Chapter 19

A Measure of the Knowledge Reorganization Underlying Insight*

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No phenomenon has remained as inscrutable under the probing eye of cognitive methodologies as has insight. The sudden rush to solution, the click of comprehension, continues to fascinate us. This is not merely because insight has been credited for saving Hiero II the price of an alloyed crown, for structuring the benzene molecule, and for leading to velcro, but because it is a threat to the analytic, incremental Zeitgeist of information-processing theory. Intuitively, the solution to an insight puzzle does not seem to be obtained in the same way as other puzzles or problems. To share in the intuition, consider a problem used by Bowden (1985):

> A woman walked for twenty minutes on the surface of a lake without sinking into the water. She was not using any form of flotation device, such as a boat or a raft. How did she manage to do it? (p. 285)

The Phenomenology

The most apparent characteristic of insight is the "aha!" or "eureka!" phenomenology (Ellen, 1982, p. 324; Metcalfe & Wiebe, 1987). Although the "aha!" has implicitly been a defining feature of insight in all research discussions, no one studied it explicitly until Metcalfe (1986a, 1986b; Metcalfe & Wiebe, 1987). The feature of insight problems that makes them appear special to subjects and researchers alike is the phenomenology, and the goal of formal work on insight has been to explain (or explain away) that phenomenology. The Gestaltists regarded insight not as a process, but as the experience that accompanies problem solving when knowledge is dramatically reorganized (Dominowski, 1981; Ellen, 1982, p. 324). Despite the primacy and centrality of the phenomenology in any definition of insight, its quantification waited until Metcalfe (1986a) measured subjects' initial confidence in their ability to solve insight problems versus confidence in their ability to solve memory questions. Subjects were poor at predicting whether they would eventually solve the insight problems, but were good at predicting whether they could answer the memory questions: "Insightful solutions could not be predicted in advance, which would be expected if insight problems were solved by a sudden 'flash of illumination'" (Metcalfe, 1986b, p. 239).

Metcalfe (1986b) refined her earlier (1986a) dependent measure by looking at changes in subject confidence during insight problem-solving sessions. Her subjects repeatedly estimated how close they were to the correct solution (how "warm" they were). Subjects who eventually submitted the correct solution gave consistently low warmth-ratings

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throughout the session, then gave high warmth-ratings in the few seconds just before they proposed the correct solution. In contrast, subjects who were destined to submit incorrect solutions gradually became more confident through the session. Metcalfe and Wiebe (1987) went on to show that solution of insight problems was accompanied by a sudden increase in rated warmth at the time of solution, but noninsight problems had rated warmth increasing gradually up to the solution. Thus, correct solution of insight problems—but not of failed attempts, noninsight problems, or problems requiring only memory retrieval—was accompanied by a dramatic change in metacognition that presumably corresponded to the "aha!" phenomenology. "These findings indicate in a straightforward manner that insight problems are, at least subjectively, solved by a sudden flash of illumination" (Metcalfe & Wiebe, 1987, p. 243).

Fixedness

What produces this phenomenology? Fixedness is often blamed for preventing such an "aha!" (e.g., Scheerer, 1963), and Weisberg and Alba (1981a, 1981b) have concluded that some Gestaltists went even further to define insight as a breaking of the fixation. We think that fixedness is somewhat independent of insight, though insight problems often have some aspect that creates fixedness. Subjects are fixated when they are incapable of abandoning a substantial but incorrect knowledge structure, and that is what prevents them from adopting the correct structure (Scheerer, 1963). In the lake problem, subjects are fixated on the idea that the lake is liquid; they do not solve the problem until they question that assumption. The story's explicit denial of any form of flotation device entices subjects to assume that the lake surface was liquid by getting them to assume that a flotation device would be appropriate.

There is evidence that fixation breaking is not sufficient for insight. Weisberg and Alba (1981a, 1981b, 1982) showed that subjects often did not solve the nine-dot problem even when the experimenters broke the subjects' fixation by telling them to draw lines outside of the square. Problems like the nine-dot problem and match-triangle problem have a nontrivial verification component after the illumination stage (Wallas, 1926). The problems logically require additional steps after the fixation is broken. Because we do not necessarily equate insight with the breaking of fixation, it is useful to minimize the verification stage to focus on illumination. The lake problem is from that class of problems not requiring additional steps: *The lake was frozen* is both the key assumption that reorganizes knowledge, and the answer to the problem's question, "How did she manage to do it?" Solution is rapid and direct because no further steps are necessary after the insight; the insight *is* the solution.

If insight is not equivalent to overcoming fixation, then what does underlie insight? "When familiar objects acquire a place in a new perceptual organization, they become new things and have new meanings. It is this change in meaning that gives us the jolt and to which the term *insight* is applied" (Ellen, 1982, p. 324). We think that this new organization need not arise by changing a previous strong organization; it is not necessary for a fixation to exist and to be broken. A dramatic change in organization can also occur from a previous state of disorganization. In other words, subjects may fail to solve a problem without being fixated if they simply have no strong knowledge structure to begin with.

Reorganization of Knowledge

Realizing that the lake was frozen is more than the addition of one more piece to the puzzle; it is more than beginning to think that the lake is not liquid. It is a reorganization of knowledge, a new view of the material, a new gestalten. This reorganization is the underlying mechanism we are exploring as the explanation of the insight phenomenology.

Metcalfe (1986a, 1986b; Metcalfe & Wiebe, 1987) provided the empirical support necessary to justify inclusion of the phenomenology in a definition of insight, but no one has filled the corresponding gap for reorganization of knowledge. This absence of relevant data—pro or con—led Weisberg and Alba to conclude that the terms *insight* and *fixation* are no better than other descriptors of insight problem solving, because "the only way we know that a subject was fixated was that the subject did not solve the problem. However, the reason that the problem was not solved was that the subject was fixated, which puts us in a circle. A parallel circularity concerns the use of insight" (1981a, p. 188).

Dominowski noted that the obstacle to utilization of the insight and fixedness constructs was not merely absence of data, but inability to gather relevant data because of the limited tools available for knowledge measurement. Although he wrote of fixedness, a similar argument could be made for insight: "If some means could be found to distinguish varying degrees of adherence to ideas (separate from whether a person solves the problem), then fixation could serve some useful theoretical purpose. Otherwise, we are probably better off without it, as Weisberg and Alba suggest" (Dominowski, 1981, p. 197). In this chapter we describe our use of Pathfinder to capture subjects' knowledge of our insight problem. We then apply the method to show a dramatic difference in knowledge organization between solvers and nonsolvers of the problem, thereby providing some empirical support for reorganization as the cause of the insight phenomenology.

An Experiment

The Puzzle

We chose the following puzzle as the insight problem because (a) When we first heard it, we experienced an "aha!" that we attributed to crystallization of knowledge in a novel way; (b) it is the same type of problem used by authors such as Bowden (1985); and (c) rapidity and directness of solution are not at issue, because the insight *is* the solution. Like Metcalfe and Wiebe (1987), we acknowledge that our criteria for labeling this an insight problem are ill defined. Subjects were told,

> A man walks into a bar and asks for a glass of water. The bartender pulls a shotgun on the man. The man says "thank you" and walks out. What missing piece of information would cause the puzzle to make sense?

Rating Task

Regardless of the experimental condition or whether the puzzle was ultimately solved, each of our subjects made their knowledge available by providing pairwise relatedness judgments among 14 terms that were relevant to the puzzle. To prevent confounding of asymmetries of association, we randomized the left-right presentation order of pair members. In addition, half of the subjects made similarity judgments (high numbers for high similarity) and half of the subjects made dissimilarity judgments. Within each subject's list of 91 pairs, the order of pairs was randomized. All subjects were told to use a scale of 1 through 10.

Some of the 14 terms to be judged came directly from the puzzle: *man, bar, bartender, glass of water, shotgun, thank you.* Other terms were absent from the puzzle but were relevant to the solution: *surprise* (the man was surprised by the shotgun), *remedy* (the shotgun was the remedy of the man's ailment), *relieved* (the man was relieved to be cured), *friendly* (the bartender was friendly, not hostile, and that was the reason he pulled the shotgun), *loaded* (the shotgun need not have been loaded in order to effect the surprise, but needed to be loaded if the bartender intended to shoot the man), *paper bag* (a paper bag can be used as a hiccough cure). The final two terms, *pretzels* and *TV*, had nothing to do with the insight that the man had the hiccoughs, but represented items typically present in a bar.

We used Pathfinder (Schvaneveldt, Durso, & Dearholt, 1989) to turn the pairwise relatedness judgments into graphs. If subjects' insight was accompanied by dramatic reorganization of their knowledge structures, the graphs of the solvers should produce poor correlations with those of the nonsolvers. We selected the 14 terms carefully so that there were several plausible organizations. For example, *remedy* and *relieved* should be remote from the rest of the graph of a subject who does not know the solution, but should be central in the graph of a subject who knows that the *shotgun, water*, and *paper bag* can be hiccough *remedies* that lead to *relief*. Microanalysis of the graphs' specific links could then explain low correlations between solver and nonsolver graphs; we could make specific predictions because of our judicial choice of the 14 terms. For example, we expected that a subject who did not know the solution might think of *paper bag* only as a container for *pretzels*, whereas a subject who knew the hiccough solution might think of *paper bag* as another means to *remedy* hiccoughs, and thereby to acquire *relief*.

Subject Groups

There were four groups of subjects:

1. Story Only: These subjects were told the puzzle story and immediately judged relatedness of the 14 words, without being asked for the solution and without being allowed to ask questions. They were not even told it was a puzzle. Afterward they were told it was a puzzle and asked if they knew the solution; none did.
2. Active Nonsolver: This group did the rating task after failing to solve the puzzle despite asking yes-no questions for two hours.
3. Passive Nonsolver: Subjects in this condition were each yoked to a counterpart in the solver condition: Each listened to an audio tape of one solver being told the puzzle and asking yes-no questions. They listened to the entire session until immediately before the solver asked the critical question that directly preceded the solution; thus, passive nonsolvers did not hear the solution. We did not allow them to ask any questions, and at the end of their sessions none could provide the solution when asked.
4. Solver: This group comprised subjects who had successfully solved the puzzle after asking yes-no questions for up to two hours. Examples of the questions and answers are: "Does the man drive to the bar?"—"No." "Is the man bigger than the bartender?"—"No." "Does the man get what he wants?"—"Yes." "Does the man have any animals with him?"—"No." "Does the bartender intend to shoot the man?"—"No." "Does the bartender understand what the man wants?"—"Yes." The subjects in this group rated the stimuli after they achieved the solution.

Each of the four groups ultimately contained six subjects. One of the subjects intended for the passive nonsolver group solved the puzzle and was therefore replaced by a subject who did not solve it. All subjects were students in Introductory Psychology at the University of Oklahoma, who participated in partial fulfillment of a research requirement for the class.

Conversion of Ratings to Pathfinder Graphs

We converted all the ratings to dissimilarities, with 10 for maximum dissimilarity between pair members and 1 for minimum dissimilarity. The form of the resulting data was a 14×14 symmetric matrix for each subject, with zeros on the diagonal. The individual subject matrices were averaged to yield four mean dissimilarity matrices, one for each of the groups of subjects.

For each subject group, we submitted the mean dissimilarity matrix to the Pathfinder algorithm (Schvaneveldt et al., 1989) as implemented in Pascal on a Zenith PC-compatible microcomputer with an 8087 math coprocessor. We used the Pathfinder r parameter equal to infinity so as to make only ordinal assumptions about the subjects' ratings. We set the q parameter at $n-1 = 13$ to achieve the simplest graph for our chosen value of r.

Results and Discussion

Macroanalysis

Pictures. The Pathfinder solutions (PFNETs) for the four subject groups are represented as graphs in Figures 1 through 4. Each of the 14 terms relevant to the bartender problem is a node, with links between nodes showing that the concepts represented by those terms are connected in the subjects' gestalten. The four knowledge structures are apparently different. The story-only graph had 15 links (Figure 1), the active nonsolver had 14 (Figure 2), the passive nonsolver 15 (Figure 3), and the solver had 13 (Figure 4). The solver PFNET is a tree, but all the others contain cycles.

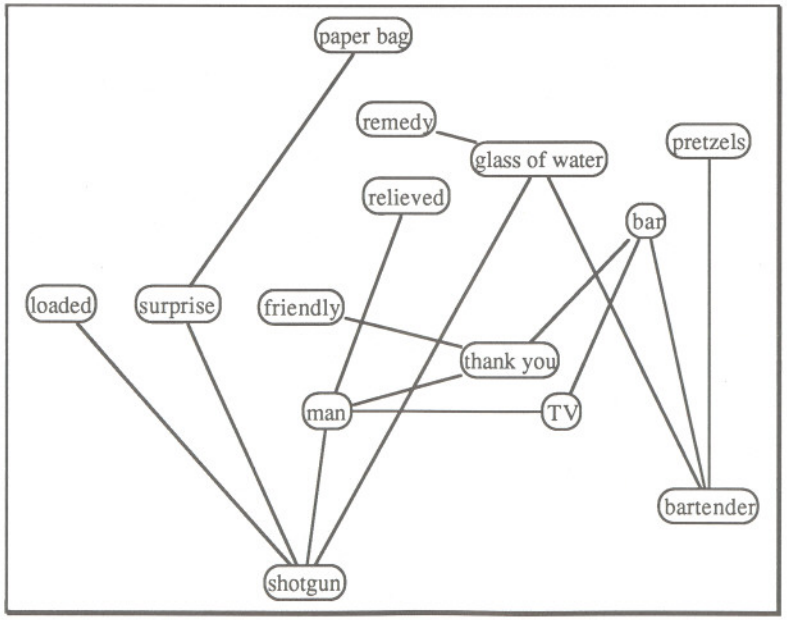

Figure 1. PFNET($r = \infty, q = n-1 = 13$) for the Story-Only group.

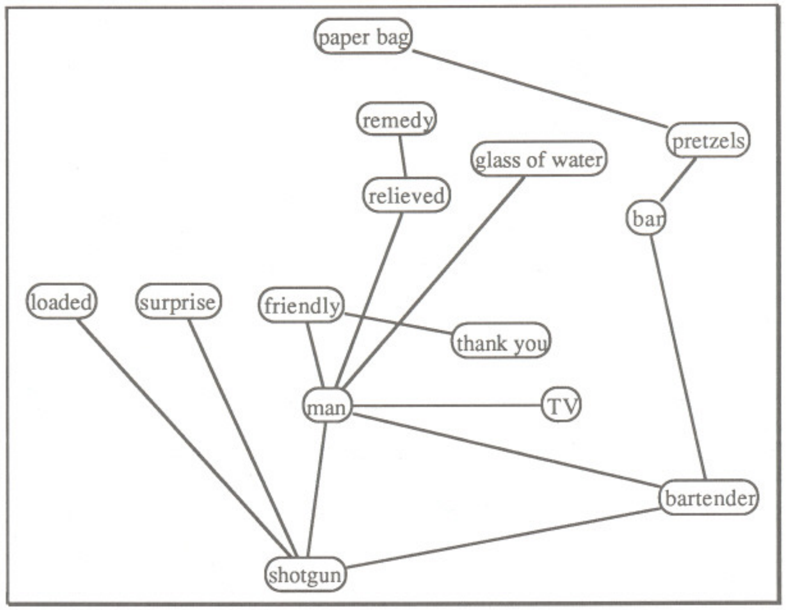

Figure 2. PFNET($r = \infty$, $q = n-1 = 13$) for the Active Nonsolver group.

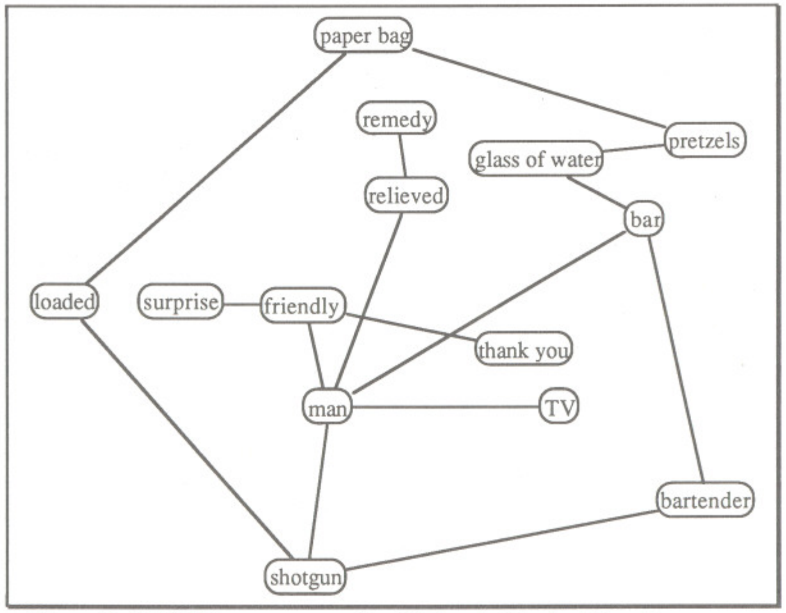

Figure 3. PFNET($r = \infty$, $q = n-1 = 13$) for the Passive Nonsolver group.

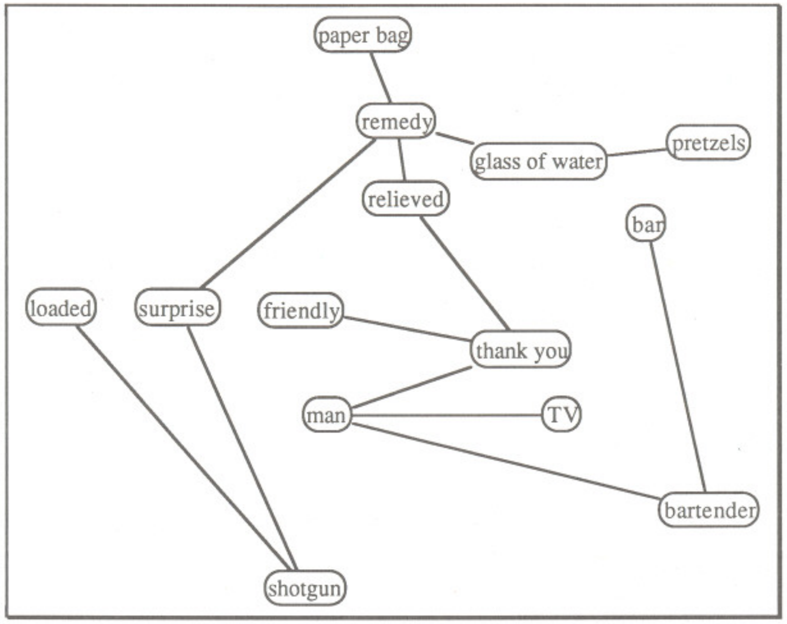

Figure 4. PFNET($r = \infty$, $q = n-1 = 13$) for the Solver group.

Correlations among graph links. Gross differences among the graphs of the four subject groups were quantified by correlating the upper triangular halves of the adjacency matrices with each other. (An adjacency matrix contains ones and zeros to show presence and absence of links.) Table 1 displays the proportions of variance in each graph that are accounted for by the other graphs. There were several uninteresting links common to all the graphs, such as *man* to *TV*, and *friendly* to *thank you*, which resulted in all the correlations being significantly greater than 0.

The correlations reveal that the similarities between groups' knowledge structures met our expectations. Despite the passive nonsolvers' exposure to the same information that the solvers heard, passive nonsolvers were less correlated with solvers than with active nonsolvers. This supports insight's sudden and dramatic restructuring of knowledge instead of gradual change, because if information were slowly accumulated, passive nonsolvers should have been very similar to solvers. Indeed, there is more similarity between the two nonsolver groups than between any other groups. All other correlations were similar and equally low. The difference between nonsolvers and solvers cannot be due simply to the quality of the information they received, because the active and passive nonsolvers had similar organizations despite their potentially different information, whereas the passive nonsolvers and solvers had less similar organizations despite their virtually identical information. In fact, passive nonsolvers were less similar to solvers than were any other subjects, though these differences were not significant. Just as solvers were unlike any other group, the story-only group had an organization different from any group that attempted to solve the puzzle. Thus, hearing a story created one organization, attempting to solve the puzzle created another, and solving the puzzle created a third. This reorganization implied that going from the attempt to the solution was accompanied by the "aha!" phenomenology, but that the change in going from the story to the mere attempt was not.

Table 1. Proportion of shared variance among Pathfinder graphs (squared correlations[a] on adjacency matrices).

	Story Only	*Active Nonsolver*	*Passive Nonsolver*	*Solver*
Story Only	1.00	.15	.08	.17
Active Nonsolver	.15	1.00	.40	.19
Passive Nonsolver	.08	.40	1.00	.11
Solver	.17	.19	.11	1.00

[a]All correlations are significantly greater than zero ($p < .01$). The correlation between Active and Passive Nonsolvers ($r^2 = .40$) is significantly higher than all other correlations except Active with Solver, which is marginal ($p = .066$). Comparisons of correlations used $p \leq .05$, via Fisher's z-transform.

Graph-theoretic indices of the focal node. We used the graph theory constructs of highest degree, median, and center to identify each graph's central node (see Table 2). The degree of a node is simply the number of links incident to the node. The median and center nodes are the least distant from all other nodes, but in different senses. The median is the node with the shortest average distance to all other nodes, whereas the center is the one with the shortest maximum (i.e., minimax) distance to any other node. An analogy will clarify this distinction. If one wanted to place a hospital in a city's graph of roads so that travel time to the hospital was minimized for the most people—so the *average* travel time was minimized—then the hospital should be at the graph's median. But suppose instead that one was trying to place a cardiac arrest ambulance station so that all patients would be reached in less than the critical first four minutes. It might matter little that many people would require close to the four-minute limit, and that few people would be reached in less than two minutes. Because the four-minute limit is a catastrophic threshold, the average time is not important. The ambulance station should be at the road graph's center instead of its median.

The median and center for each group of subjects in Table 2 were computed from that group's matrix of path distances among all the nodes. Each node-to-node path was composed only of links in that group's Pathfinder solution. For instance, the Story-Only group's path distance from *pretzels* to *man* was computed by finding all possible paths through Figure 1, between those two nodes. The length of each of those possible paths was defined as its number of links. The shortest of all those possible paths was selected as *the* path between *pretzels* and *man*, and its length was entered at the path-distance matrix (14 nodes by 14 nodes) *pretzels* column intersection with the *man* row. From this column we found the largest distance from *pretzels* to any other node. From all 14 such column maximums we selected the smallest, and used its column's node as the center—the node whose maximum distance to any other node is smaller than all other nodes' maximum

distances. To find the median node, we averaged the distances within each column, found the smallest of those 14 column means, and chose that column's node as the one with the smallest mean distance to all other nodes.

The most relevant feature of Table 2 is that *remedy* and *relieved* are the focus of the solver graph, but not of any other graph. This is consistent with our belief that *remedy* and *relieved* are of little relevance to someone who does not know the solution to the bartender problem. The other groups oriented their graphs around *man*, *shotgun*, *bar*, or *bartender*. The solver group's insight did not just strengthen the solution-relevant nodes but considerably restructured the graph around them. Table 2 is consistent with the correlations in its implications that the solvers were different from either nonsolver group, and that the two nonsolver groups were similar. Unlike the correlations, Table 2 suggests that the story-only people were more like the nonsolvers than they were like the solvers.

Table 2. Three graph-theoretic versions of the focal nodes.

Subject Group	*Highest Degree Node*[a]	*Median Node*[b]	*Center Node*[c]
Story Only	Man & Shotgun 4	Shotgun 1.9	Shotgun 3
Active Nonsolver	Man 6	Man 1.8	Bartender 3
Passive Nonsolver	Man 5	Man 1.8	Man, Bar, & Shotgun 3
Solver	Remedy 4	Remedy & Relieved 2.5	Relieved 4

[a]The node(s) with the greatest number of links. The highest degree is given below the node names.
[b]The node(s) with the smallest average distance to all other nodes. The smallest average distance is given below the node names.
[c]The node(s) with the smallest maximum-distance-to-any-other-node. The smallest maximum distance is given below the node names.

Microanalysis of Solvers and Nonsolvers

The intergroup correlations (Table 1) revealed that the graphs of passive and active nonsolvers were similar to each other but different from the solvers' graphs. The graph-theoretic indices of centrality (Table 2) showed that both active and passive nonsolver graphs were built around the same nodes despite the differences in information the two groups received. The nonsolver graphs also had different central nodes than did the solver graphs. Now we will pinpoint the specific links that distinguish solvers from nonsolvers, with the aid of Figure 2. Figure 2 shows only links that differ between solvers and nonsolvers, where "nonsolvers" include both the passive and the active. It is most useful to interpret the differences by focusing on the links added by the solvers, represented in the figure by thick lines.

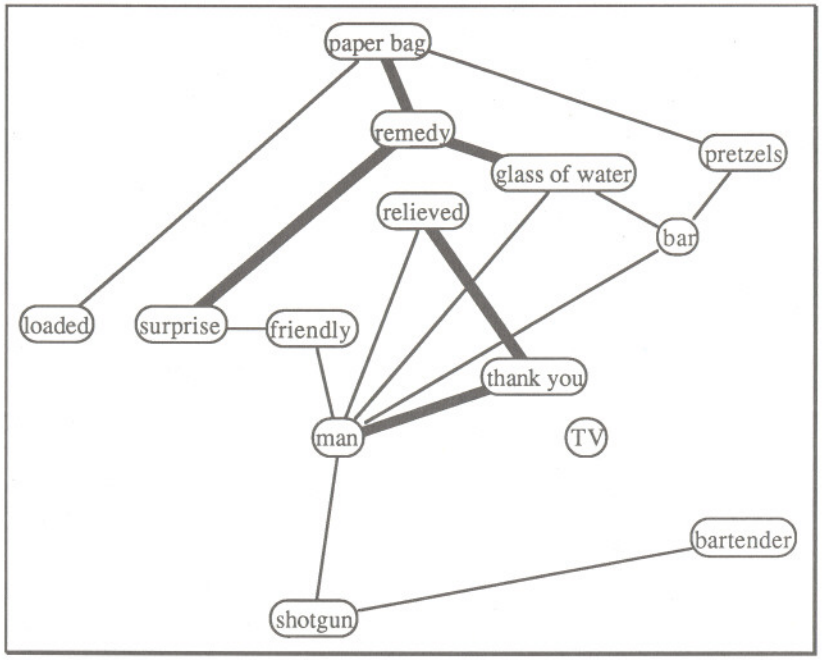

Figure 5. Differences between solver and nonsolver graphs. Active and passive nonsolvers are combined. Thick lines are links present in solvers but not in nonsolvers. Thin lines are links present in nonsolvers but not in solvers.

The concrete reason for the abstract graph-theoretical conclusion (Table 2) that *remedy* and *relieved* were central to the solver graph and not to the nonsolver graphs is that for the nonsolvers, *remedy* was connected only to *relieved*, and *relieved* was attached to the rest of the graph only by its connection to *man* (see Figure 2). We had predicted that nonsolvers would not be thinking of the paper bag or glass of water as instruments for a remedy; we put *paper bag* in the list of terms to be judged for just this reason, because it could easily be considered a container for pretzels. Another important deviation of nonsolvers from solvers is that *shotgun* was not connected to *surprise* for passive nonsolvers, and though active nonsolvers tied *shotgun* to *surprise*, they did not join *surprise* to *remedy* or to *relieved.* We think nonsolvers might have viewed the shotgun primarily as a possession of the bartender, and associated *remedy* and *relieved* to the graph only loosely, as attributes of *man.* In contrast, solvers might have seen the paper bag and glass of water as remedies, and surprise as the vehicle for the shotgun remedy. By these three additional links (*remedy* to *paper bag*, *glass of water*, and *surprise*), the solvers made *remedy* a central concept.

It is also apparent that *relieved* and *remedy* switched from mere attributes of *man* for nonsolvers, to reasons for the man to say "thank you" for solvers: The nonsolver links from *relieved* to *man* disappeared for the solvers, who instead directly connected *relieved* to *thank you.* Also, nonsolvers connected *thank you* to the rest of the graph through its mundane association to *friendly*, which was perhaps seen as an attribute of *man.* Solvers, in contrast, might have seen *thank you* as an action of *man* (*man* linked directly to *thank you*)

and *thank you* as a consequence of *relieved.* Solvers also dropped links from *friendly* to *man* and to *surprise*, changing *friendly* from a hub into an isolate, connected to the graph only through its link to *friendly.*

These solution-coincident, sudden changes in knowledge structure undoubtedly required preparation of the ground by subtler shifts resulting from the long question and answer period. Yaniv and Meyer (1987, p. 189), among others, suggested that incubation effects in problem solving are due to the problem solver encountering new stimuli that trigger chains of associations. This spreading activation could improve access to memories critical to problem solution—memories that before were only partially accessible. There is evidence that when people are trying to solve insight problems, they fail to use relevant memories because they cannot retrieve them (Lockhart, Lamon, & Gick, 1988; Perfetto, Bransford, & Franks, 1983). Perhaps an insightfully sudden change of organization occurs when the set of necessary memories is finally available so that a novel stimulus can quickly and easily cause activation propagation through them to form or to reach the answer. An analogy is a seed crystal's ability to crystallize a solution explosively only when the solution is supersaturated.

Conclusions

In this chapter we showed the practicality of our Pathfinder-based method for revealing detailed knowledge patterns. Our approach is the practical support for an operationalization of knowledge reorganization that we think should be added to Metcalfe and Wiebe's (1987) quantitative assessment of the phenomenology to form a two-part, measurable, definition of insight.

We have shown that people who solve an insight problem have a much different knowledge organization than do people who do not solve it or who are unaware of the problem. We have also shown that the correct organization is not achieved merely by exposure to the relevant information, and we believe this is evidence that the difference in structure between problem solvers and nonsolvers is due to a sudden and substantial shift in connections as contended by the Gestaltists (e.g., Dominowski, 1981; Ellen, 1982), rather than to an incremental response to accumulated information (e.g., Weisberg & Alba, 1982). Reorganization of knowledge obviously *can* occur incrementally—the nonsolver groups were more similar to each other than to the story-only group—so the rarity of insight implies that incremental reorganization is not sufficient for insight.

Reorganization alone was never thought to produce the "aha!" experience. The key is the jolt, the click, the suddenness of the reorganization. In current models of information processing, a massive reorganization can take place by the importation of a schema into the comprehension situation. Together with the existing goals of the situation, such importation can have dramatic effects on cognitive processing (e.g., Bransford & Johnson, 1972; Smith, Adams, & Schorr, 1978). We speculate that in problem solving it is the importation of the schema that causes the breathtaking reorganization. With our more sophisticated understanding of cognitive representations this can be considered incremental, but it is certainly not incremental in the same sense as increments in other problem-solving situations. In this view it may be a step, but it is a very large step. What is one small step technically, can be one giant leap phenomenologically.