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Causal Reasoning in the Construction of a Propositional Textbase

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Abstract

The goal of this research is to unify two different approaches to the study of text comprehension and recall. The first of these approaches, exemplified by the work of Trabasso and his colleagues (Trabasso & Sperry, 1985; Trabasso & van den Broek, 1985) views comprehension as a problem solving task in which the reader must discover a series of causal links that connect a text's opening to its final outcome. The second approach, typified by Kintsch and van Dijk (1978; van Dijk & Kintsch, 1983) emphasizes the importance of short-term memory as a bottleneck in the comprehension process. We combine these approaches by assuming that the most likely causal antecedent to the next sentence is always held in short-term memory. Free recall data from three texts are presented in support of this assumption.

The research reported here represents an attempt to unify two separate approaches to the study of text comprehension and recall. The first of these approaches views comprehension as a problem solving process in which the reader must discover a sequence of causal links that connect a text's opening to its final outcome (Black & Bower, 1980; Schank, 1975; Trabasso & Sperry, 1985; Trabasso & van den Broek, 1985). The second approach (Kintsch & van Dijk, 1978; Miller & Kintsch, 1980; Fletcher, 1981, 1986; van Dijk & Kintsch, 1983) emphasizes the importance of short-term memory as a bottle-neck in the comprehension process. We will show that a reader's short-term memory always contains the most likely causal antecedents of the next sentence. This allows the discovery of a "causal chain" linking a text's opening to its final outcome within the constraints imposed by a limited-capacity short-term memory.

Both of the approaches we are considering here have been used to predict which elements of a text will be recalled best. In the problem solving approach of Trabasso and his colleagues clauses are treated as the primary unit of analysis and it has been demonstrated that: (1) Clauses that lie on the causal chain that connects a text's opening to its final outcome are recalled better than otherwise comparable clauses (Black & Bower, 1980; Trabasso & van den Broek, 1985). (2) The more causal connections a clause has to the rest of the text, the better it is recalled

(Trabasso & van den Broek, 1985). These results provide clear support the conclusion that the causal structure of a text is an important determinant of how that text will be understood and remembered.

Kintsch and his colleagues (see e.g. Kintsch & van Dijk, 1978; Miller & Kintsch, 1980) have also been successful at predicting which portions of a text will be recalled best. They begin with the following assumptions: (1) The meaning of a text is represented in long-term memory as a network of semantic propositions called a textbase. (2) Texts are processed in cycles, roughly corresponding to sentences. (3) During each cycle, short-term memory can only hold the current sentence plus one to four propositions from earlier in the text. (4) Two propositions must co-occur in short-term memory to be strongly associated in long-term memory. (5) Two propositions must be referentially coherent (i.e., they must refer to the same person, object, or event) to be strongly associated in long-term memory. They then argue that each proposition from a text should be recalled with probability $1-(1-p)^{k}$ where p is the probability of recalling a proposition that remains in short-term memory for just one processing cycle and k is the number of cycles that a given proposition remains in short-term memory. A procedure called the "leading-edge strategy" is used to predict the contents of short-term memory during each processing cycle and, therefore, the value of k for each proposition. This strategy uses formal properties of the underlying textbase to determine which propositions remain in short-term memory.

Clearly, there are important differences between these two approaches. They assume different basic units of analysis (clauses vs. propositions). They assume that the components of a texts are held together by different relations (causal vs. referential). One assumes that two text elements can only be connected if they co-occur in a limited capacity short-term memory, the other assumes that all possible connections are made by the reader. Finally, different mechanisms are assumed to contribute to the recallability of a text element (causal structure vs. time in short-term memory).

We believe that each approach has captured elements of the truth. As an initial step toward a unified model, we will attempt to show: (1) That Trabasso's causal analysis works as well when propositions are taken as the fundamental unit of analysis as it does with clause units. (2) That both referential and causal connections contribute to the coherence of a text. (3) That the propositions most useful for understanding the causal structure of a text are always held in short-term memory. (4) That both the number of processing cycles that a proposition spends in short-term memory and the number of referentially and causally related propositions that co-occur with it in short-term memory influence its recallability.

The success of our approach depends critically on the assumption that readers can identify and hold in short-term memory the propositions that are the most likely causal antecedents of the next sentence they read. Yet it is obvious that Kintsch and van Dijk's (1978) leading-edge strategy does not accomplish this task. In three simple narratives that we analyzed, the leading-edge strategy only allowed 31% of the possible causal connections between propositions to be detected. Two alternative strategies that we examined offer a significant improvement over this figure. The first of these we call the current-state strategy. A reader following this strategy would select the last proposition, or conjunction of propositions, added to the causal chain to retain in short-term memory at the end of each processing cycle. This strategy allows 51% of the causal connections in a text to be detected. The other alternative strategy we wish to consider will be referred to as the current-state plus goal strategy. A reader using this strategy would always retain in short-term memory the current-state in the causal chain (as defined above) as well as the proposition, or conjunction of propositions, describing the current goal in the text. This strategy represents a significant increase in short-term memory load relative to the current-state strategy, essentially doubling the number of propositions that must be held-over from earlier in the text. But it allows 69% of the causal connections in a text to be detected and bears a marked similarity to state-space search models of human problem solving (see e.g. Newell & Simon, 1972). In what follows we will attempt to determine which of these short-term memory allocation strategies (leading-edge, current state, or current-state plus goal) most accurately describes the performance of college student readers.

Method

Subjects

Twenty-four students recruited from the subject pool at the University of Minnesota participated in the study for course credit. All subjects were native speakers of English. Subjects were run in small groups of up to eight people.

Materials

Nine texts were used in the experiment: six fillers and three targets. Each text consisted of ten sentences, and contained four goals hierarchically embedded with one superordinate goal. Test booklets were constructed that contained a page of instructions followed by the nine texts in the following sequence: two filler texts at the beginning, two filler texts randomly distributed among the three target texts, and two filler texts at the end, followed by free recall instructions for each of the five middle texts. Recall of the five texts was in the same order as presented. Each text and each recall was on a separate page.

The propositional structure for each text was derived independently by the two authors using the procedures described in Bovair and Kieras (1985). The causal connections and the propositions included in each causal unit were determined independently by the two authors according to the criteria proposed in Trabasso and Sperry (1985). Any discrepancies were resolved through discussion.

Procedure

The experiment consisted of two self-paced phases. During the first phase, all subjects were instructed to read the nine texts through once at their normal reading speed, paying close attention to the stories because later they would be asked to recall them. In the second phase, subjects were given the titles from the five middle texts on separate pages and instructed to try to write down as much as they could from each text using the exact words if possible.

Results

All recall protocols for the three target texts were scored against their corresponding propositional structures independently by the two authors. A proposition was scored as recalled if any meaning-preserving paraphrase of it was present in the recall protocol. Agreement was 95% and all discrepancies were resolved through discussion.

All analyses were conducted on the three target texts combined (i.e., analyzing for the effect of text and its interactions), as well as independently. But because the effect of text and its interactions accounted for less than one percent of the variance in each of our analyses, we will only present results for the three texts combined.

The first step in attempting to integrate the two approaches to text comprehension and recall is to assess whether or not the causal analysis of text, as proposed by Trabasso and Sperry (1985) can be applied to the proposition as the unit of analysis. Multiple regression analyses were carried out on the probability of recall of each proposition in each story, with the independent variables being whether or not a proposition was on the causal chain (Causal Chain Status), and the number of direct causal connections a proposition had with the other propositions in the story (Causal Connections Possible). Causal Chain Status was a categorical independent variable, with propositions on the causal chain receiving a score of one, and propositions not on the causal chain receiving a score of zero.

Table 1
Proportions of Variance Accounted for by Causal Chain Status and Causal Connections Possible

	R^2	
	Alone	Unique
Full Model = .1934**		
Causal Connections Possible	.1273***	.0016
Causal Chain Status	.1918***	.0661**

* $p<.05$; ** $p<.01$; *** $p<.001$

As can be seen by examination of Table 1, Causal Connections Possible alone, and Causal Chain Status alone each accounted for significant proportions of variance. In addition, Causal Chain Status uniquely accounted for a significant proportion of variance, while Causal Connections Possible failed to account for any significant unique variance. The interaction between the two factors was not significant.

The previous results demonstrate that causal analysis works using the proposition as the unit of analysis. However, these analyses were conducted under the operational assumption that the working memory is of unlimited capacity. A critical assumption of the Kintsch and van Dijk (1978) text processing model is that because of the limited capacity of short-term memory, readers process a text in a number of cycles. During each cycle, a limited number of propositions enter short-term memory and are interrelated with propositions retained from the previous cycle.

The next step in attempting to integrate the two approaches is to test the causal assumptions within the confines of a limited capacity short term memory. To accomplish this, the next set of analyses was conducted to ascertain which of the various short term memory allocation strategies described earlier provides the best fit with the recall data. First, a minimum chi-square criterion was used to find the value of p which produces the best fit between predicted and observed recall probabilities in the equation $Pr(recall) = 1-(1-p)^k$ for each combination of strategy and text. Then separate multiple regression analyses on the probability of recall were computed for each strategy, with the independent variables being the time each proposition was predicted to spend in Short-term memory (Time in STM), computed as $1-(1-p)^k$, the number of direct causal connections a proposition had with the other propositions allowed by their co-occurrence in Short-term memory (Causal Connections Allowed), and the number of referential connections a proposition had with the other propositions allowed by their co-occurrence in Short-term memory (Referential Connections Allowed). The present experiment used sentence boundaries to delimit the number of propositions entering Short-term memory in each cycle. Table 2 presents the proportions of variance accounted for by each model.

Table 2
Proportions of Variance Accounted for by the Different Short Term Memory Allocation Strategies

	R^2 Alone	R^2 Unique
Current-State: Full Model = .2521***		
Time in STM	.1976***	.0466*
Causal Connections Allowed	.2050***	.0455*
Referential Connections Allowed	.0470*	.0003
Current-State Plus Goal: Full Model = .1506***		
Time in STM	.1099***	.0090
Causal Connections Allowed	.1330***	.0400**
Referential Connections Allowed	.0211	.0105
Leading-Edge: Full Model = .1293***		
Time in STM	.0278*	.0010
Causal Connections Allowed	.1283***	.0921***
Referential Connections Allowed	.0305*	.0006

* $p<.05$; ** $p<.01$; *** $p<.001$

Table 2 shows that although all three full models account for significant amounts of variance, the Current State model accounts for the most. Within the Current State model, all three variables alone account for significant proportions of variance. However, only Time in STM and Causal Connections Allowed account for significant amounts of unique variance. It appears that within the confines of a limited capacity Short-term memory, the use of a strategy based on retaining the last items added to the causal chain provides the best fit with the data.

One result that is somewhat incongruous with previous findings has to do with the influence of referential connections. Trabasso and van den Broek (1985) found that referential connections did not account for any significant variance when compared with causal connections. However, their analyses were based on phrases as the unit of analysis, and on all of the possible connections among those phrases within an unlimited capacity working memory. The present study found referential connections to contribute a significant non-unique amount of variance within the confines of a limited capacity Short-term memory. Subsequent multiple regression analyses carried out on the probability of recall for each proposition in an unlimited capacity Short-term memory, with the number of referential connections and the number of causal connections as the independent variables, replicated the findings of Trabasso and van den Broek (1985). However, a model containing both causal and referential connections accounts for more variance in a limited capacity Short-term memory (R^2=.206), than it does in an unlimited capacity Short-term memory (R^2=.129).

These findings address the question of the manner in which the propositions become interrelated. Trabasso and his colleagues assume these connections to be solely causal. However, the present experimental results seem to suggest that both causal and referential connections are established, with the causal connections being of greater strength.

The final step in integrating these two approaches involved a direct comparison of the variables employed in the structural analyses (e.g., Causal Chain Status and Causal Connections Possible), with the variables employed in the processing analyses (e.g., Time in STM, Causal Connections Allowed, and Referential Connections Allowed).

Table 3
Proportions of Variance Accounted for by Both the Structural Analysis and the Processing Analysis Variables

	R^2 Alone	R^2 Unique
Structural Analysis Variables	.1934***	.0199
Processing Analysis Variables	.2521***	.0786***

* $p<.05$; ** $p<.01$; *** $p<.001$

Examination of Table 3 reveals that although both the structural and processing analysis variables alone account for significant amounts of variance, the processing analysis variables account for both more variance, as well as a significant amount of unique variance.

Discussion

The results of this experiment can be summarized as follows. First of all, we have shown that the causal analysis suggested by Trabasso and his colleagues (e.g. Trabasso & Sperry, 1985; Trabasso & van den Broek, 1985) can be applied at the level of individual propositions. Next, we have demonstrated that the propositions necessary for building causal chains, as identified by the current-state strategy, are held in short-term memory as a reader progresses through a text. Finally, we have shown that causally significant propositions are recalled best because: (1) they remain in short-term memory longer, and (2) they form more referential and causal links to other propositions. These findings are important because they provide a linkage between two separate, and sometimes competing, approaches to the study of text comprehension and recall.

We are currently extending this research in a number of directions. One of these involves examining of the generality of the current-state strategy. Here we are interested in two issues: (1) is the same strategy used with other genre of texts, and (2) do both good and poor readers employ this strategy? We are particularly interested in the possibility that poor readers might use a more random or idiosyncratic selection strategy. The instructional implications of such a finding are obvious. We are also developing a computer model that uses the current-state strategy to cycle through a text and construct a propositional textbase. Our goal is to combine this comprehension model with a model of retrieval from long-term memory so that we can better understand how these processes interact.

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