A MODEL OF QUESTION ANSWERING

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Abstract

This short report summarizes a new model of question answering that we have developed and tested. The model specifies how humans answer many different kinds of questions (including _why_, _how_, _when_, _where_, _enablement_, _consequence_, and _significance_ questions) after comprehending narrative passages. For example, if a narrative passage contained the episode _the dragon kidnapped the maidens_, the why-question for this episode would be _why did the dragon kidnap the maidens?_ and possible answers would be _because the dragon wanted to eat the maidens_ and _because the dragon was lonely_. According to the model, the major information sources for answers to questions include the passage structure and the generic knowledge structures that are associated with the content words in the query (i.e., DRAGON, MAIDEN, KIDNAPPING). After these knowledge structures are activated in working memory, there are convergence mechanisms which narrow down the node space to a set of relevant answers to a given question. The convergence mechanisms involve four major components. First, there is an arc search procedure, associated with each question category, which specifies what categories and paths of arcs are sampled when knowledge structures are tapped for answers. Second, there are a set of heuristics for establishing priorities among knowledge structures. Third, there is an intersecting node identifier which segregates those nodes in a given knowledge structure which overlap (match) a node in at least one other knowledge structure in working memory. Fourth, there is a constraint propagation component which prunes out erroneous nodes during the evaluation of (a) the intersecting nodes and (b) the nodes that radiate from intersecting nodes. The model has been tested by simulating question answering protocols collected from human subjects.

This paper summarizes a model which accounts for the answers that adults give to questions after they comprehend simple narrative passages. For example, suppose that the comprehender reads a passage about a dragon who kidnaps some maidens in a forest and some heroes who rescue the maidens from the dragon. (Of course, the setting and plot would be a bit more embellished.) After the passage is read, the comprehender may be asked a number of questions about the episodes in the passage. The following actions could be asked about the episode _the dragon kidnapped the maidens_):

Why did the dragon kidnap the maidens?
How did the dragon kidnap the maidens?
When did the dragon kidnap the maidens?
Where did the dragon kidnap the maidens?
What enabled the dragon to kidnap the maidens?
What are the consequences of the dragon kidnapping the maidens?
What is the significance of the dragon kidnapping the maidens?

The proposed model explains how adults answer these seven categories of questions (why, how, when, where, enablement, consequence, and significance). The model specifies the knowledge structures that are tapped for answers and the process of converging on the relevant answers to specific questions.

During the last decade, researchers in artificial intelligence have vigorously investigated the process of question answering in the context of narrative text and mundane world knowledge (Bobrow & Winograd, 1977; Dyer, 1983; Lehnert, 1978; Schank & Abelson, 1977). However, research in cognitive psychology has only recently begun to emerge (see Graesser & Black, 1985). Perhaps the most comprehensive psychological model of question answering was introduced and developed by Graesser (Graesser, 1981; Graesser & Clark, 1985; Graesser & Murachver, 1985; Graesser, Robertson, & Anderson, 1981). The present model constitutes a major extension and modification of Graesser's earlier work on question answering.

A Rich Data Base for Testing Models of Question Answering

Graesser has collected an extensive set of question answering protocols and other relevant data from adult subjects (Graesser & Clark, 1985). These data provide a testbed for evaluating alternative models of question answering. First, Graesser has has mapped out passage structures for four short narrative passages which vary in cohesiveness. The passage structures include explicit statements and knowledge-based inferences that are needed for establishing conceptual connectivity between explicit statements. The bridging inferences were extracted from subjects empirically (for details about methods, see Graesser and Clark, 1985). Second, Graesser mapped out generic knowledge structures (GKSs) associated with explicit content words in the four narrative passages and with higher-level GKSs which are triggered by patterns of information. Again, the content of each GKS was extracted empirically from human subjects (see Graesser and Clark, 1985 for details). Third, Graesser collected question answering protocols from adult subjects after they comprehended the four narrative passages. Graesser queried each statement in the passages with seven questions (why, how, when, where, enablement, consequence, and significance). Thus, there was an answer distribution for each specific question. These data (and other data which we will not discuss here) provided a rich data base for discovering question answering mechanisms and for testing models of question answering. The model proposed in this paper is grounded in a rich foundation of data collected from adults.

The knowledge embodied in each passage structure and GKS was translated into a <u>conceptual graph structure</u>. A conceptual graph structure is a set of categorized statement nodes which are interrelated by a network of categorized, directed arcs. In the representational system adopted by Graesser and Clark (1985), a statement node is a proposition-like description that is assigned to one of five categories: Event, State, Goal, Action, and Style specification. There are nine arc categories: Reason, Outcome, Initiate, Manner, Consequence, Implies, Property, Set Membership, and Referential Pointer. It is beyond the scope of this report, however, to define these node and arc categories. The important point is that the empirically extracted knowledge was structured according to a representational system developed by Graesser and Clark (1985).

When considering the four narrative passages, an average passage contained 125 statement nodes, with 25 explicit nodes and 100 inference nodes. A typical passage activated 35 GKSs. Approximately two-thirds of the GKSs associated with a passage corresponded to a content word in the text. For example, the passage statement <u>the dragon kidnapped the maidens</u> would activate three GKSs: DRAGON, KIDNAP, and MAIDEN. The other third of the GKSs were pattern-activated GKSs, that is, they were triggered by patterns of information rather than explicit words in the text (e.g., FAIRYTALE, CONFLICT, FEAR). An average GKS contained 166 statement nodes in its conceptual graph structure. Once again, the nodes in these structures had been extracted empirically from human subjects.

<u>One Problem with Graesser's Previous Models of Question Answering</u>

Graesser's previous models (Graesser & Murachver, 1985) went a long way in explaining the answers that humans produce when they answer the seven categories of questions. The models identified the major information sources for the answers to the questions. Specifically, 75-80% of the answers to questions tap nodes in either (a) the passage structure or (b) the GKSs corresponding to the content words in the query. For example, suppose that the question is <u>why did the dragon kidnap the maidens?</u> in the context of narrative passage N. The answers to this question would come from four knowledge structures: passage structure N, the GKS for DRAGON, the GKS for KIDNAP, and the GKS for MAIDEN. Graesser's previous models also identified the <u>arc search procedures</u> associated with the different question categories. An arc search procedure specifies the categories of arcs that are sampled when searching through knowledge structures for answers. For example, answers to why-Action questions sample forward Reason arcs (leading to superordinate goals) and backward Initiate arcs (corresponding to events, states, and actions that initiate goals in animate agents). The arc search procedures of other question categories are different. Graesser reported that 98% of the obtained answers to questions would be generated if the theoretical arc search procedures were applied to the relevant knowledge structures (given that the answer node can be found in these knowledge structures).

There was one major problem with Graesser's previous models of question answering. The models generated too many theoretical answers to specific questions when theoretical question answering procedures were applied to the relevant knowledge structures. For example, the model would generate 50 answers to a question (out of thousands of nodes) whereas adults would generate only 10. Thus, there was a convergence problem in the models--the models did not satisfactorily converge on a small set of answers that are relevant to the question. Our new model of question answering does a better job capturing convergence mechanisms.

The New Model of Question Answering

The new model of question answering incorporates many of the assumptions and components of Graesser's earlier models. However, the new model addresses the problem of convergence more satisfactorily. Listed below are the six major components or properties of the new model.

Working memory. During the process of answering a question, knowledge structures enter a limited capacity working memory and interact with each other. Sometimes one structure directly communicates with another knowledge structure according to a private line or party line. Alternatively, one structure may post constraints that are broadcasted to all other knowledge structures in working memory.

Activation of knowledge structures in working memory. During question answering, a given knowledge structure is activated in working memory through pattern recognition processes. Graesser and Clark (1985) specified what knowledge structures occupy working memory during passage comprehension and during question answering. We adopted these assumptions in the present model. Specifically, when a question is asked (e.g., why did the dragon kidnap the maidens?) the knowledge structures in working memory include (a) the passage structure (actually, a proximate substructure from the passage structure), (b) the GKSs corresponding to the content words in the question (i.e., DRAGON, KIDNAP, and MAIDEN), and (c) occasionally some pattern-activated GKSs (e.g., EVILNESS, FAIRYTALE).

Arc search procedure. For each question category, there is an arc search procedure which specifies the legal paths of arcs that may be pursued when the procedure is applied to a knowledge structure. We adopted the arc search procedures specified in Graesser and Clark (1985) because they proved to be satisfactory in accounting for the question answering protocols.

Priorities among knowledge structures in working memory. We adopted a set of heuristics for establishing priorities among knowledge structures in working memory. These heuristics were needed for resolving conflicts when knowledge structures interact in working memory. For example, one heuristic is that the passage structure has priority over GKSs in working memory. Another heuristic is that the GKS associated with the verb has priority over the GKSs associated with nouns in the query. It should be noted that the verbs convey action/event information that is central to the plot in narrative passages.

Intersecting nodes. Nodes that intersect (i.e., match, overlap) between/among knowledge structures have a special status in the question answering process. The analyses revealed that the intersecting nodes had a much higher likelihood of being produced as answers to questions than did the nonintersecting nodes. Moreover, nodes that were proximate to intersecting nodes were produced as answers with a higher likelihood than were distant nodes. When we inspected the knowledge structures in working memory, we found that the likelihood of producing an answer decreased exponentially as a function of the distance from the nearest intersecting node.

Constraint propagation. When knowledge structure X has priority over knowledge structure Y in working memory, constraints from X are imposed on knowledge structure Y and thereby prune out nodes in Y from consideration (as answers to the question). We identified many of the criteria for pruning out nodes in the constraint propagation mechanism. One criterion is direct contradiction. A node in structure X directly contradicts a node structure Y, so the node in Y is pruned from consideration (as well as all nodes that radiate from the pruned node, away from the nearest intersecting node). Other criteria include time frame incompatibilities, argument frame incompatibilties, and conflicts in resources when agents try to execute plans (see Wilensky, 1983).

It is important to emphasize that the assumptions of our model of question answering were discovered and/or tested by examining the rich, qualitative database that was collected in Graesser and Clark's (1985) earlier study. Moreover, parts of the model have been simulated on computer in LISP and in PROLOG.

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