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ABSTRACT

This paper provides a general description of schema-theoretic models of language comprehension and examines some extensions of such models to the study of reading. The goal of schema theory is to specify the interface between the reader and the text: to specify how the reader's knowledge interacts with and shapes the information on the page and to specify how that knowledge must be organized to support the interaction. The general theory is illustrated with an analysis of knowledge and processing at four levels of a good reader's understanding of Aesop's fable, "Stone Soup": the letter and word level, the syntactic level, the semantic level, and the interpretive level. The analyses illustrate that comprehension depends on the reader's ability to relate knowledge and textual information, both within and between levels of analysis. The power of schema-theoretic models lies in their capacity to support these interactions through a single, stratified knowledge structure and a few basic processing mechanisms. They provide a way of integrating our understanding of text with our understanding of the world in general. (AA)

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Technical Report No. 32

A SCHEMA-THEORETIC VIEW OF READING

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A SCHEMA-THEORETIC VIEW OF READING

At one level, reading can be described as the process of translating graphemic strings into spoken words. However, what we really mean by reading is not the ability to decode words but the ability to extract the meaning, both explicit and implicit, from the written text. It depends on the intricate coordination of our visual, linguistic, and conceptual information-processing systems. If we are to understand reading, we must find a way to break it down into a set of more tractable subskills and to identify their interrelations.

The standard approach is to begin with the ultimate goal of the reader and then to determine its prerequisites. At the highest level, the reader has successfully read a passage if he understands it both as it was intended by the author and in terms of its impact on himself. This presumes that the reader has extracted the information provided by the text, which in turn, depends upon his having comprehended the individual sentences, which depends upon his having correctly processed the clauses and phrases of those sentences, which depends upon his having recognized the component words of those units, which depends upon his having recognized their component letters.

When reading is analyzed in this way, the component levels of processing appear to be organized hierarchically. The attainment of any given level presumes the execution of all subordinate or less complex levels; moreover, the converse is not strictly true: whereas the reading of a written passage depends on the reading of its sentences, words, and letters, the dependency is, in some sense, unidirectional. An individual letter may be perfectly legible whether or not it is embedded in a word, a sentence, or a passage. Similarly, we are fully capable of reading individual words and sentences in the absence of a larger context. This asymmetry has been exploited by traditional analyses of reading. For teachers, it provides a rational structure for instructional programs: start at the bottom, with single letter recognition, and successively work up through the higher level skills. For researchers, it provides a means of empirically isolating the processes involved at any given level in the structure: the effects of higher order processes on the level in question are supposed to be null, and the effects of lower processes can be empirically identified and subtracted out.

The problem with this approach is that when we are reading a meaningful passage, we are not reading its component letters, words, and sentences in the same way as when they are presented in isolation. Rather, processing at each level is influenced by higher, as well as lower order information. Thus, individual letters become more perceptible when they are embedded in words (Reicher, 1969, Wheeler, 1970). Individual words are recognized more easily when they are embedded in meaningful sentences (Tulving & Gold, 1963, Schuberth & Eimas, 1977). Unfamiliar words may be processed more easily if they are embedded in a familiar story (Wittrock, Marks, & Doctorow, 1975). Sentences that more coherently integrate the underlying semantic relations may be assimilated more easily than those that do not, irrespective of their syntactic complexity (Pearson, 1974; Haviland & Smith, 1974).

These sorts of interactions tremendously ease the task of the skilled reader. Because of them, he is not obliged to grind through every graphemic detail of the written representation. Instead he may opt to process lower order information only as is necessary for checking his higher order hypotheses about the content of the passage. By contrast, these sorts of interactions greatly complicate the task of analyzing the reading process. They challenge the wisdom of bottom-up instructional strategies, and they all but nullify the generality of empirical findings based on "isolated" processes. Moreover, they leave us without a good working model of the reading process.

Recently, however, through the combined efforts of cognitive psychologists, linguists, and specialists in artificial intelligence, a new set of formalisms for analyzing language comprehension has begun to emerge. These theories are, at core, related to the old notion of a schema (Bartlett, 1932; Kant, 1781;

Woodworth, 1938). In the current literature, they are variously referred to as frames (e.g., Charniak, 1975; Minsky, 1975) and scripts (e.g., Schank & Abelson, 1975; Lehnert, 1977), as well as schemata (e.g. Becker, 1973; Bobrow & Norman, 1975; Rumelhart & Ortony, 1976). We would argue that schema theory for the first time provides a structure powerful enough to support the interactions among different levels of processing in reading.

In the remainder of this chapter, we will first provide a general description of schema-theoretic models and the way they work, and then examine some extensions of the models to the study of reading. A disclaimer is in order at this point. Many schema-theoretic models have been, are being, and will be developed, and there are some fundamental differences among them. In view of this, we have not tried to provide a faithful description of any one model. Instead we gloss over controversies and differences between models in the hope of providing a coherent tutorial glimpse of the overall effort.

SCHEMA THEORY AND LANGUAGE COMPREHENSION

A fundamental assumption of schema-theoretic approaches to language comprehension is that spoken or written text does not in itself carry meaning. Rather, a text only provides directions for the listener or reader as to how he should retrieve or construct the intended meaning from his own, previously acquired knowledge.

The words of a text evoke in the reader, associated concepts, their past interrelationships and their potential interrelationships. The organization of the text helps him to select among these conceptual complexes. The goal of schema theory is to specify the interface between the reader and the text -- to specify how the reader's knowledge interacts and shapes the information on the page and to specify how that knowledge must be organized to support the interaction.

Structural Organization of Schema-Theoretic Models

A schema is a description of a particular class of concepts and is composed of a hierarchy of schemata embedded within schemata. The representation at the top of the hierarchy is sufficiently general to capture the essential aspects of all members of the class. For example, if the conceptual class represented by a schema were "going to a restaurant" (Schank & Abelson, 1975), its top level representation would include such information as that a restaurant is a commercial establishment where people pay money to have someone else prepare their food and clean up after them. At the level beneath this global characterization, are more specific schemata (e.g., going to a diner, going to a fast hamburger operation, and going to a swanky restaurant). In general, as one moves down the hierarchy, the number of embedded schemata multiplies while the scope of each narrows, until, at the bottom most level, the schemata apply to unique perceptual events. Each schema at each level in the hierarchy consists of descriptions of the important components of its meaning and their interrelationships, where these descriptions are themselves schemata defined at the appropriate level of specifity. The power of this structure derives from the fact that the top level representation of any schema simultaneously provides an abstraction of and a conceptual frame for all of the particular events that fall within its domain.

Because the top level description of a schema must pertain to every member of its class, many of its components may be but vaguely specified. For example, in the restaurant schema very few properties of the place to be served could be extended to all possible members of that class, be they any variety of booths, tables or counters; accordingly, very few properties could be explicitly attached to its superordinate description. On the other hand, the most general schema for the place to be served in a restaurant effectively contains all of the service arrangements one has experienced, or, equivalently, the collective features of those service arrangements weighted in terms of their likelihood in different contexts. Thus, while no specific value is anticipated, a stereotype is defined; in the absence of further information, the concept is still meaningful.

Because the schema specifies the interrelationships between its underlying components, once any element is specified, it can be understood in the proper context. For example, if a counter is mentioned within the restaurant schema, it can immediately be understood as a place at which food can be served and not as an abacus or a parrying boxer's blow. Moreover, the introduction of a counter might be sufficient to eliminate swanky restaurants from consideration, thereby indirectly narrowing the probable range for other, as yet unspecified component, of the restaurant schema.

Any important element or schema within a schema may be thought of as a <u>slot</u> (Minsky, 1975) that can accept any of the range of values that are compatible with its associated schemata. The comprehension of a specific situation or story involves the process of instantiation whereby elements in the situation are bound to appropriate slots in the relevant schema. This process not only serves the purpose of filling out the details of the schema, but also of temporarily connecting it to characteristics of the bound schemata. Thus, if there is a nervous old man in the story who takes the order in the restaurant, he will be bound to the waiter role. If subsequently the waiter knocks over a glass of water, this fact will be related back to the nervous quality of the old man currently assigned to the waiter role. Often, a text will not explicitly provide the element to be bound to a particular slot even though it is an integral component of some relevant schema. In these cases, the reader may assign <u>default</u> values. The default assignment will be determined by the values associated with its slot. The precision of the default description will depend on the specifity of those values. If one knew that the restaurant in the story was swanky, the default assignment might be that the customer sat at a table; if one also knew it was an authentic Japanese restaurant, the default assignment might be that the customer sat on cushions rather than a chair; if the story were about a particular, familiar Japanese restaurant, the default assignment might be very elaborate.

The Processing of Information

Within schema theory, the process of interpretation is guided by the principle that all data must be accounted for (Bobrow & Norman, 1975). Every input event must be mapped against some schema, and all aspects of that schema must be compatible with the input information. This requirement results in two basic modes of information processing. The first mode, bottom-up processing, is evoked by the incoming data. The features of the data enter the system through the best fitting, bottom-level schemata. As these schemata converge into higher level schemata, they too are activated. In this way, the information is propogated upwards through the hierarchy, through increasingly comprehensive levels of interpretation. The other mode, top-down processing, works in the opposite direction. Top-down processing occurs as the system searches for information to fit into partially satisfied, higher order schemata.

An important aspect of a schema-theoretic account of reading comprehension, is that top-down and bottom-up processing should be occurring at all levels of analysis simultaneously (Rumelhart, 1976). The data that are needed to instantiate or fill out the schemata become available through bottom-up processing; top-down processing facilitates their assimilation if they anticipated or are consistent with the reader's conceptual set. Bottom-up processing insures that the reader will be sensitive to information that is novel or that does not fit his on-going hypotheses about the content of the text; top-down processes help him to resolve ambiguities or to select between alternative possible interpretations of the incoming data. Through the interactions between top-down and bottom-up processing, the flow of information through the system is considerably constrained. Even so, these processes are not, in themselves, enough to ensure apt comprehension.

The notion that the human mind is guided by a central, limited capacity processor is, by now, taken for granted within many psychological theories of information-processing. The general acceptance of this notion among psychologists has been principally due to empirical demands. Recently, however, Bobrow and Norman (1975) have argued that some such construct must be incorporated into any schema-theoretic type of system, be it person or machine, if its responses to its environment are to be rational and coherent.

Bobrow and Norman's argument is based on three observations. First, in order for a system that is so diffuse and receptive to maintain coherence, it must be imbued with purpose. In their words (p. 146), "without purpose, the system will fail to pursue a line of inquiry in any directed fashion." Moreover, too many purposes can be the same as none. Their second observation is related: individual purposes are by definition, single-minded. In order to select among different, and possibly conflicting purposes, the system must have some more global self-awareness or, in Bobrow and Norman's words, "a central motivational process." Third, some mechanism which has access to all memory schemata must guide the interpretive process. This is necessary in order to decide when a schema has been adequately filled out for the current purpose, to evaluate the goodness of fit of the data to the schemata, and to detect and appropriately connect metaphorical or analogical references. These observations led Bobrow and Norman to conclude that the schemata must culminate in some central, omniscient processor -- a grand self schema, if you will. The primary responsibility of this processor is to adaptively allocate the limited resources for active processing among the various activities of the system.

Taking this notion back to the schema-theoretic model, we see that there are two basic ways in which the processing capabilities of the system may be limited (Norman & Bobrow, 1975). First, there may be some difficulty in mapping input data to the memory structure with the result that their normally automatic, bottom-up propagation through the system is obstructed; in this case, the system is data-limited. Second, the various, simultaneous demands for active control may exceed the system's capacity to cope; in this case, the system is resource-limited and the execution of some of the ongoing activities will be compromised. Both kinds of limitations are relevant to the reading process.

Norman and Bobrow (1975) have distinguished two types of data-limits on processing. The definitive characteristic of each is that no amount of effort on the interpreter's part will eliminate the problem. The first, signal data-limits, occur when the quality of the input confuses the mapping process, as, for example, when one is listening for faint signal in a noisy environment. Examples of signal data-limits in the reading domain range from the deciphering of poor handwriting to the comprehension of a wholly incoherent passage. For the second kind of data-limits, memory data-limits, the quality of the input may be impeccable, but the mapping process is obstructed for lack of appropriate memory structures. Both of us would, for example, suffer from a memory data limit in trying to understand a Japanese speech; since we know no Japanese, we could not, with any amount of effort, succeed. With respect to reading, problems related to memory data-limits are pervasive. For the beginning reader, they may occur at the level of single letter recognition. For more experienced readers, they may persist at the levels of word recognition, syntactic analysis, and of course, in any dimension of semantic interpretation.

As an example of resource-limited processing, Bobrow and Norman describe the familiar situation in which one is simultaneously driving a car and carrying on a conversation. Both activities can be managed as long as they are proceeding as expected. If one, however, absorbs inordinate attention, it does so at the expense of the other. Surprising news may result in bad driving; a busy intersection may provoke a pause in the driver's speech or distract him from listening. The analogy exists in the reading situation -- we can tolerate more or less distraction while reading, depending on the difficulty of our material or our reasons for reading it.

But, with respect to reading, the more critical problems related to resource-limited processing arise when activities subserving the same end compete for attention. If their respective demands cannot be met, the comprehension process breaks down. A good reader may encounter this problem when, for example, he is trying to read a legal document or a scientific paper that is outside of his area of expertise; he may devote a lot of energy toward understanding the words and sentences, only to find that he has not understood the meaning of the paragraph. For young readers, this kind of problem may be especially frequent since many of the subskills and concepts presumed by a text may not yet be well learned or integrated.

SCHEMA THEORY AND READING COMPREHENSION

A crucial idea for a schema-theoretic account of reading comprehension is that it involves the coordinated activity of schemata at all levels of analyses. As schemata at the lower levels (e.g., visual features) are activated, they are bound to and thus evoke schemata at the next, higher level (e.g., letters); as these schemata are activated, they, in turn, trigger their own superordinate schemata (e.g., words). In this way, through bottom-up processing, the input data are automatically propogated up the hierarchy toward more meaningful or comprehensive levels of representation. At the same time, schemata at higher levels are competing to fill their slots with elements from the levels beneath through top-down processing. Again, the theory is that, for the skilled reader, both top-down and bottom-up processing are occurring simultaneously and at all levels of analysis as he proceeds through the text (Rumelhart, 1976).

A necessary assumption here is that schemata exist at all levels of abstraction (Abelson, 1975; Rumelhart & Ortony, 1976). At the letter level, the schematic descriptions may be relatively concrete and specific. For example, the schema for an uppercase K might consist of three subschemata: (1) a vertical line on the left; (2) an oblique line extending upwards from near the center of the vertical line to a point to the right of and perpendicular with the top of the vertical line; and (3) a second oblique line extending downwards from some where along the bottom half of the first oblique line to a point directly beneath the top end of the first oblique line and perpendicular to the bottom of the vertical line.

At the other extreme, schematic descriptions may be very abstract and general. As an example, consider Rumelhart & Ortony's (1976) tentative verson of the problem solving schema. In it there are three variables: a Person P, an Event E, and a Goal G. The schema has a two step structure:

1. E causes P to want G;
2. P tries to get G until P gets G or until P gives up.

Each of the elements like cause, want, and try in this schema are themselves schemata, just as the letters in the schemata for words are themselves schemata. Rumelhart and Ortony's version of the try schema has two variables which are bound in the problem solving schema: a Person P, a Goal G. The proposed steps are:

1. P decides on an action A which could lead to G;
2. While any precondition A' for A is not satisfied, P tries to get A';
3. P does A.

The problem solving and trying schemata reflect what Newell and Simon (1963), have called means-ends analysis. In means-ends analysis, whenever a goal cannot be obtained directly, an appropriate subgoal is set up. This subgoal may itself be recursively dissolved into sub-subgoals, until a stepwise means has been found to attain the original goal. We would argue, as have Newell and Simon (1963), that just such problem solving pervades many human motivations and actions. It follows that a full understanding of many stories by and about people, depends on being able to interpret their events in terms of something like the problem solving and trying schemata that Rumelhart and Ortony (1976) have outlined.

The power of a schema-theoretic account of reading derives from the assumption that lower level schemata are elements or subschemata within higher level schemata. It is, above all, this aspect of the theory that allows perceptual elements to coalesce into meaning, that allows such abstract, higher order schemata, as the problem solving schema, to be appropriately and usefully accessed. Moreover, it is this aspect of the theory which provides a structure for conceptualizing the interrelationships between levels of processing.

In order to give a more detailed description of what is theoretically happening as one reads, it is easiest to consider different levels of processing as if those levels were separable (which they are not). In the next four sections of this chapter, we will deal successively with letter and word processing, syntactic processing, semantic processing, and processing at the interpretive level. In each case, the basic argument in favor of a schema-theoretic explanation of these processes is that they cannot be explained in terms of bottom-up processing and that the top-down influences seem to be too automatic and too well structured to be attributable to simple guessing.

We will describe these processes in terms of how a skilled reader might arrive at an understanding of the following fable:

Stone Soup

A poor man came to a large house during a storm to beg for food. He was sent away with angry words, but he went back and asked, "May I at least dry my clothes by the fire, because I am wet from the rain?" The maid thought this would not cost anything, so she let him come in.

Inside he told the cook that if she would give him a pan, and let him fill it with water, he would make some stone soup. This was a new dish to the cook, so she agreed to let him make it. The man then got a stone from the road and put it in the pan. The cook gave him some salt, peas, mint, and all the scraps of meat that she could spare to throw in. Thus the poor man made a delicious stone soup and the cook said, "Well done! You have made a wonderful soup out of practically nothing."

--Aesop

Knowledge and Processing at the Letter and Word Levels

The first step towards understanding the Stone Soup story is that of recognizing the words. The processes involved in recognizing written words have been a topic of prolonged debate among educators and psychologists. On one side, there are those who argue that word recognition must be mediated by more elementary activities, like letter identification; on the other, there are those who argue that words are recognized wholistically.

The first position has many practical arguments in its favor. First, for example, the pattern analyzing mechanisms that must be posited would be far less cumbersome if the system worked on single letters or even their elementary features, than if it worked on whole word patterns. The importance of this argument is stressed when one considers the innumerable variety of type styles and scripts that are legible. Second, there must be some connection in the system between written and spoken language, and our alphabetic cipher provides a natural candidate for such a link. In addition, it provides a means by which unfamiliar written words that are familiar in their spoken expression, can be "decoded." However, the potential advantages of an alphabetic language are denied if letters are not functional stimuli in reading. Third, thorough instruction in letter-to-sound correspondences has been shown to be an important component of early reading curricula (Barr, 1974; Chall, 1967); by implication these correspondences, or some aspect of the analysis they involve, must be useful to the reading process.

In support of the other contention -- that people recognize words wholistically -- is the fact that people act like that's what they do. Certainly skilled readers are rarely aware of reading in a letter-by-letter fashion. Moreover, experimental studies have shown that whole words can be perceived at least as quickly and accurately as single letters (Cattell, 1886; Reicher, 1969; Wheeler, 1970).

The most reasonable solution to this dilemma is that the process of recognizing written words involves analyses at both the letter and the word level, and that these analyses occur simultaneously and interact with each other. Recently, Adams (1975) ran a series of experiments comparing the visual processing of words, pseudowords, and orthographically irregular non-words, which yielded direct support for this explanation. She then proposed a model which is very much in the spirit of schema theory.

The basic assumption underlying Adams' model is that any set of internal units or schemata that are repeatedly activated at the same time, become associated such that the activation of one of them facilitates the activation of the others. The essential idea of the model is that the extraction of visual information proceeds in the same way for words, pseudowords, and orthographically irregular strings, and that their differential perceptibility is due to interactions between the schemata against which the visual information is mapped. These interactions are illustrated in Figures 1 and 2.

The circles in Figure 1 represent letter recognition schemata, the arrows represent associations between them. The full circles correspond to schemata receiving activation from both an external stimulus and other activated schemata while the broken circles correspond to those receiving activation from other schemata only. The degree of interfacilitation should be determined by both the strength of the external input and the strength of the association, where the latter is presumably a function of the letters' history of co-occurrence. The strengths of these interletter associations can therefore be estimated from transitional probabilities, as has been done in this Figure.

Insert Figure 1 about here

This structure would predict a considerable perceptual advantage of words and pseudowords over orthographically irregular

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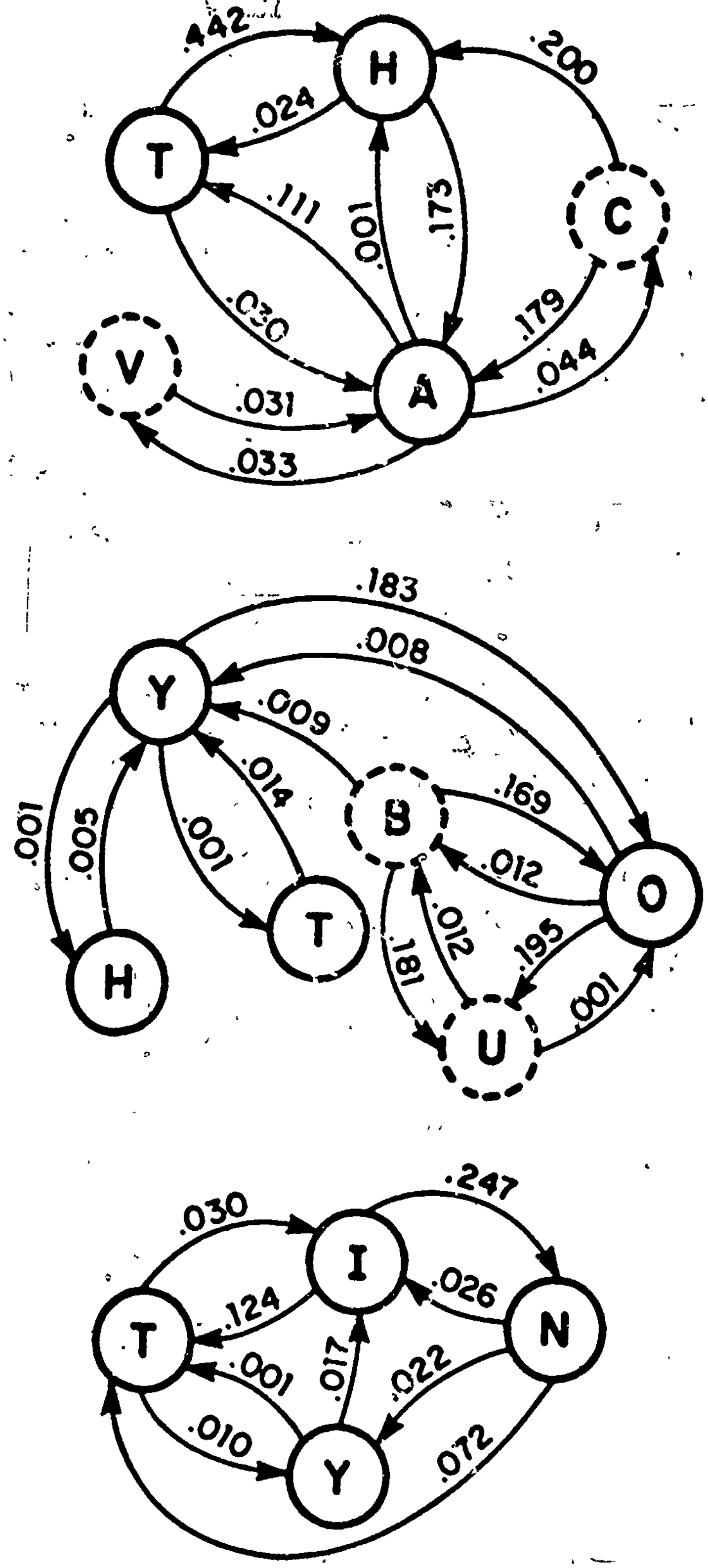

(a) THAT

(b) YOTH

(c) IYTN

Figure 1. Associated letter network. (From Adams, 1975)

nonwords, especially given that the extraction of visual information proceeds in parallel. That is, interfacilitation between the component letters of words and pseudowords would be mutual and coincident with external input. With reference to the example in Figure 1A, the T, the H, and the A would all be simultaneously receiving external activation from the stimulus and internal activation from each other. By contrast, the activation of the component letters of nonword strings, as in Figure 1C, would depend almost entirely on external input; since the transition probabilities between the adjacent letters of irregular nonwords are quite small, their mutual facilitation must also be minimal.

In order to explain the perceptual advantage of real words over pseudowords a second, lexical level of analysis must be included in the model. This level is diagrammed in Figure 2. The connections between the lexical schemata and the letter schemata represent the associations between them. The weightings of these associations are supposed to depend on lognormal word frequency. As the individual letter schemata receive input, they relay activation to all appropriate word schemata, and as a given word schema becomes active, it proportionately and reciprocally facilitates the letter schemata corresponding to its component letters.

Insert Figure 2 about here

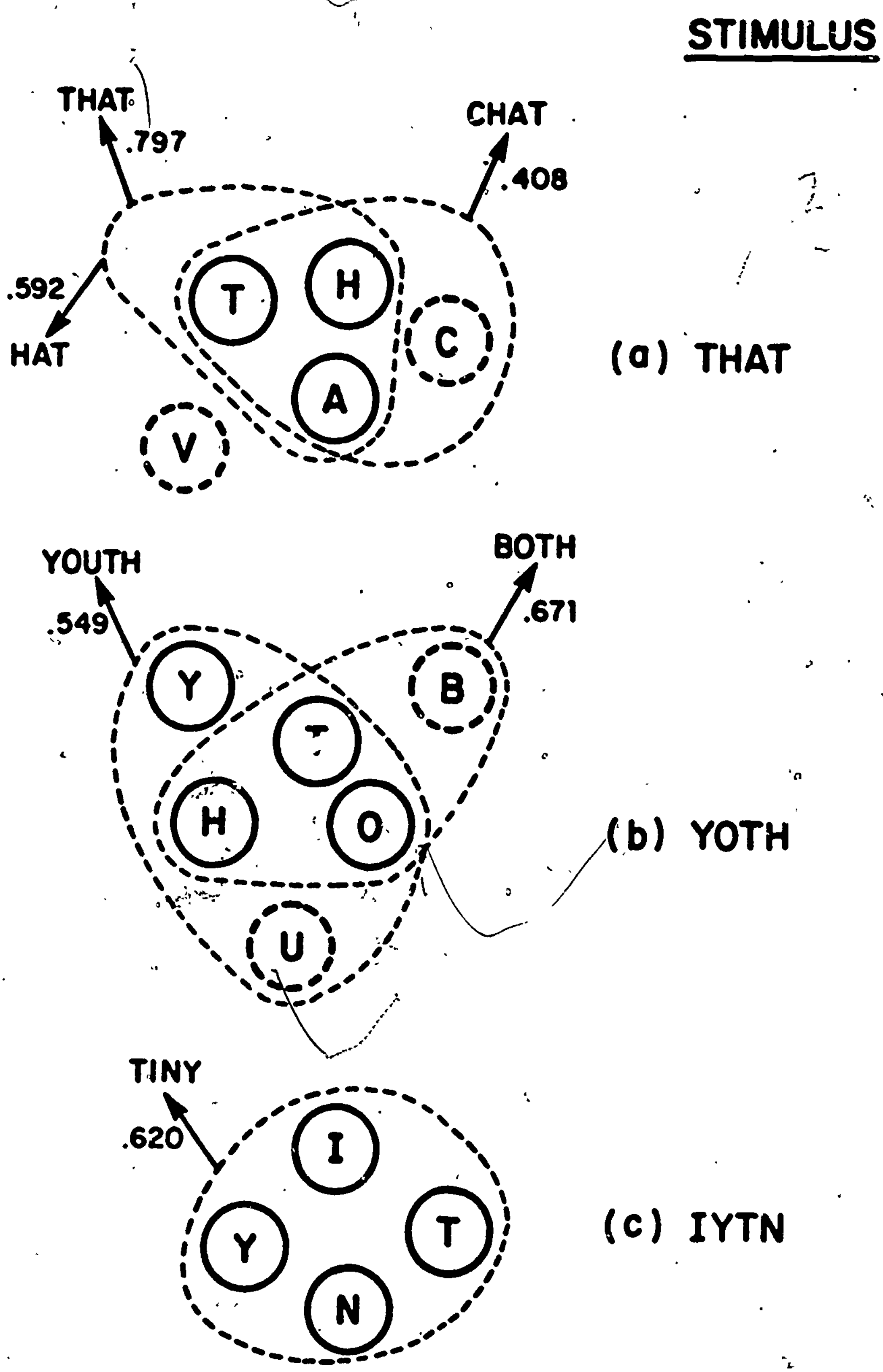

Figure 2. Associated lexical network. (From Adams, 1975)

In terms of schema theory, Adams is positing two kinds of interactive processes that go on simultaneously in recognizing words: the first depends on interconnections between schemata at the letter level, where one letter triggers an expectation for another letter; the second depends on the structure within schemata at the word level, where competing words are looking for letters to fill their respective slots.

What happens concurrently at the feature, letter, and word levels as the reader scans through the Stone Soup story is something like this. The eye collects information about different visual features that are present. These are features that are automatically bound to slots that they fit in the letter schemata. Meanwhile, partially instantiated letter schemata are trying to find the appropriate visual features to fill their remaining slots. In addition, they are facilitating other letter schemata that correspond to likely neighbors and, finally, fitting themselves to slots in the word schemata. While all of this is happening, partially activated word schemata are trying to identify the appropriate letters for their own unfilled slots.

A natural extension of Adams' model would be that word schemata facilitate other word schemata that are likely to occur in the same sentence. This extension could explain the semantic priming effects that have been reported in the psychological literature (e.g., Schuberth & Eimas, 1977; Meyer, Schvaneveldt &

Ruddy, 1975; Tulving & Gold, 1965). But when a person is reading connected discourse, syntactic and higher order semantic knowledge must also be influencing the identification of words. As described below, words themselves are subschemata within these higher level schemata.

Knowledge and Processing at the Syntactic Level

Perhaps more than anything else, it was Chomsky's (1957) "Review of Skinner's Verbal Learning," that dealt the death blow to bottom-up theories of syntactic processing. Chomsky argued cogently that in building a descriptive model of linguistic behavior, the "...elimination of the independent contribution of the speaker and learner...can be achieved only at the cost of eliminating all significance from the descriptive system, which then operates at a level so gross and crude that no answers are suggested to the most elementary questions" (p. 30). In other words, top-down processes must be incorporated into models of syntactic processing if they are to have any explanatory power.

Recent experimental evidence not only supports the contention that syntactic analysis is guided by top-down processes, but, further, indicates that this happens in a way that is consistent with schema theory. That is, the syntactic processing of a phrase occurs not subsequent to, but in parallel with the processing of its lexical elements (Marslen-Wilson, 1973; 1975; Wannemacher, 1974). Moreover, the syntactic hypotheses interact with and thus facilitate the lower level processes (Marcel, 1974; Marslen-Wilson & Tyler, 1975).

One of the most powerful formalisms that researchers in artificial intelligence have developed for syntactic processing is the augmented transition network (ATN) grammar (Woods, 1970). Recently experimental evidence has been accumulating that ATN theory provides at least a plausible account of human syntactic processing (Stevens and Rumelhart, 1975; Wanner and Maratsos, 1975).

The ATN formalism is best explained in terms of a small network that can parse a subset of English. There exists an ATN grammar for most of English (Woods, Kaplan, and Nash-Webber, 1972), but it is complicated to understand. Figure 3 shows a sample network for analyzing English sentences (S) from Woods (1970), and associated networks for analyzing noun phrases (NP) and prepositional phrases (PP). The arcs (or pointers) in the ATN formalism act like slots in the schema formalism. Thus, going out from the S state in Figure 3, any auxiliary will satisfy the lower arc. "Auxiliary" defines the range of values that can satisfy that arc (or slot). The ATN formalism, however, has no notion equivalent to default values in the schema formalism. Like schemata, ATN networks are embedded: going along an NP arc in any network means jumping to the NP network to analyze a noun phrase.

By allowing whole networks to replace arcs, the network for analyzing noun phrases need only be specified once. This is the same kind of power that comes from embedding in schema or semantic network theory: one can have a schema for "trying" or a "restaurant" which can be referred to in a wide variety of different places by higher level schema, so it need only be specified once. ATN networks can in fact be viewed as procedural schemata for representing syntactic knowledge.

Insert Figure 3 about here

Woods (1970) describes how the ATN network in Figure 3 analyzes sentences as follows:

"To recognize the sentence "Did the red barn collapse?" the network is started in state S. The first transition is the aux transition to state q2 permitted by the auxiliary "did." From state q2 we see that we can get to state q3 if the next "thing" in the input string is an NP. To ascertain if this is the case, we call the state NP. From state NP we can follow the arc labeled dec to state q6 because of the determiner "the." From here, the adjective "red" causes a loop which returns to state q6, and the subsequent noun "barn" causes a transition to state q7. Since state q7 is a final state, it is possible to "pop up" from the NP computation and continue the computation of the top level S beginning in state q3 which is at the end of the NP arc. From q3 the verb "collapse" permits a transition to the state q4, and

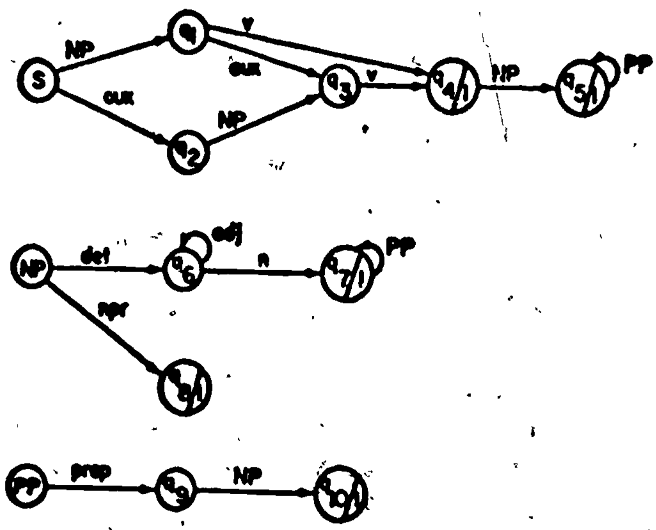

Figure 3. A sample transition network. S is the start state. g_4, g_5, g_6, g_7, g_8, and g_{10} are the final states. (From Woods, 1970)

since this state is final and "collapse" is the last word in the string, the string is accepted as a sentence [pp. 591-592]."

Most ATN parsers that have been developed to date have been top-down processors: the parser starts out looking for a sentence in the S network, and the parser wll fail if the input is not a well formed string according to the grammar. But there is nothing about the ATN formalism that is inherently top-down. In fact, Woods (1976) has recently developed an ATN parser that proceeds in bottom-up fashion from the words first identified. This is important in speech processing, where the small function words that are crucial for top-down syntactic processing are the most difficult words to identify phonetically in the speech stream. In human comprehension, we envision both a top-down process, as most ATN grammars are currently designed, and a bottom-up process proceeding outward from the first words recognized to identify noun phrases, verb phrases, prepositional phrases, etc.

At the syntactic level then, the reader's processing of the Stone Soup fable must be something like the following. From the top down the reader starts looking for a sentence. There is a high probability that a sentence starts with a noun phrase (i.e., arcs must have frequencies associated with them as in Adams' model in Figure 1), and so the reader's initial expectation may be for a noun phrase, which "A poor man" satisfies. But different words in the sentence trigger expectations in a bottom-up fashion: "a" is usually followed by an adjective or noun; "man" is likely to be the final state in a noun phrase and therefore triggers expectations for determiners, adjectives, and possessives to the left and a verb phrase to the right. Thus, the nature of syntactic constraints is different from word and letter level constraints, but they operate in the same top-down and bottom-up patterns. Furthermore, they operate in conjunction with constraints at the other levels to determine what the reader comprehends.

Knowledge and Processing at the Semantic Level

In reading the Stone Soup fable the skilled reader fills in many details that are not in the text. For example, 1) that the man came to the house because he was hungry and the maid sent him away, because she didn't want to give away her master's food, 2) that the poor man asked to dry himself by the fire because he thought the maid might let him in and he wanted to get into the house so he could get some food, 3) that the maid let him in because she felt sorry for him and did not realize his request was a ploy to get food, 4) that the man suggested making stone soup because he though the cook might be fooled into thinking that a stone could be used to make soup, and, if so, she would throw in scraps of food as she normally does in making soup, 5) that the cook agreed because she thought the man knew about a novel dish, and she did not realize he had invented the dish as a ploy to get food, 6) that the cook did not realize that the man had contributed nothing to the soup and 7) that the reason the soup tasted good was because of the ingredients the cook added. None of these motivations and causal connections are in the passage itself.

There is a large amount of the reader's world knowledge that must be invoked in order to construct such an interpretation for the Stone Soup fable. Table 1 shows what some of that information might look like in schema-theoretic terms.

Insert Table 1 about here

The process of comprehending the passage at the semantic level must be something like the following. The fact that the man is poor, triggers the notion that he does not have much money or wealth. The large house he comes to, therefore, must not be his own house. Begging is one means of obtaining food (see <u>How to obtain goods</u> in Table 1), and the fact that the man does not have money satisfies the precondition for begging. Because the reader tries to interpret actions in terms of the problem solving and trying schemata, he will bind the poor man to the person P in both schemata, and the begging of food to the action A in the trying schema that could lead to some goal G. Because no goal and no initiating event are specified in the story, the reader makes the default assumptions that the man is hungry (event E) and his goal G is to eat. It is the need to satisfy these slots in the problem

TABLE 1

Some World Knowledge Schemata Needed for Stone Soup Fable

A maid

1. A woman servant P1 who cleans and takes care of residence I for master and/or mistress P2.
2. The goal of P1 is to please P2.
3. P2 pays P1 with money and/or by providing room and board.

How to please a master

1. A person P1 can please a master P2 by working hard, by being nice to P2, and by protecting P2's property.

How to obtain goods

1. If a person P1 has money M, P1 can buy goods G from a store I or person P2 possessing G.
2. If a person P1 has no money M, P1 can borrow M or P1 can steal goods G from a store I or person P2 possessing G, or beg for G from P2, or con P2 into giving G.

How to con somebody

1. If a person P1 has a goal G1, and
2. If another person P2 has a means M and a goal G2 to prevent P1 from obtaining G1, and

TABLE 1 (continued)

3. If P1 performs an action A which P2 thinks is directed toward a different goal G3 and which leads P1 to obtain G1 without P2 giving up either M or G2,
4. Then P1 cons P2 by doing A.

How to make soup X

1. A person P1 puts potable liquid in a pan.
2. P1 adds a large quantity of food X or a base for meat stock X like soup bones or scraps.
3. P1 adds spices and other bits of food F that are available.
4. P1 cooks over low heat for a long time.

solving schema that forces these assumptions. Obviously they could be wrong; the man might be seeking food for his dog or casing the house to rob it, but the default values are assumed unless and until the reader is forced to revise them.

When the poor man is sent away with angry words, the reader similarly makes a default assumption that a resident of the house sends the poor man away, not because the poor man offended the resident but in order to preserve property (i.e. food). When the poor man comes back for permission to dry his clothes, this doesn't fit the earlier goal of wanting to eat, so the reader assumes that the poor man's goal has changed to getting dry from the storm mentioned in the first sentence. The reference to the maid in the last sentence of the first paragraph binds her to the resident that sent the poor man away originally. To fill the slots in the problem solving schema, the reader assumes that the maid's goal in letting the beggar come in is to make him happy, out of a general kindness to the poor. This is reconciled with her earlier refusal of food, because the action taken in this case does not violate the means by which she can please her master (see Table 1).

Inside, the man apparently adopts another new goal of teaching the cook how to make stone soup. The reader has no schema for making stone soup; it is news to the reader as well as the cook. But the reader, in order to understand the story, must have a schema like that in Table 1 as to how to make soup in general. One of the conditions for making soup is violated, namely that the basic ingredients be edible or meat bones or scraps. This triggers the reader to look for another goal for the poor man's actions. The fact that the cook put a lot of scraps into the soup means that she has supplied the base for the soup. This suggests that the man's original goal of getting food might be his goal in making stone soup. There is nothing in the story that says he eats the soup, but the cook says the soup tastes good, which imples that it has been made. The default value when people perform some task together is that both share the fruits ot the labor, so that the reader should assume the poor man gets to eat the soup. Therefore, the reader can make sense of this episode in terms of the man's reaching his original goal of obtaining food.

Furthermore, if the reader is clever, he will see he can reduce the number of independent goals for the poor man to one, if the man's request to dry himself by the fire is interpreted as a subgoal to getting into the house, and getting into the house is, in turn, a subgoal to getting food. This interpre ation works because an alternative to begging for goods is conning someone for goods (see Table 1). The way the con operates here is that the man has the goal to get food, which the maid wants to prevent. By asking to dry himself by the fire the man takes an action which leads to getting food, but which the maid thought was directed to getting dry. Thus, she misinterpreted his action and was conned.

A still more difficult inference is to see that the man conned the cook as well as the maid. To make this inference the reader must infer that the cook also would have refused the man food. In the case of the maid, this is revealed by her actions. In the case of the cook, it must be inferred from the fact that she too would want to please her master by preserving his property. Furthermore, the reader must infer both that the cook believed that the man's goal was to make soup from a stone, and that his real goal was to get her to give him some food. We saw how the reader could realize that the man's goal was to obtain food. The clue that the cook did not understand the man's goal is only indirect; she marvels at his having made a wonderful soup out of practically nothing, which implies she does not see that it was she who contributed all of the substantial ingredients to the soup and that he and his stone added nothing. Therefore, she too was conned by the poor man.

Thus, the skilled reader can make sense of the actions and motivations in such a story through a variety of inferences and default assumptions. This involves the use of a wide variety of world knowledge from the schema for problem solving, to the schema for maids, to the schema for how to con somebody. Different readers may misunderstand the story in many different ways depending on which of these assumptions or inferences they fail to make or which they make incorrectly.

Knowledge and Processing at the Interpretive Level

An understanding of the interrelationships between the character and events in a story typically requires a host of complex inferences. But the goal of the skilled reader goes beyond that of following the story: in addition, he seeks to interpret or impose a structure on the passage as a whole. Processing at this level requires even more abstract knowledge and more complex inferences, since it depends less on the actual content of the text than it does on the goals of the reader and his perception of the author's intentions.

If the reader knows about fables, the Stone Soup story will be much easier for him to interpret. This is because fables are constructed according to a regular formula. A fable is a short story. Its characters, which are often animals, are stereotypes (e.g., maids are subservient, rabbits are frivolous, foxes are self-serving and cunning). Fables are generally based on the theme that life requires that we be flexible: the individual who is too nearsighted is liable to suffer the consequences--his goals will be thwarted or he will be outsmarted; the individual who is adaptive and resourceful will be successful even in the face of adversity. Any particular fable is intended to convey a more specific lesson or moral within this theme. The moral is often summarized by the last line of the fable. All of this knowledge would presumably be organized in a general fable schema.

For purposes of interpreting the Stone Soup story, the reader's first task is that of recognizing that it is a fable. If this information is not explicitly given, it may be signalled in bottom-up fashion from the structure of the story or from the fact that it was authored by Aesop. Once the fable schema has been suggested, top-down processes will be initiated in the effort to satisfy its slots. Most importantly, the fable schema must (1) find either a flexible successful character or a rigid, foiled character, and (2) interpret the events leading to this character's success or failure in terms of some general lesson of conduct. If the moral were summarized in the last line, as is often the case with fables, the reader would be half way there: he would only need to relate that synopsis back to the events in the story -- the relevant characters would be brought out in the process. The moral is not summarized in the last line of the Stone Soup story, but the fable schema demands that there be one. The reader's task is therefore to use the event structure of the story to discover what the moral could be.

If the reader has made the inferences described in the previous section, then he should have constructed an event structure for the Stone Soup fable something like the following:

1. The goal of the poor man is to get some food.
2. The goal of the maid and the cook is to protect their master's goods.
3. The man's initial attempt to reach his goal is denied by the maid.
4. He devises a clever subterfuge to get part way to that goal.
5. He devises an even cleverer subterfuge to get the rest of the way to that goal.
6. The cook and the maid are conned into giving the man some food and, thus, betraying their master against their wills.

In this fable, Aesop seems to have killed two morals with one stone. While the poor man satisfies the flexible-and-successful description, the maid and the cook satisfy the rigid-and-foiled description. Moreover, both the success of the poor man and the plight of the servants can be translated into general lessons of conduct. The generality of these lessons is evidenced by the fact that they can be captured by other maxims: for the man, "Where there's a will, there's a way;" for the servants, "Beware of Greeks bearing gifts." If the reader has recognized these lessons, he has understood the story in the fullest sense.

Since schemata at the interpretive level are not compelled by the text, one can enjoy and feel like he understands a story perfectly well without them. One might be fully satisfied with the Stone Soup story without drawing out its lessons. Or one might be entertained by the story of Candy without interpreting it as a spoof on Candide. But interpretive schemata add a level of understanding that may be enlightening and is often critical. We would argue that skilled readers have a variety of specialized schemata, like the fable schema, at the interpretive level that enable them to read such things as algebra problems, mysteries, political essays, allegories, recipes, contracts, and game instructions to their most useful ends.

CONCLUSION

The analysis of the Stone Soup fable at these four different levels illustrates how reading comprehension depends as much on the reader's previously acquired knowledge as on the information provided by the text. Moreover, comprehension depends on the reader's ability to appropriately interrelate his knowledge and the textual information both within and between levels of analysis. The power of schema-theoretic models of reading lies in their capacity to support these interactions through a single, stratified knowledge structure and a few basic processing mechanisms.

Top-down and bottom-up processing are fundamental mechanisms which apply at all levels of analysis. Bottom-up processing occurs when schemata that have been identified suggest other candidate schemata at the same level or the next level up.

Examples of bottom-up processes at the four levels of analysis are:

1) Letters that have been identified suggest neighboring letters and candidate words.

2) A determiner such as "a" suggests that a noun or adjective will follow and that a noun phrase has been started.

c) Reference to "begging for food" suggests the schemata for "obtaining goods" and "trying."

d) The man's persistent, devious, and successful measures to get food suggest a candidate moral such as "Where there's a will, there's a way."

Top-down processing occurs when schemata that have been suggested try to find schemata from the same level or the next level down to fill out their descriptions. Examples of top-down processes at the four levels of analysis are:

a) A candidate word such as MAN looks for M, A, and N to fill its three slots.

b) A noun phrase looks for particular parts of speech, such as a determiner or a proper noun, to fill its initial slot.

c) The problem solving schema looks for a goal, such as eating, to account for the man begging for food.

d) The fable schema looks for a moral as the point of the story.

As top-down and bottom-up processes operate simultaneously at all different levels of analysis, they work to pull the various fragments of knowledge and information into a coherent whole.

Finally, neither the basic knowledge structure nor the processing mechanisms that have been described are supposed to be unique to a particular story or even to the reading process in general. Rather, within schema theory, the same knowledge structures and processes are supposed underlie all cognitive processes. Clearly people must have knowledge about maids, and stories, and problem-solving, and grammar like that described here. Such knowledge has many uses in addition to that of understanding text. Schema theory provides a way of integrating our understanding of text with our understanding of the world in general.

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