


# 文章理解における因果的橋渡し推論処理過程の精緻化 Elaborations for the Validation of a Causal Bridging Inference in Text Comprehension

森島 泰則 MORISHIMA, Yasunori

● 国際基督教大学  
International Christian University

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## ABSTRACT

The validation model (e.g., Singer, 1993) claims that before a causal bridging inference is accepted, it must be validated by existing knowledge. For example, to understand “Dorothy took the aspirins. Her pain went away,” one first computes a mediating idea RELIEVE [ASPIRIN, PAIN]. Then, the truth of it is validated on the basis of existing knowledge. The present study examined the hypothesis that the causal inference would be drawn and validated even when particular knowledge that validates the mediating idea is not readily available because elaborations are done to retrieve or construct such knowledge. To test this hypothesis, two experiments were conducted. The first experiment showed that people tended to judge coherence of a text based on causal relations and that causality was indeed recognized in those texts in which the antecedent sentence and the consequence sentence were not linked by familiar knowledge. The second experiment involving reading times showed that while sentence processing time was longer for such texts than texts involving familiar knowledge, there was no difference between these types of texts in reading the subsequent sentence describing the validating idea. These results provided evidence supporting for the elaboration and validation of the causal bridging inference. Computational aspects of these processes are discussed based on Kintsch’s (1998) Construction-Integration Model.

Singer (e.g., 1993) が提唱する validation model によれば, 因果的橋渡し推論が成立するためには, その推論が読み手の既有知識によって確認されなければならない。例えば, 「ドロシーはアスピリンを飲んだ。痛みがなくなった。」という文章を理解するには, RELIEVE [ASPIRIN, PAIN] のような仲介命題が想起される必要がある。そして, この命題が既有知識によって確認されるのである。一方, そのような既有知識が存在しないか, 容易に検索可能でない場合はどうか。本論文では, 必要な知識が検索あ

るいは生成されるまで精緻化作業が行われ、その結果、因果的推論が生成・確認されるという仮説を立て、2つの実験によって検証した。第1実験は、読み手は文章の整合性を因果関係によって判断する傾向があること、また、一般的な既有知識によって因果関係が確立しない文章でも因果性が認められることを確認した。第2実験では、リーディング・タイムの計測によって、因果関係が弱い文章も因果関係が導かれるが、精緻化作業のための文処理時間が、因果性の高い文章より、余分にかかることを確認した。Kintsch (e.g., 1998) の構築-統合モデルによって、この文処理過程を計算モデル的に議論する。

## 1. Introduction

Research on the nature of the mental representation of a text in recent years has focused primarily on the notion of coherence (van den Broek & Gustafson, 1999). To establish coherence of a discourse representation, comprehenders engage themselves in the processes of connecting text elements (e.g., clauses, sentences, and propositions) and integrating the information retrieved from knowledge base, or long-term memory, into the text representation created in working memory. These processes and the end products by them are called inferences. While a number of inferences have been identified by cognitive scientists in the text comprehension field (e.g., Graesser & Kreuz, 1993), it is generally agreed that causal inferences play a particularly important role in reading and are generated on-line, that is, during comprehension (e.g., Graesser, Singer, & Trabasso, 1994).

Singer and colleagues have proposed the validation model of bridging inferences (Singer, 1993; Singer & Halldorson, 1996; Singer, Halldorson, Lear, & Andrusiak, 1992). According to the model, the comprehender first computes a mediating idea that, when coupled with the cause, would account for the appearance of the outcome. Then, the truth of the validating fact is assessed on the basis of existing knowledge. To illustrate the point, consider the following example:

(1) Dorothy poured the bucket of water on the

fire. The fire went out.

To understand the sequence as a coherent text, one should detect that the first event caused the second. The validation model states that in order to establish such a causal connection, the comprehender should identify an idea such as “water extinguishes fire.”

It is claimed that the initial construction of a mediating idea is done regardless of the content (Singer, 1993). Thus, the mediating idea may or may not be consistent with general knowledge. Consider the following example:

(2) Dorothy poured the bucket of water on the fire. The fire grew hotter.

The validation model predicts that the comprehender first computes a mediating idea such as “water feeds fire.” Then when this idea is tested against general knowledge, it will be rejected, and thus the comprehender does not interpret the text causally unless she/he engages in a problem-solving type of processing and finds a causal link.

Previous research by Singer and colleagues only focused on testing validating knowledge that is supposed to be easily available common-sense knowledge such as “water extinguishes fire.” However, it is argued that this type of textual situation is not common. Rather, in more common textual situations, possible causal relations do not necessarily involve such familiar knowledge, and yet the comprehender apparently interprets many of those textual situations causally (e.g., Graesser, et al., 1994). There are at least

a couple of factors for this tendency or bias toward causal interpretation. First, we humans have a strong inclination to look for causes in the world (Gärdenfors, 2004). Second, there is a discourse factor that information that is provided linguistically is assumed to be relevant and therefore related. For example, Grice (1975) proposed his conversational maxims, according to which one makes one's information relevant to what has gone before and provides just as much information as needed to be informative.

The above observation leads to the hypothesis that because of the prevalent tendency of causal interpretations by the comprehender, when two events are explicitly mentioned in the text in a certain manner, causal coherence could be perceived even if particular validating knowledge is not readily available in long-term memory. An example of such a case is the following:

- (3) Keiko had some herb tea. Her headache went away.

This may be compared to the next example that involves familiar knowledge:

- (4) Keiko took some painkillers. Her headache went away.

The present study reports two experiments that tested the hypothesis stated above. It also addresses the question concerning the cognitive processes for establishing such an interpretation. Specifically, according to the validation model, it is hypothesized that establishing a causal relation for Sentence (3) would require more elaborations to draw a mediating idea that validates the causal bridge than Sentence (4) because the validating idea for Sentence (3), which is assumed to be something like "herb tea relieves pain," either does not exist in the comprehender's knowledge or at least is not readily available as in the validating idea needed for Sentence (4) (i.e., painkillers relieve pain).

## 2. Experiment 1

The first experiment tested the question of whether comprehenders make a causal interpretation for texts like "Keiko had some herb tea. Her headache went away."

### Method

*Participants:* A total of one hundred and eight undergraduate students at International Christian University (ICU) participated in the experiment. They were all native speakers of Japanese.

*Materials and Design:* Three types of Japanese sentence pairs were created and used for this and subsequent experiments. An example set in English translation are shown below:

1. Keiko took some painkillers. Her headache went away.
2. Keiko had some herb tea. Her headache went away.
3. Keiko had some water. Her headache went away.

The first kind of text is called the *causal condition* because, in the above example, painkillers are generally known to release pain.

The second type of text is referred to as the *test condition*. Unlike the causal condition, herb tea is not known as having pain-relieving effects. However, it is plausible to assume that comprehenders have the knowledge that herbal tea has some medicinal effect. This knowledge is presumably more abstract, but a causal bridge may be supported after some elaborative inferences such as the medicinal effect could include pain relief.

The third type is called the *non-causal condition*, as water is not generally known to release pain. It is assumed that this type of sentence pair does not have a causal coherence in that there is no existing general knowledge that can validate the causal relation between the antecedent (i.e., drinking

water) and the consequence (i.e., pain going away).

A total of forty sets of the experimental texts like the above example were created. Three versions of the test booklet were then created in the following fashion. The text sets were randomly ordered once and all test package versions had the same text order. In Version A, the first 13 texts were the causal condition texts, the next 13 texts the test condition texts, and the last 14 the non-causal condition texts. In Version B, the first 13 texts were the test condition texts, the next 13 the non-causal texts, and the last 14 the causal condition texts. In Version C, the first 13 were the non-causal condition texts, the next 13 the causal condition texts, and the last 14 the test condition texts.

*Procedure:* Each participant was tested individually and was randomly assigned to one of the text booklet versions (A, B, or C). The participant was given the booklet. They were instructed to evaluate each experimental text, using a ten-point scale with 1 being “strong disagree” and 10 being “strongly agree,” either in terms of naturalness of sentence connectedness (the *coherence condition*) or in terms of causal relation between the sentences of the text (the *causality condition*). The assignment of these conditions was random. There was no time limit to complete the task.

## Results and Discussion

The data from all the participants were used for analyses. For each participant, the mean rating score for each condition was calculated. The mean rating scores and standard deviations for the three conditions by evaluation method are shown in Table 1.

Table 1. Mean Rating Scores and Standard Deviations from Experiment 1.

Conditio	Evaluation	
	Coherence	Causality
Causal	8.71 (.89) <sup>a</sup>	8.60 (.99)
Test	6.03 (1.16)	5.69 (1.43)
Non-Causal	3.16 (1.14)	2.85 (1.40)

<sup>a</sup> standard deviation

An a nalysis of variance with participants as a random factor was performed on the data. For coherence evaluation, the main effect of booklet version turned out to be significant [ $F(2, 51) = 6.94, p < .003$ ]. Similarly, for causality evaluation, the main effect of booklet version was found to be significant [ $F(2, 51) = 5.40, p < .008$ ]. However, since test booklet version was the between-participant variable that did not have theoretical importance, the rating data were collapsed across the versions for the subsequent analyses.

The rating scores in general showed similar patterns between the coherence evaluation and the causality evaluation. Indeed, collapsing across the text types, there was no significant difference in rating between these evaluation methods [ $F(1, 106) = 1.95, n.s.$ ]. This seems to suggest that the participants did coherence judgments based on the degree of causal relation between the sentences.

From these results, it seems reasonable to assert that at least some, yet significant, degree of causal relation was recognized for the texts in the test condition. Based on these results, it is argued that comprehenders draw a causal bridging inference not only when the validating knowledge is readily available but also when it is less common. Then, it makes sense to ask the question of whether the validation of the causal bridge is indeed executed. The next experiment examined this question.

### 3. Experiment 2

This experiment examined firstly the hypothesis that it would take a longer time to bridge the sentences for the test condition than for the causal condition because in the former condition, for instance, the knowledge that herbal tea relieves pain is not readily available and thus requires more time-consuming elaborative processing to validate the causal connection. The experiment also examined the hypothesis that once the causal connection has been validated, the mediating idea (“herbal tea relieves pain”) is encoded. The experiment measured reading times of sentences that reflected the processing times of the sentences.

#### Method

*Participants:* Thirty native speakers of Japanese in the ICU community participated in the experiment.

*Materials and Design:* A total of eighteen Japanese text sets were chosen from the materials for Experiment 1. As in Experiment 1, there were three text conditions (i.e., Causal, Test, and Non-causal). For each two-sentence text in the set from Experiment 1, a third sentence was added. The third sentence stated the mediating idea for connecting the first and the second sentences causally. The following example illustrates the text set for Experiment 2 in English translation:

1. Takeshi drank coffee. He was not able to sleep at night. The coffee had an effect.
2. Takeshi drank cocoa. He was not able to sleep at night. The cocoa had an effect.
3. Takeshi drank milk. He was not able to sleep at night. The milk had an effect.

In addition to the experimental texts, eighteen filler texts which had different sentence relations from the experimental texts were created as shown below in English translation:

4. Emi fell from the staircase. She was injured badly. She was sent to the hospital by an ambulance.

*Procedure:* Experiment 2 was conducted on the Macintosh iBook computer with a 12-inch screen. The experiment employed self-paced reading. In each trial, the participant read a text sentence by sentence presented on the computer screen. She pressed a designated key to indicate that she had finished reading a sentence. When the participant finished reading the sentence, it was immediately replaced by the next one on the screen. Five hundred milliseconds (500 ms) after reading the third sentence, there was a Yes/No comprehension question to which the participant responded as quickly and accurately as possible by pressing a designated key. After the comprehension question, there was a 1500-ms interval before the next trials. The participant repeated this task until she completed all the experimental texts. There was a practice session with four trials prior to the test session. The whole experiment took approximately 15 minutes. The reading time for each sentence and accuracy for the comprehension question were measured.

#### Results and Discussion

To examine the participant’s comprehension performance in the experiment, the mean accuracy score of the comprehension questions was calculated by counting the number of correct responses from each participant. The value was 32.13 (SD = 2.16) out of 36 questions. There was no participant who demonstrated a remarkably low comprehension performance, and thus all participants were included in the subsequent analyses.

For each participant, the mean reading times for the three sentences were calculated for each condition. Note that the sentence lengths of the first sentence and the third sentence differed

depending on the condition while the second sentence was identical across conditions. Therefore, to control for sentence length of the first and third sentences, the mean reading time was divided by the number of characters in the sentence. Table 2 shows the mean reading times for the three conditions.

Analyses of variance with participants and items as random factors were performed on the data. All analyses were based on the mean reading time for each participant or for item under each condition. The  $F$  values by the participant analysis and the item analysis were reported here as  $F_p$  and  $F_i$  respectively.

For the first sentence (antecedent sentence), there was no significant difference in mean reading time per character across conditions by either analysis [ $F_p < .6$ ;  $F_i < .6$ ]. This pattern of results was expected since the first sentence did not have any prior context into which the information from the sentence integrated, and thus there was no reason to expect differing processing. This result also provides support for the reliability of the experiment, suggesting that there was no unexpected bias to yield differing reading times across conditions.

For the second sentence (consequence sentence), the main effect of sentence relation on reading time was significant by both analyses [ $F_p(2, 28) = 9.78, p < .001$ ;  $F_i(2, 16) = 5.48, p < .02$ ]. More specifically, the mean reading time was faster for the causal condition than for the test condition by approximately 140 msec. This difference was

significant by participant analysis [ $F_p(1, 29) = 4.25, p < .05$ ], and marginally significant by item analysis [ $F_i(1, 17) = 3.39, .05 < p < .09$ ]. The reading time was faster for the test condition than the non-causal condition by approximately 160 msec. This difference was significant by participant analysis [ $F_p(1, 29) = 5.63, p < .03$ ] and marginally significant by item analysis [ $F_i(1, 17) = 4.33, .05 < p < .06$ ]. These results appear to suggest that there is a tendency that more time is required to process the consequence sentence under the test condition than the causal condition.

For the third sentence (mediating idea sentence), the main effect of sentence relation on reading time per character was found to be significant by participant analysis [ $F_p(2, 28) = 5.75, p < .01$ ] and marginally significant by item analysis [ $F_i(2, 16) = 2.52, .05 < p < .07$ ]. More specifically, there was no significant difference between the causal and test conditions by either analysis [ $F_p < .7$ ;  $F_i < .1$ ]. However, the non-causal condition yielded a significantly longer reading time than the causal condition by both analyses [ $F_p(1, 29) = 10.11, p < .004$ ;  $F_i(1, 17) = 6.78, p < .02$ ]. Likewise, the reading time per character for the non-causal condition was significantly longer than that of the test condition by both analyses [ $F_p(1, 29) = 6.17, p < .02$ ;  $F_i(1, 17) = 4.71, p < .05$ ]. The results suggested firstly that the processing of the third sentence was performed in a similar way for the causal and test conditions and secondly that the processing was faster than the processing performed for the non-causal condition. Previous

Table 2. Mean Reading Times and Standard Deviations from Experiment 2 (in msec.).

Condition	Sentence 1	Sentence 2	Sentence 3
Causal	149.5 <sup>a</sup> (53.3) <sup>b</sup>	1329.1 <sup>c</sup> (364.2)	123.2 <sup>a</sup> (38.6)
Test	150.9 (47.6)	1469.7 (475.0)	130.6 (56.3)
Non-Causal	145.9 (43.9)	1633.7 (466.8)	160.9 (68.8)

<sup>a</sup> mean reading time per character; <sup>b</sup> standard deviation; <sup>c</sup> sentence reading time

research in the literature has established that with causal texts a causal bridge has been validated and the validating knowledge has been encoded in the text representation in memory upon reading the consequence sentence. The results of the current experiment are consistent with those in the literature. Then, it follows that for the test condition too the causal bridge has been validated and the validating knowledge has been encoded in the text representation by the time of reading the third sentence since the third sentence is an explicit mention of the validating knowledge.

In light of this, it is therefore plausible to interpret the longer reading time of the consequence sentence (second sentence) in the test condition to reflect the time needed to perform more elaborations to make a causal bridge and integrate the current sentence into the text representation.

#### **4. General Discussion and Conclusion**

The present experiments presented further evidence for the validation model of bridging inferences. The experimental results were consistent with the finding from the previous studies (Singer, 1993; Singer & Halldorson, 1996; Singer, et al., 1992). Namely, when the mediating idea for a causal bridging inference was to be validated by general knowledge that was readily available (e.g., water extinguishes fire), the processing time needed to integrate the second sentence was faster than when it was not. More importantly, the data showed that the bridging inference appeared to be validated not only in the situation that involved familiar knowledge such as “painkillers relieves pain” was readily available but also in the situation that involved the validating knowledge that were considered to be more abstract and indirectly related to the causal inference such as “herbal tea has some medicinal

effects.” Thus, the present study has successfully shown that the principle of validation of a causal bridging inference can be generalized to a wider range of texts.

The current study has demonstrated not only the validation of a causal bridging inference but also the elaborations involved in it. On the one hand, when the mediating idea that validates a causal bridge is familiar common-sense knowledge, the elaboration may be minimal, and the comprehender can integrate the sentence quickly into the preceding context. On the other hand, when the mediating idea is not easily available, the comprehender performs more elaborations to bring a relevant idea into the text representation. In both cases, when the inference is made, the mediating idea is encoded in the text representation in memory.

One question that arises here is how prevalent this tendency to establish causal or explanatory coherence is. One extreme position would be the claim that the comprehender makes causal or explanatory reading on any two events explicitly mentioned in a text. According to this position, for example, “Susan poured water on the campfire. The fire grew hotter.” would be interpreted causally as something like “The campfire grew hotter because Susan poured water on it.” Obviously, this kind of interpretation would not be made unless an extraordinary story is thought of. Indeed, the data from previous and current studies do not support the conjecture that such an interpretation would be made. The texts in the non-causal condition from Experiment 1, in which the text provided the information that would lead to the mediating idea that does not correspond to any existing knowledge (e.g., water relieves pain), had quite low ratings. In Experiment 2, the non-causal condition showed longer reading times for both the consequence and mediating idea sentences, indicating the difficulty of integrating the

information into the text representation. Therefore, causal bridging inferences are constrained by the availability of relevant knowledge that validates a bridge. This leads to the question of what determines the availability of relevant knowledge. In other words, how can certain knowledge be brought into working memory for validation?

In the case of familiar common-sense knowledge, it is assumed that such knowledge resides in long-term memory and it is the retrieval process that makes access to relevant knowledge. An example of this type is the painkiller text shown above. How about the herb tea text then? It is not generally considered that herb tea is known to have a pain-relieving effect or that cocoa is known to have an awakening effect. In these cases, the search-and-retrieval process cannot make the relevant validating knowledge available. The process that is required is the construction of new information for a particular textual situation, which presumably takes place after the search process.

To illustrate the plausibility of these processes, a computational model based on Construction-Integration (CI) Model (e.g., Kintsch, 1998) is proposed here. According to the model, text comprehension proceeds in two processing phases. The first one is the construction phase in which a text representation as a network of propositional nodes is constructed by weak rules, as opposed to strong, smart rules. The resulting representation contains associations and inferences that are irrelevant to a given context as well as relevant ones. In the subsequent integration phase, activation spreads through the network via the links among the nodes until it stabilizes. The effect of the integration process is that irrelevant associations and inferences are filtered out as they do not receive activation and their activation decays. The representation that emerges out of this process is a coherent situation model (e.g., Kintsch, 1998; Zwaan, 1999; Zwaan & Radvansky, 1998).

Morishima (2003) extended the standard CI Model by proposing an incremental construction-integration mechanism. According to this modified model, the process of construction-integration may take place repeatedly as long as one or more nodes in the network are activated beyond a pre-set threshold level. As long as there are such high-activation nodes, some knowledge keeps being retrieved. The activation level threshold can be considered to be a parameter that manipulates the level of processing. It is set to be a default (high) value, it would simulate the comprehension process with no particular motivation or goal. If the threshold is lowered, more nodes can potentially act as retrieval cues. Then, this situation corresponds to more elaborative processing.

Consider the earlier example repeated here:

- (5) Keiko had taken some painkillers. Her pain went away.
- (6) Keiko had had a cup of herbal tea. Her pain went away.
- (7) Keiko had had a glass of water. Her pain went away.

The construction of a mediating idea is assumed to be done during the construction phase by applying a rule such as “IF P THEN Q” or “CAUSE [P, Q].” This is a weak rule in that, as mentioned earlier, it applies to a text regardless of its content. The model would construct the mediating ideas for Examples (5), (6), and (7) respectively as follows:

- a) CAUSE [PAINKILLER, PAIN-RELIEF]
- b) CAUSE [HERB-TEA, PAIN-RELIEF]
- c) CAUSE [WATER, PAIN-RELIEF]

In each case, memory search would be done with the corresponding proposition and its elements as retrieval cues. The key retrieval process would work, among other things, as follows:

- a) PAINKILLER would retrieve a semantic association, RELIEVE [PAINKILLER, PAIN] as well as other associations. Since



it is semantically equivalent with CAUSE [PAINKILLER, PAIN-RELIEF], they would be linked.

- b) HERB-TEA retrieves a semantic association, HAS [HERB-TEA, MEDICINAL-EFFECT] as well as other associations, which would be linked to the HERB-TEA node.
- c) WATER may retrieve associations such as ISA [WATER, LIQUID], FREEZE [WATER, 0-DEGREE], etc., which would be linked to the WATER node.

The propositional network thus constructed goes through the integration phase. In each case, since the CAUSE node is not yet validated, its initial activation is 0. The retrieved nodes are assumed to have some level of activation. When activation spreads through the representation, in the causal condition a) the CAUSE node is more strongly activated than the other conditions due to the link shown above. This pattern of behavior of the model can be regarded as the simulation of the causal condition, i.e., a faster reading time of the consequence sentence. This also means that the CAUSE node has now been integrated into the text representation. When the third sentence (mediating idea) is input, this node can be activated strongly, hence simulating a fast reading time of the sentence.

In the next cycle of processing, in Case b) MEDICINAL-EFFECT may retrieve PAIN-RELIEF and some other instantiations of medicinal effects: HAS [HERB-TEA, MEDICINAL-EFFECT] retrieves INSTANCE [MEDICINAL-EFFECT, PAIN-RELIEF]. From these propositions would be converted to HAS [HERB-TEA, INSTANCE [MEDICINAL-EFFECT, PAIN-RELIEF]], a new proposition RELIEVE [HERB-TEA, PAIN] is assumed to be constructed. Just as in Case a), RELIEVE [HERB-TEA, PAIN] and CAUSE [HERB-TEA, PAIN-RELIEF] are equivalent, and thus they are linked. When

activation spreads in the integration phase, the CAUSE node is strongly activated. This situation corresponds to the test condition. That is, it takes longer to process the second consequence sentence since it involves more processing cycles. However, the causal inference bridge has been made and integrated in the network. Just as in the causal condition, when the third sentence (mediating idea) is input, this node can be activated strongly, hence simulating a fast reading time of the sentence.

Finally, in Case c), assuming that there is no knowledge that WATER is related to PAIN-RELIEF in long-term memory, no knowledge may be linked to the CAUSE node, and thus it would not be activated. This simulates the condition for non-causal condition.

The brief simulation walkthroughs above illustrate the ways in which elaboration and validation of bridging inferences are performed based on the construction-integration framework. An examination of these processes raises new questions about the on-line bridging process. Of particular interest is in Case b), which simulates the ambiguous text like (6). In the simulation, it is assumed that through the chain of inferences, a new proposition, RELIEVE [HERB-TEA, PAIN] will be constructed. What is the nature of such a construction? The original Construction-Integration Model does not specify principles of construction production rules. On the empirical side, the simulation processes described above have not been experimentally investigated.

Another issue is that not all texts used in the experiment have this kind of word association structure (i.e., herb tea - medicine: pain relief) though there are a few other examples that can easily assume associations (e.g., cocoa - coffee: awakening effect). To have a better understanding, details of the elaboration processes have to be further worked out for other types of texts.

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## Notes

1. International Christian University