Interactive Causal Schematics for Qualitative Scientific Explanations

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Abstract. We present a simple model for describing causal processes. We apply it to generate schematics of complex scientific processes. Our interface allows users to select among causal threads and then to follow the state transitions of those explanations. Moreover, these schematics can provide a framework for interacting with texts.

1 MODELING EVENTS AND CAUSATION

Here, we extend our ongoing investigation on helping people to understand the relationship of events using timelines [1–3]. We turn from focusing on chronological order to showing causal relationships among the events in the timelines. There is evidence that much human reasoning about physical processes is qualitative (e.g., [6, 9]). Thus, we have developed a qualitative model for describing causal relationships. Specifically, events are described as simple state transitions, causes are the factors which make state changes, Fig. 1, and a state change is a change in one or more attributes.

For instance, a change in the mayor of a town (a state change) could be caused by an election. The entity "Mayor" is changed from one person to another. Or, if we said that "Jill gave the book to John", the "possessed-by" attribute of the book has been changed from Jill to John and that was caused by Jill's action. Furthermore, we can chain events together. If we said that Jane took the book from Tim and gave it to John, there would be three states for the book (possession by Tim, by Jill, and by John).

We use this model to describe the contents of a science text and build a browser to explore the network of events and causes described in the text. Thus, we show the network of causal links as a type of interactive hypertext map; we call it an interactive causal schematic.

Such a system should be useful for a student trying to understand the associated text. It will be a interactive cognitive organizer which extends Franks and Bransford's original notion of cognitive organizers [7].

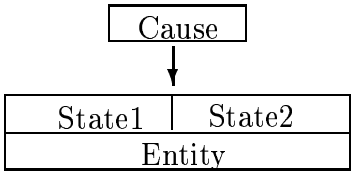

Fig. 1. A cause creates a change of state in an entity.

2 IMPLEMENTATION

2.1 Overview

We analyzed texts about the relatively complex scientific processes of the "Snowball Earth" theory as described in [8]. This theory proposes that the earth froze over and the freeze finally ended with the accumulation of greenhouse gasses. We also developed a much simpler causal schematic to describe the failure of the immune system in AIDS. We developed a Java applet for displaying the causal schematics developed from these analyses.

2.2 Interactive Causal Schematics

We initially tried to develop rigid timeline-like grids in which each event was a discrete point or interval. However, that model rapidly became overly tangled as more events and links were introduced. Therefore, we adopted a model with fragments of timelines that illustrates state changes qualitatively (Fig. 2).

In this view, time moves left to right. These interval markers are relative and not exact values since the article does not provide exact values and they may not even be knowable.

The links between states are presented one at a time as the user follows the explanation. For instance, the description shown in the figure starts with a causal link from the frozen-ocean-water state to the reduction in the absorption of CO_2. The theory is complex involving the impact of that freeze on ocean sediments and on evolution. We identified three argument threads in the theory: Atmospheric CO_2, Mineral Deposits, and Biological Abundance. The Atmospheric CO_2 cycle (illustrated in the figure) restores the earth to its thawed state and it is the primary scientific hypothesis being presented. The other threads suggest processes that are confirmed by other evidence and contribute to the richness and believability of the entire model.

The user can view all the threads or select among them. For Ocean Water Temperature within the Atmospheric CO_2 thread (Fig. 2) there was a transition from Frozen to Thawed. That is, there was a state transition. That transition can be decomposed and explained by a sequence of other transitions as shown in the figure.

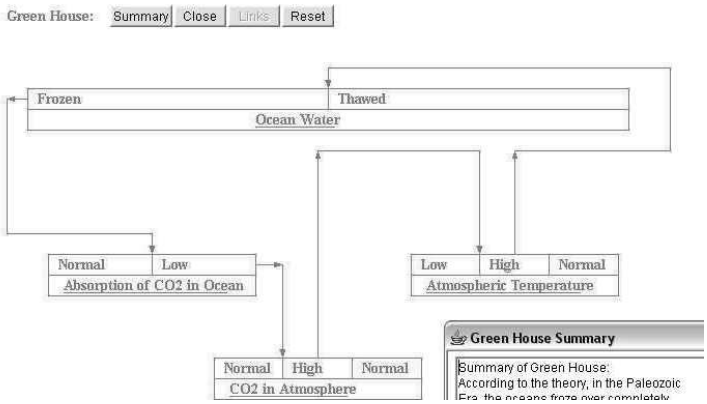

Fig. 2. One thread of the Snowball Earth explanation is shown which describes the subsystem of atmospheric CO_2 and temperature by which the theory claims the frozen earth was thawed. The user follows the steps by clicking the "Links" buttons at the top of the screen.

2.3 Associating the Text with the Schematics

The causal schematics should be both informative in themselves and an interactive cognitive organizer to help users to understand and navigate the texts from which they are drawn (Fig. 3). Cognitive organizers, such as a descriptive a schematic, or a concept map, can facilitate understanding complex material such as a text [7]. A cognitive organizer helps a reader either instantiate a previously existing conceptual cognitive schema or develop an entirely new cognitive schema. Cognitive organizers are generally static, but interactive cognitive organizers have the potential to be better focused on the user's interests and needs. For example, an interactive table of contents is both a navigation aid and a cognitive organizer. Beyond simply illustrating the process, like SuperBook [5], the interface would point back into the text of the document. Thus, when the links are shown in the graphic, the corresponding section of text is displayed and highlighted.

3 CONCLUSIONS AND FUTURE WORK

We have extended the basic model of causation in Fig. 1 into cascaded sets of causes and states to provide visualization of scientific explanations. The current implementation is a prototype to which several features should be added; for instance, there should be an automatic layout manager.

While the simplicity of this model is a virtue, the interface could be enhanced by extending it with multimedia and even animation. Moreover, there could be a smooth transition from these schematic interfaces to ones which provide more detailed temporal order.

It would also be helpful for the interface to include conditionals, non-causal relationships and the many different senses of "causality" [11]. For instance,

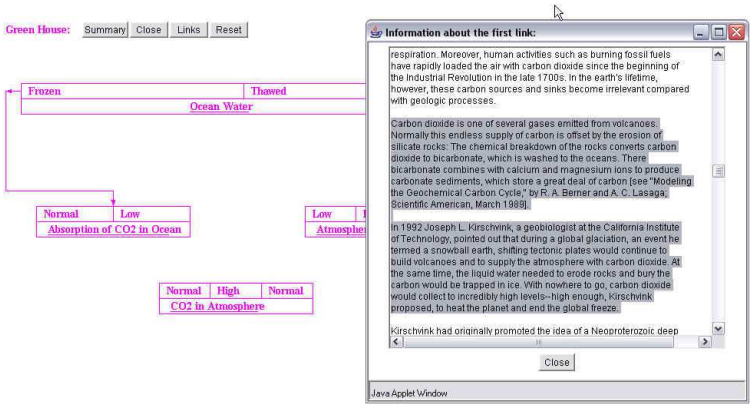

Fig. 3. Highlighting the text corresponding to the schematic display. The text in the widget on the right scrolls to the passage associated with the causal link.

much of the article on the Snowball Earth hypothesis [8] discusses alternative hypotheses and the collection of evidence relevant to them. Similarly, a full browser for discourse structure (e.g., [10, 12]) would be useful. For example, recent research has modified the theory to describe the earth as more "slushball" than snowball and the debate could be captured by such a browser. It would be helpful to have a mechanism for replicating a process across several instances. For instance, the Snowball Earth freeze was postulated to have occurred four times. This mechanism might be generalized by introducing some processes (e.g., chemical reactions) as templates or macros that apply to a large number of specific instances.

Earlier we developed a browser for the plots of narratives [4] (Fig. 4). Plots often describe how a goal is reached or a problem is resolved by following a causal chain. However, narratives are more complex than many scientific processes because they may involve human personality and emotional reactions. In comparison to narratives that are based on complex human motivation, explanations of physical processes such as geologic history can generally be reduced to objective processes. In the present work, this reduction in complexity was used to advantage to simplify the interface options. We intend to revisit the representation of human agency with the current model. We are working to apply these approaches to much more complex material such as describing historical events in the context of browsing collections such as digitized historical newspapers (e.g., [3]).

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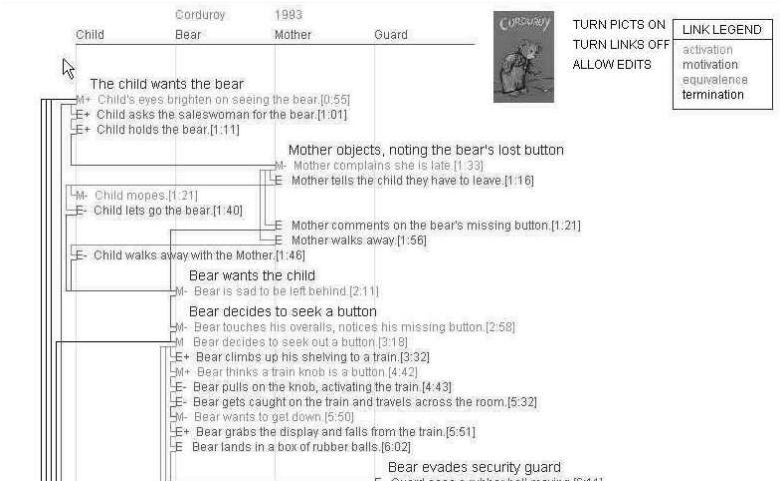

Fig. 4. A Java interface showing a narrative path through a children's story (from [4]).

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