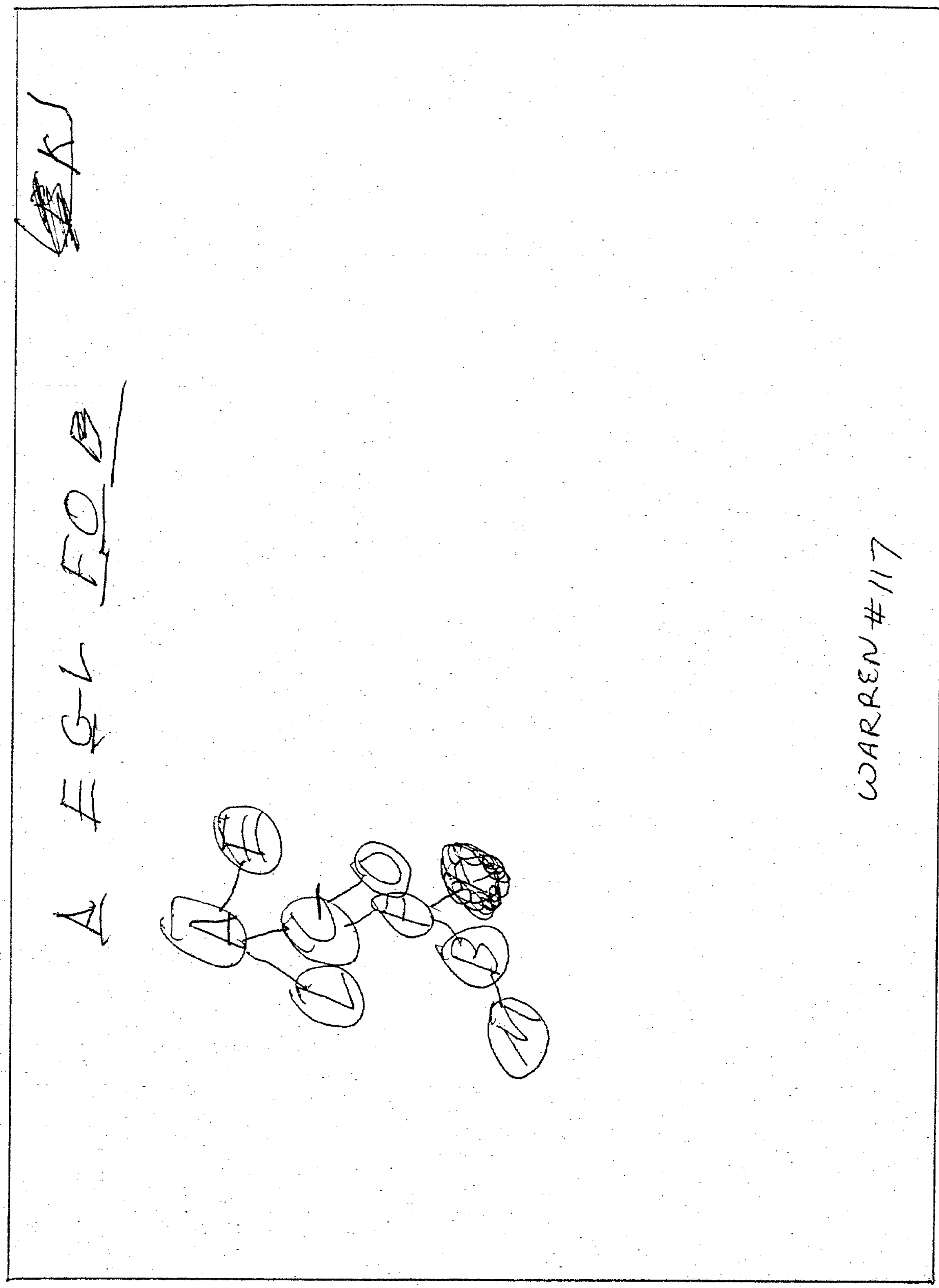
"It wasn't as big a chance as if you'd made up these [warrens]. You'd have put the other pit in B."

***Little did he know. It is interesting that he thought I would try to trick people, but did not credit the computer with the ability to do so. It might have put the other pit in B as well, but certainly not maliciously.

What now? SHOOT

Into which cave would you like to shoot? M

Congratulations, Joel, you have shot the wumpus!


WARREN #117

In this game, Joel, we will be in warren 118. There will be 18 caves all total, one pit and one cave with bats. NOTE: You will be able to smell the wumpus only if it is in a neighboring cave.

We are now in cave A. The neighboring caves are caves K,I and J.

What now? J

We are now in cave J. The neighboring caves are caves M,K and A.

What now? M

We are now in cave M. The neighboring caves are caves E,R,I and J.

Brrrr. I feel a breeze. We must be next to a pit.

"R or E is not safe."

What now? K

We are now in cave K. The neighboring caves are caves Q,A and J.

What now? Q

We are now in cave Q, The neighboring caves are caves F,D,L and K.

Squeak. I hear bats. They must be in one of the neighboring caves.

What now? I

We are now in cave I. The neighboring caves are caves M and A.

"I went everywhere [that was safe]. Take a chance. D."

***At this point Joel was asked "Why cave D instead of R or E."

"There's a bigger chance that I'll miss it 'cause there are three [neighbors]."

***Joel was the only one to explicitly use any probabilistic of this sort. It is worth noting that this was his reason, and not that the bats were safer, since from his comments at the beginning of the sequence about using the more conservative representation for warrens with pits, it is clear that he was aware of the difference in the danger posed by bats and pits.

What now? D

We are now in cave D. The neighboring caves are caves Q,L and N.

What now? L

We are now in cave L. The neighboring caves are caves D,Q and N.

What now? N

We are now in cave N. The neighboring caves are caves G,D and L.

What now? G

We are now in cave G. The neighboring caves are caves O,C and N.

What now? C

We are now in cave C. The neighboring caves are caves G,H and F.

Squeak.

What now? H

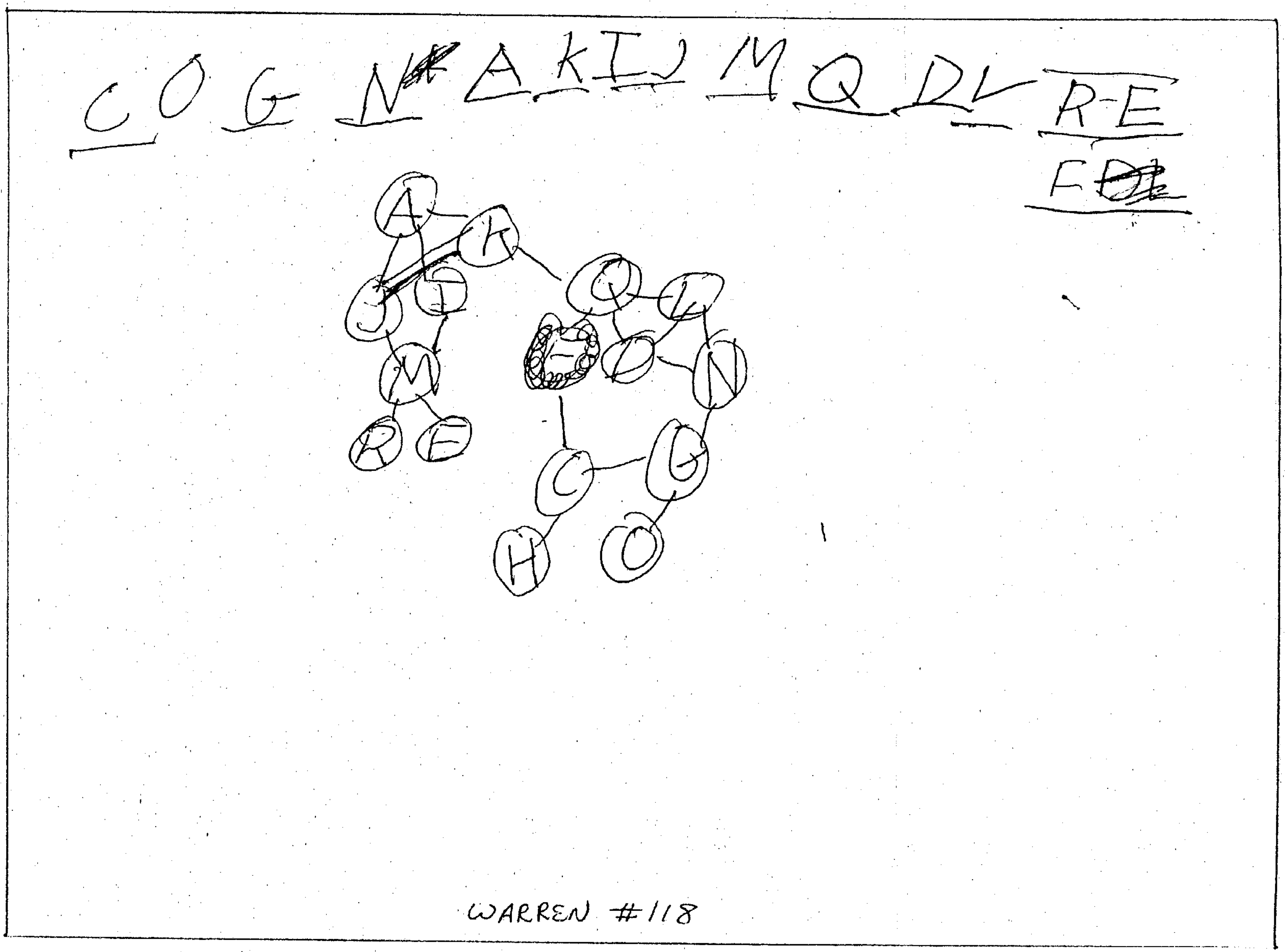
We are now in cave H. The neighboring caves are caves C,O and B.

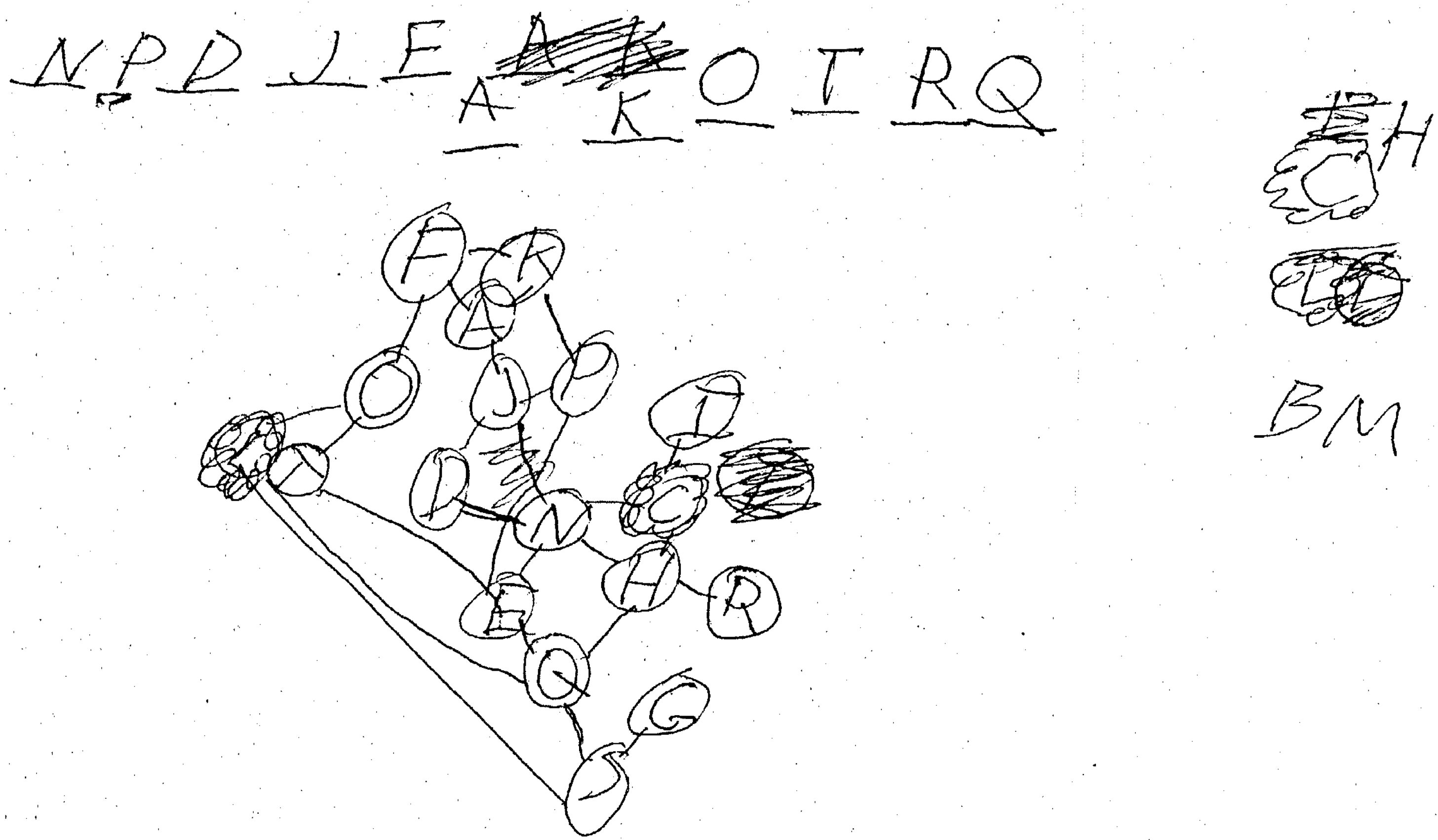
What a stench!

What now? SHOOT

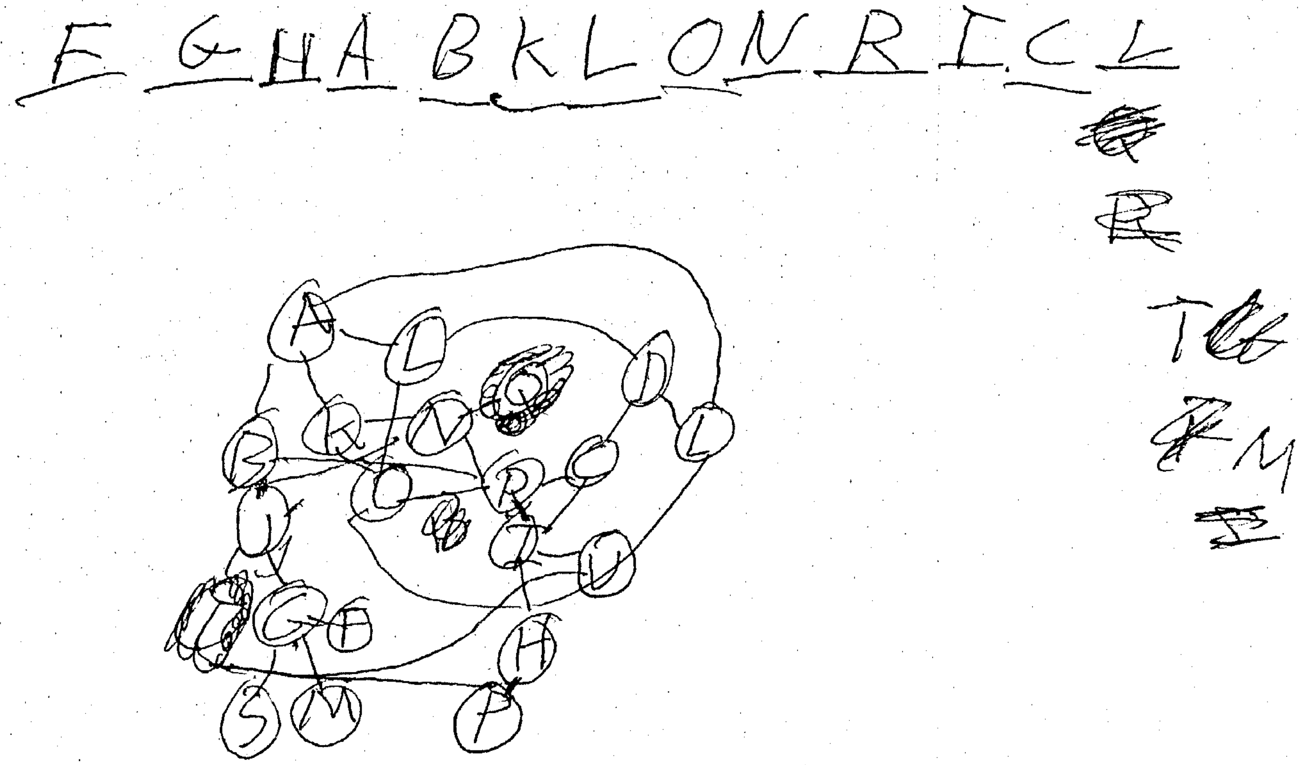
Into which cave would you like to shoot? B

Congratulations, Joel, you have shot the wumpus!


COGNAKIJMQDLRE
F
WARREN #118




WARREN #119




WARREN #120

## FOOTNOTES

[1] First described by Yob in an article called "Hunt the Wumpus", Creative Computing, September-October, 1975

[2] A more detailed version of this development may be found in Goldstein, 1976, The Computer as Coach: An Athletic Paradigm for Intellectual Education, pp. 48-52

[3] Brown, J.S., Burton, R.R., and Bell, A., "SOPHIE: A Step Toward Creating A Reactive Learning Environment", 1975

[4] The West program tutors simple mathematical skills for the game "How the West was Won", and is described in Burton, R. and Brown, J.S., "A Tutoring and Student Modelling Paradigm for Gaming Environments", 1976

[5] The first version of the Wumpus Advisor, Wusor I may be found in Wumpus Advisor I, Stansfield, Carr, and Goldstein, 1976

[6] Carr's 1977 thesis, Wusor II: A Computer Aided Instruction Program With Student Modelling Capabilities, gives a full description of this, the current Wumpus Advisor

[7] An excellant discussion of the different representation types is given in Wumpus Protocol Analysis, White, 1977

[8] Examples of Wusor II's tutoring strategy are given in Appendices D and E of Carr's thesis.

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Burton, R., and Brown, J.S., "A Tutoring and Student Modelling Paradigm for Gaming Environments", in R. Coleman and P. Lorton, Jr., editors, Computer Science and Education, SIGCSE Bulletin, Vol. 8, February 1976, pp. 236-246

Carr, B., Wusor II: A Computer Aided Instruction Program With Student Modelling Capabilities, MIT Artificial Intelligence Laboratory Memo 417, May, 1977

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Stansfield, J.L., Carr, B.P., and Goldstein, I.P., Wumpus Advisor I, A first implementation of a program that tutors logical and probabilistic reasoning skills, MIT Artificial Intelligence Laboratory Memo 381, October, 1976

White, B.Y., Wumpus Protocol Analysis, Working Paper 152, MIT Artificial Intelligence Laboratory, August, 1977

Yob, G., "Hunt The Wumpus", Creative Computing, September-October, 1975, pp. 51-54