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# Sequencing Explanations to Enhance Communicative Functionality

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## Abstract

The extent to which the segments of an explanation succeed in carrying out their intended function depends in part on ordering. A critical aspect of understanding an explanation is to integrate the concepts and propositions in the explanation with existing knowledge. Ordering should attempt to facilitate this integration and otherwise enhance the communicative functionality of the segments of an explanation. This paper presents a collection of ordering strategies that translate functional relationships between segments of an explanation into ordering constraints between those segments. The material presented here is one component of a functional analysis of explanation that has been applied to the design and implementation of a computer-based question answering system.

## Introduction

The author's research is concerned with explanation as a communicative activity, focusing most recently on question-answering dialogues. Explainers do more than just provide requested information. Explainers also try to facilitate the questioner's understanding, acceptance, and retention of the informative content. They do so by

- basing explanations on domain models that provide new and relevant knowledge while remaining comprehensible to the questioner,
- supplementing explanations with material not directly requested by the questioner, and
- sequencing utterances in a manner that helps

the questioner understand their meaning and significance.

The present paper addresses the third item by identifying a number of strategies for the coherent ordering of an explanation. This analysis is one component of a multifaceted study of explanation which includes an analysis of how the content and organization of explanations function to achieve communicative goals under potentially conflicting constraints, the design of a planner for generation of explanations by computer, and an implementation of this planner as a multimedia question answering system (Suthers 1993a; Suthers, Cornell, & Woolf 1992).

## Coherent Sequential Structure

Superficially, the sequential structure of an explanation is simply the order in which its segments are positioned in a sequential medium. This might be a temporal ordering, as in speech, or a spatial one, as in text. However, it may be the case that only part of the ordering is non-arbitrary. In a theoretical analysis, it is useful to think of the sequential structure of an explanation as a *partial* ordering that has specific justifications. This paper provides these justifications by identifying the functional significance of ordering decisions. The ordering strategies are based on three observations about the sequential structure of a coherent explanation:

1. **Sequential Structure is Derived from Other Structure.** A *nonarbitrary* ordering of the segments of an explanation is only possible when there are relationships between the segments that have implications for ordering. Otherwise there would be no basis for the choice. Thus a theory of sequential structure is necessarily a theory of how other relationships between segments are exploited to constrain ordering. Whether performing an anal-

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ysis of explanations or designing a computer system for automated generation of explanations, it is helpful to explicitly represent the relationships that have implications for ordering.

**2. Sequential Structure Enhances Functionality.** An explanation that is ordered inconsistently with intended functionality will be less coherent. The relationships between segments that are central to the communicative functionality of those segments are prime candidates for constraining ordering. These include various kinds of informative, supplemental, and propositional relationships. Space constraints necessitate leaving taxonomies and definitions of these relationships to Suthers (1993a). In this paper, we will assume that these relationships are available (i.e., are identified and made explicit by other analytic or generative activities). We must next identify *how* (in which direction) each relation constrains the ordering.

**3. Sequential Structure Follows Integrative Gradients.** The explainer's task in producing a sequence of utterances is to facilitate the questioner's acquisition of new knowledge on the basis of his or her existing knowledge. People cannot be expected to comprehend arbitrary information at any given time. Understanding requires compatible experiences and connections with existing concepts. The functionality of an explanation is enhanced if its segments are sequenced to *exploit the "integrative gradients" along which new knowledge can be constructed*, in particular via its connections to existing knowledge.

### Three Ordering Relations

Previous work has generally used a single ordering relation, for example the "satisfaction-precedence" relation of Grosz & Sidner (1986). We distinguish two aspects of sequential structure: precedence and juxtaposition. **Precedence** indicates that one segment should occur *before* another segment. Precedence is significant when prior communication of the contents of one segment facilitate the intended functionality of the contents of another segment. For example, definitions of terms usually precede their use. **Juxtaposition** indicates that one segment should occur *next to* another segment in the sequential realization of the explana-

tion. Juxtaposition is significant when the contents of both segments must be in focus of attention at the same time in order for the segments to fulfill their intended communicative function. For example, statements of similarity and difference are usually juxtaposed when making a comparison so that the relative significance of the similarities and differences can be weighed. Any constraint on sequential structure must involve precedence or juxtaposition. We use **Contiguity** to indicate the presence of both constraints (i.e., that one segment should occur *immediately before and next to* another segment).

Sequential constraints can be expressed at three granularities. **Inter-segmental** constraints, placed between rhetorical and communicative acts (Suthers 1993a) or intentions to perform those acts, specify the sequencing of *groups of clauses* (e.g., compound sentences and paragraphs) relative to each other. **Inter-propositional** constraints, placed between propositions, specify the sequencing of *individual clauses* in surface text expressing the propositions. Finally, **intra-propositional** constraints, placed between roles of a proposition, controls *voice*, that is, which role filler is expressed as the subject of a clause. Juxtaposition constraints between role fillers discourage the insertion of a subordinate clause between the realization of the role fillers.

### Notation for Ordering Strategies

In Table 1 a number of ordering strategies are expressed in the form of rules for translating other kinds of relationships into ordering relations. The general form of the rules is:

If  $S_1$  bears relation  $R$  to  $S_2$  then  $S_1 \xrightarrow{ord} S_2$

where  $S_1$  and  $S_2$  are segments and  $S_1 \xrightarrow{ord} S_2$  is one of the following:

$S_1 \xrightarrow{prec} S_2$  for precedence ( $S_1$  occurs sometime before  $S_2$ ),

$S_1 \xleftrightarrow{juxt} S_2$  for juxtaposition ( $S_1$  and  $S_2$  are next to each other in either order), and

$S_1 \xrightarrow{cont} S_2$  for contiguity ( $S_1$  and  $S_2$  are juxtaposed and  $S_1$  precedes  $S_2$ ).

Propositions are denoted by  $(P r_1 r_2 \dots)$  where  $P$  is a predicate and the  $r_i$  are role fillers. The notation for intra-propositional ordering is

$(P r_1 \xrightarrow{ord} r_2 \dots)$

meaning that the filler of  $r_1$  is to be expressed as the subject in a clausal realization of the proposition.

<sup>2</sup>Previously called "epistemological gradients," the phrase "integrative gradients" is used for terminological consistency with Lester & Porter (1991), who have a similar notion of "integrative explanation."

Three predicates are needed to express some of the ordering strategies:

**Familiar-p(c)** when a (possibly fallible) oracle indicates that concept *c* is familiar to the questioner.

**In-Focus-p(P)** when *P* is a proposition at the end of a chain of ordered propositions:  $P_1 \xrightarrow{ord} \dots P_n \xrightarrow{ord} P$ .

**Topic-p(t)** when *t* is a topic of a rhetorical act scoping over the propositions to be ordered.

It should be noted that the ordering strategies do not install “hard” constraints on sequential structure. The strategies can conflict, in which case the choice between them is a stylistic matter. Selected strategies, identified by number in Table 1, are discussed below. See Suthers (1993a) for further discussion.

### Constraints from Supplemental Structure

Supplemental material facilitates the understanding or acceptance of other segments of an explanation in specific ways, the success of which is often affected by order of presentation. Because of this, one or more ordering strategies are associated with each supplemental relation<sup>3</sup> (Table 1). Some relations give rise to an unambiguous ordering, and thus have only one rule in the table. The ordering implications of others are complicated by possible differences in tutorial strategy and individual differences in learning style. This is where the advantage of separating ordering decisions from supplemental relationships lies: we can model stylistic differences with different sets of ordering strategies that can be changed independently of the supplemental strategy.

**Ordering Background (Rule 2).** Background material is usually a prerequisite to the foreground, since the function of background is to enable the *comprehension* of the foreground. One would make an exception to the  $B \xrightarrow{prec} F$  constraint only if another ordering constraint had priority. Contiguity is not necessary as long as the temporal distance between background and foreground is small enough that the background will not have been forgotten when the foreground is encountered. This will be the case in the short, interactive explanations of the kind examined by this research.

<sup>3</sup>Supplemental relations are a subset of “rhetorical” relations (McKeown 1982; Mann & Thompson 1986).

Table 1: Rules for Ordering Strategies

<i>Constraints from Supplemental Structure</i>	
1	If <i>A</i> is an <i>antithesis</i> of <i>T</i> then $T \xrightarrow{ust} A$ .
2	If <i>B</i> is <i>background</i> for <i>F</i> then $B \xrightarrow{prec} F$ .
3	If <i>E</i> is an <i>enrichment</i> of <i>S</i> then $S \xrightarrow{cont} E$ .
4	If <i>E</i> provides <i>evidence</i> for assertions in <i>H</i>
a	then $E \xrightarrow{cont} H$ .
b	or $H \xrightarrow{cont} E$ ( <i>stylistic choice</i> ).
5	If <i>E</i> provides an <i>exemplification</i> for <i>G</i>
a	then $G \xrightarrow{cont} E$
b	or $E \xrightarrow{prec} G$ ( <i>stylistic choice</i> ).
6	If <i>M</i> provides a <i>motivation</i> for <i>S</i> then $S \xrightarrow{cont} M$ .
7	If <i>P</i> provides a <i>preview</i> of <i>B</i> then $P \xrightarrow{cont} B$ .
8	If <i>S</i> is a <i>summary</i> of <i>B</i> then $B \xrightarrow{prec} S$ .
<i>Constraint from Questioner's Familiarity</i>	
9	If $(P \dots f \dots n \dots)$ , Familiar-p( <i>f</i> ), and Familiar-p( <i>P</i> ) then $(P \ f \xrightarrow{prec} \dots n \dots)$ .
<i>Constraints from Domain Knowledge</i>	
10	If $(N \ x \ y)$ where <i>N</i> is a Natural-Ordering and <i>x</i> is in the <predecessor> role of <i>N</i> , then $(N \ x \xrightarrow{prec} y)$
11	If (Subsumption <i>c s</i> ) and <i>s</i> is differentiated within <i>c</i> by $(P \ s \dots)$ then $(\text{Subsumption } c \ s) \xrightarrow{cont} (P \ s \dots)$ .
<i>Informative and Attentional Structure</i>	
12	If Topic-p( <i>t</i> ), $(P_1 \dots t \dots)$ is unordered and $(P_2 \dots)$ does not contain <i>t</i> then $(P_1 \ t \xrightarrow{prec} \dots) \xrightarrow{prec} (P_2 \dots)$ .
13	If $R = (P_1 \ x \xrightarrow{ord} \dots y \dots)$ , In-Focus-p( <i>R</i> ), and $(P_2 \ y \ z \dots)$ is unordered then $(P_1 \ x \dots y \dots) \xrightarrow{cont} (P_2 \ y \xrightarrow{prec} z \dots)$ .

**Ordering Exemplification (Rules 5a and 5b).** Strategic variation is possible in the ordering of examples and illustrations. An explainer can encourage a questioner to engage in inductive inference by giving examples before the generalizations or concepts that they exemplify, as expressed by the  $E \xrightarrow{prec} G$  constraint of rule 5b. However, induction is a difficult task, and the desired conclusions are often underconstrained by small sets of examples (vanLehn 1987). Alternately, the example can be given immediately after the concept or generalization being exemplified, as expressed by the  $G \xrightarrow{cont} E$  constraint of rule 5a. Under this strategy, the questioner does not have to guess the generalization and will appreciate why the example was introduced. An active questioner can still engage in inference to verify that the example is subsumed by the generalization.

**Ordering Motivation (Rule 6).** A motivation segment is intended to point out the utility of another segment of an explanation so that the hearer will appreciate the relevance of the motivated segment enough to take it seriously. Motivation to attend doesn't work retroactively, so the motivating segment should occur prior to the motivated segment. Contiguity is preferred, but not necessary.

**Ordering Previews and Summaries (Rules 7 and 8).** By definition, a preview precedes the main body of an explanation. To serve the function of preparing the questioner for the sequence of utterances to follow, a preview should be contiguous with the body previewed, because a preview sets up an expectation that the subsequent segments will be those mentioned in the preview. Violation of this expectation with intervening material can cause confusion. A summary is similar to a preview in that both provide skeletal characterization of the main body of an explanation, though summaries can refer back to content that was not available at the time of a preview. The pedagogical utility of a summary is in repetition and consolidation. Contiguity is not as important for summaries. In fact, a summary might be used *because* there is some extra material between the segments related by the summary relation: the summary functions to refocus on the main points after the digression.

## Constraints from Questioner's Familiarity with Concepts

New concepts can be introduced in relation to familiar ones using any domain relation (notationally, by propositions of any  $n > 1$ -ary predicates). Suppose concept  $f$  is familiar and  $n$  is new. Then any proposition ( $P f n$ ) or more generally any ( $P c_1 \dots f \dots n \dots c_k$ ) will do the job, provided the predicate  $P$  itself is familiar. (An unfamiliar predicate won't be much help in integrating an unfamiliar concept with existing knowledge.) Strategy 9 installs an intra-propositional constraint that the role played by  $f$  should be expressed as the subject, yielding expressions of form " $F$  is  $P$ -related to  $n$ ." (not " $n$  is  $P^{-1}$ -related to  $f$ "). We need not identify distinct strategies for each  $P$ . The strategy applies to any ( $P f n$ ) in which we can independently identify  $f$  as familiar. This strategy cannot exploit a relationship ( $P x y$ ) in which neither  $x$  nor  $y$  can be identified as being more familiar. In such a situation, an "integrative connection" is available, but there is no indication of in what direction it should be exploited. Other information is needed in order to activate a concept filling one of the roles.

## Constraints from Domain Knowledge Structures

Now we consider constraints derived from relationships in the domain knowledge being expressed.

**Natural Orderings (Rule 10).** Temporal and causal relations are normally experienced in a particular direction, from prior to posterior events or from cause to effect, for example. The assumption that our cognitive apparatus is adapted to more easily use these relations in the "forward" direction suggests that predicates categorized as "natural orderings" be expressed with the prior event or cause as the subject (Bienkowski 1986):

" $X$  caused  $y$ " (not " $y$  is caused by  $x$ ").

**Ordering Genus and Differentia Propositions (Rule 11).** The "differentia" relation holds between two propositions when one proposition ( $P s \dots$ ) differentiates a subclass  $s$  from other subclasses of a class  $c$ . An explainer chooses the statement ( $P s \dots$ ) from amongst all the possible predicates one could apply to  $s$  because  $P$  distinguishes  $s$  from the other subdivisions of  $c$  that the questioner might know about. The questioner cannot recognize or assess this significance of ( $P s \dots$ ) unless he or she has been informed of the contrast set

(van Frassen 1980) against which the claim (*P s . . .*) is being made. Rule 11 suggests that the contrast class *c* be introduced first:

“An electric field is a kind of force field that applies a force to a charged object.”

not

“An electric field applies a force to a charged object and is a kind of force field.”

Mere precedence is insufficient because the differentia should be evaluated in light of the genus. The genus provides the context in which the differentia is meaningful. Contiguity places them both in focus of attention at once. At the intra-propositional level the constraint can be weakened to one of juxtaposition to allow adjective attachments (e.g., “A mammal is a hairy animal”). This strategy can be generalized to the level of sibling communicative acts or rhetorical acts; see Suthers (1993a).

### Constraints from Informative and Attentional Structure

The informative relations used in Suthers (1993a) represent the intentional hierarchy of an explanation (Gross & Sidner 1986). (They are called “informative” relations because they are derived entirely from consideration of what kind of information must be expressed in order to perform a rhetorical act.) These are containment relations rather than relations between segments to be ordered. For example, the textual realization of each communicative act that contributes towards the performance of a rhetorical act will be a *subsequence* of the textual realization of the rhetorical act as a whole. Because the informative relations do not occur between segments that can be ordered with respect to each other, these relations cannot be directly exploited to constrain ordering. However, informative structure constrains ordering indirectly as follows.

**Inheritance of Ordering Constraints.** The informative relations control the *application* of ordering constraints from other sources. For example, if one rhetorical act must be completed before another begins, then the communicative acts performing the first rhetorical act must be completed before the communicative acts performing the second rhetorical act. That is, ordering constraints are *inherited down the intentional hierarchy*.

**Ordering Based on Local Focus of Attention (Rules 12 and 13).** Suthers (1993a) discusses

how certain items can be identified as the **topic** of a rhetorical act. When a questioner asks a question, the topics of the query are brought into the focus of attention. Their focal status motivates the relevance of assertions made and concepts introduced by the explainer in the response. If assertions or concepts that had no apparent relation to the focal topics were introduced, the questioner might be unable to integrate them and could become confused due to the conversational implicature of the apparent change in subject (Grice 1975). For example:

“What killed the dinosaurs?”

“Many rocks at the KT-boundary have an unusual concentration of iridium ...

*(The iridium poisoned them? The speaker doesn't want to talk about dinosaur demise?) ...*”

In contrast, the following explanation changes focus of attention from the topic to other concepts and propositions in a well connected manner:

“The dinosaur extinctions may have been caused by a huge meteorite. Evidence for such a meteorite is provided by an unusual concentration of iridium found in KT-boundary rocks. ...”

Two ordering strategies are needed to exploit and extend local focus of attention (Gross 1977; Sidner 1979): one strategy to constrain the transition from a topic concept to other concepts, and another to constrain the transitions between propositions that share concepts. The first, strategy 12, ensures that some topic *t* is introduced before non-topics. The second, strategy 13, introduces a proposition when it involves a concept or proposition that is brought into immediate focus of attention by another ordering decision (the inter-propositional  $\xrightarrow{\text{cont}}$  constraint) and makes the subject of each proposition be the role filler by which it was introduced (the intra-propositional  $y \xrightarrow{\text{prec}} z$  constraint). The contiguity constraint could be downgraded to precedence if necessary to resolve a conflict with other ordering strategies. When a proposition introduces a new concept or proposition then this new concept or proposition becomes a new focal topic and strategy 13 can be iterated.

### Constraints from the “Epistemic Context”

Suthers (1993a, 1993b) discusses how the “epistemic context” (the knowledge available to the explainer and questioner and the knowledge shared

in prior dialogue) influences the choice between alternate domain models on which to base an explanation. Some of the "preferences" presented in these publications address sequential concerns. For example, when preferences to "say something new," "minimize new propositions," and "elaborate on focal models" are applied together in a dialogue about some phenomenon, incremental construction of increasingly elaborate domain models of the phenomenon will result (Suthers, Cornell, & Woolf 1992; White & Frederiksen 1990). In general, the epistemic context provides important constraints on sequential structure across *multiple* exchanges but has less impact on our present concern — sequential structure within a *single* utterance. Hence this paper does not discuss these other constraints further.

### Summary and Future Work

The significance of sequential structure is in how the expression of an explanation in a sequential medium such as text enhances the communicative functionality of the segments being ordered and facilitates the questioner's integration of the content of an explanation. Three types of ordering relations were differentiated, **precedence**, **juxtaposition**, and **contiguity**. A number of strategies were presented that install ordering constraints based on other functional relationships between segments.

The strategies presented in this paper were derived from analysis of example explanations and found to be necessary to enable an automated explanation generator to produce coherently sequenced explanations (Suthers 1993a). However, psychological validity has not been tested. In collaboration with Rich Thurlow, the author is currently designing a series of psychological experiments to test the impact of the strategies through on-line and recall studies.

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