Discourse Relations and Defeasible Knowledge*

Alex Lascarides†
Human Communication Research Centre
University of Edinburgh
2 Buccleuch Place, Edinburgh, EH8 9LW
Scotland
alex@uk.ac.ed.cogsci

Nicholas Asher
Center for Cognitive Science
University of Texas
Austin, Texas 78712
USA
asher@sygmund.cgs.utexas.edu

Abstract

This paper presents a formal account of the temporal interpretation of text. The distinct natural interpretations of texts with similar syntax are explained in terms of defeasible rules characterising causal laws and Gricean-style pragmatic maxims. Intuitively compelling patterns of defeasible entailment that are supported by the logic in which the theory is expressed are shown to underly temporal interpretation.

The Problem

The temporal interpretation of text involves an account of how the events described are related to each other. These relations follow from the *discourse relations* that are central to temporal import.[1] Some of these are listed below, where the clause α appears in the text before β:

$Narration(\alpha, \beta)$: The event described in β is a consequence of (but not necessarily *caused* by) the event described in α:

(1) Max stood up. John greeted him.

$Elaboration(\alpha, \beta)$: The event described in β contributes to the occurrence of the culmination of the event described in α, i.e. β's event is part of the preparatory phase of α's:[2]

(2) The council built the bridge. The architect drew up the plans.

$Explanation(\alpha, \beta)$: For example the event described in clause β caused the event described in clause α:

(3) Max fell. John pushed him.

$Background(\alpha, \beta)$: For example the state described in β is the 'backdrop' or circumstances under which the event in α occurred (so the event and state temporally overlap):

(4) Max opened the door. The room was pitch dark.

$Result(\alpha, \beta)$: The event described in α caused the event or state described in β:

(5) Max switched off the light. The room was pitch dark.

We assume that more than one discourse relation can hold between two sentences; the sickness in (6) describes the circumstances when Max took the aspirin (hence the sentences are related by *Background*) and also explains *why* he took the aspirin (hence the sentences are related by *Explanation* as well).

(6) Max took an aspirin. He was sick.

The sentences in texts (1) and (3) and in (4) and (5) have similar syntax, and therefore similar

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[1] Extensive classifications of discourse relations are offered in (Polanyi, 1985), (Scha & Polanyi, 1988) and (Thompson & Mann, 1987).

[2] We assume Moens and Steedman's (1988) tripartite structure of events, where an event consists of a preparatory phase, a culmination and a consequent phase.

logical forms. They indicate, therefore, that the constraints on the use of the above discourse relations cannot rely solely on the logical forms of the sentences concerned.

No theory at present is able to explain the distinct temporal structures of all the above texts. Webber (1988) observes that Kamp & Rohrer (1983), Partee (1984), Hinrichs (1986) and Dowty (1986) don't account for the backwards movement of time in (2) and (3). Webber (1988) can account for the backwards movement of time in (2), but her theory is unable to predict that mismatching the descriptive order of events and their temporal order is allowed in some cases (e.g. (2) and (3)) but not in others (e.g. (1), which would be misleading if the situation being described were one where the greeting happened *before* Max stood up).

Our aim is to characterise the circumstances under which each of the above discourse relations hold, and to explain why texts can invoke different temporal relations in spite of their similar syntax.

Dahlgren (1988) represents the difference between (1) and (3) in terms of probabilistic laws describing world knowledge (WK) and linguistic knowledge (LK). Our approach to the problem is generally sympathetic to hers. But Dahlgren's account lacks an underlying theory of inference. Furthermore, it's not clear how a logical consequence relation could be defined upon Dahlgren's representation scheme because the probabilistic laws that need to interact in certain specific ways are not logically related. Unlike Dahlgren (1988), we will supply an inference regime that drives the interpretation of text.

The properties required of an inference mechanism for inferring the causal structure underlying text is discussed in (Lascarides & Oberlander, 1991). The work presented here builds on this in two ways; first by supplying the required notion of inference, and second by accounting for discourse structure as well as temporal structure.

Temporal Relations and Defeasible Reasoning

Let us consider texts (1) and (3) on an intuitive level. There is a difference in the relation that typically holds between the events being described. Intuitively, world knowledge (WK) includes a causal 'law' gained from perception and experience that relates falling and pushing:[3]

- **Causal Law 3**
  Connected events e_1 where x falls and e_2 where y pushes x are normally such that e_2 causes e_1.

There is no similar law for standing up and greeting. The above law is a *defeasible law*. Our claim is that it forms the basis for the distinction between (1) and (3), and that defeasible reasoning underlies the temporal interpretation of text.

First consider text (1). Intuitively, if there is no temporal information at all gained from WK or syntactic markers (apart from the simple past tense which is the only temporal 'expression' we consider here), then the descriptive order of events provides the only vital clue as to their temporal order, and one assumes that descriptive order matches temporal order. This principle is a re-statement of Grice's (1975) maxim of Manner, where it is suggested that text should be *orderly*, and it is also motivated by the fact that the author typically describes events in the order in which the protagonist perceives them (cf. Dowty (1986)). This maxim of interpretation can be captured by the following two laws:

- **Narration**
  Unless there's information to the contrary, clauses α and β that are discourse-related are such that $Narration(\alpha, \beta)$ holds.

- **Axiom for Narration**
  If $Narration(\alpha, \beta)$ holds, and α and β describe the events e_1 and e_2 respectively, then e_1 occurs before e_2.

Narration is defeasible and the Axiom for Narration is indefeasible. The idea that Gricean-style pragmatic maxims should be represented as defeasible rules is suggested in (Joshi, Webber & Weischedel (1984)).

The above rules can be defined in MASH—a logic for defeasible reasoning described in (Asher & Morreau, 1991). We will demonstrate shortly that an intuitively compelling pattern of defeasible inference can then underly the interpretation of (1).

MASH supplies a modal semantics for a language with a default or generic quantifier, and a

[3]The causal law's index corresponds to the index of the text for which it is relevant.

dynamic partial semantics of belief states is built on top of this modal semantics to capture intuitively compelling patterns of non-monotonic reasoning. We use a propositional version of MASH here. Defaults are represented as $\phi > \psi$ (read as "ϕ then ψ, unless there is information to the contrary"). The monotonic component of the theory defines a notion of validity $\models$ that supports axioms such as $\models \Box(\phi \rightarrow \psi) \rightarrow ((\chi > \phi) \rightarrow (\chi > \psi))$. The dynamic belief theory supplies the nonmonotonic component, and the corresponding nonmonotonic validity, $\approx\!\!\!|$, describes what reasonable entailments follow from the agent's beliefs. $\approx\!\!\!|$ supports (at least) the following patterns of common sense reasoning:

Defeasible Modus Ponens
$\phi > \psi, \phi \;|\!\!\approx\; \psi$
but not $\phi > \psi, \phi, \neg\psi \;|\!\!\approx\; \psi$
e.g. Birds fly, Tweety is a bird $|\!\!\approx$ Tweety flies, but not: Birds fly, Tweety is a bird that doesn't fly $|\!\!\approx$ Tweety flies.

Penguin Principle
$\phi > \psi, \psi > \zeta, \phi > \neg\zeta, \phi \;|\!\!\approx\; \neg\zeta$
but not: $\phi > \psi, \psi > \zeta, \phi > \neg\zeta, \phi \;|\!\!\approx\; \zeta$
e.g. Penguins are birds, Birds fly, Penguins don't fly, Tweety is a Penguin $|\!\!\approx$ Tweety doesn't fly, and does not $|\!\!\approx$ Tweety flies.

Nixon Diamond
not $(\phi > \psi, \zeta > \neg\psi, \phi, \zeta \;|\!\!\approx\; \psi$ (or $\neg\psi$))
e.g. There is irresolvable conflict in the following: Quakers are pacifists, Republicans are non-pacifists, Nixon is a Quaker and Republican.

We assume a dynamic theory of discourse structure construction in which a discourse structure is built up through the processing of successive clauses in a text. To simplify our exposition, we will assume that the basic constructs of these structures are clauses.[4] Let $\langle\alpha, \beta\rangle$ mean that the clause β is to be attached to the clause α with a discourse relation, where α is part of the already built up discourse structure. Let $me(\alpha)$ be a term that refers to the main eventuality described by α (e.g. $me(\textit{Max stood up})$ is the event of Max standing up).[5] Then Narration and the axiom on Narration are represented in MASH as follows ($e_1 \prec e_2$ means "e_1 wholly occurs before e_2"):

[4] The theory should extend naturally to an account where the basic constructs are segments of text; the approach adopted here is explored extensively in Asher (forthcoming).

[5] $me(\alpha)$ is formally defined in Lascarides & Asher (1991) in a way that agrees with intuitions.

- **Narration**
  $\langle\alpha, \beta\rangle > Narration(\alpha, \beta)$
- **Axiom on Narration**
  $\Box(Narration(\alpha, \beta) \rightarrow me(\alpha) \prec me(\beta))$

We assume that in interpreting text the reader believes all LK and WK (and therefore believes Narration and its axiom), the laws of logic, and the sentences in the text. The sentences in (1) are represented in a DRT-type framework as follows:[6]

(7) $[e_1, t_1][t_1 < now, hold(e_1, t_1), standup(m, e_1)]$

(8) $[e_2, t_2][t_2 < now, hold(e_2, t_2), greet(j, m, e_2)]$

In words, (7) invokes two discourse referents e_1 and t_1 (which behave like deictic expressions), where e_1 is an event of Max standing up, t_1 is a point of time earlier than now and e_1 occurs at t_1. (8) is similar save that the event e_2 describes John greeting Max. (7) and (8) place no conditions on the relative temporal order between e_1 and e_2. These are derived at a higher level of analysis than sentential semantics by using defeasible reasoning.

Suppose that the reader also believes that the clauses in text (1) are related by some discourse relation, as they must be for the text to be coherent. Then the reader's beliefs also include $\langle 7, 8\rangle$. The natural interpretation of (1) is derived by calculating the common sense entailments from the reader's belief state. Given the assumptions on this state that we have just described, the antecedent to Narration is verified, and so by Defeasible Modus Ponens, $Narration(7, 8)$ is inferred. Since the belief states in MASH support modal closure, this result and the Axiom on Narration entail that the reader believes the main eventuality of (7), namely e_1, precedes the main eventuality of (8), namely e_2. So the intuitive discourse structure and temporal interpretation of (1) is derived by exploiting defeasible knowledge that expresses a Gricean-style pragmatic maxim.

But the analysis of (1) is satisfactory only if the same technique of exploiting defeasible rules can be used to obtain the appropriate natural interpretation of (3), which is different from (1) in spite of their similar syntax.

[6] For the sake of simplicity we ignore the problem of resolving the NP anaphora in (8). The truth definitions of (7) and (8) are like those given in DRT save that they are evaluated with respect to a possible world index since MASH is modal.

(3) a. Max fell.

b. John pushed him.

As we mentioned before, Causal Law 3 will provide the basis for the distinct interpretations of (1) and (3). The clauses in (3) must be related by a discourse relation for the text to be coherent, and therefore given the meanings of the discourse relations, the events described must be connected somehow. Therefore when considering the domain of interpreting text, one can re-state the above causal law as follows:[7]

- **Causal Law 3**
  Clauses α and β that are discourse-related where α describes an event e_1 of x falling and β describes an event e_2 of y pushing x are normally such that e_2 causes e_1.

The representation of this in MASH is:

- **Causal Law 3**
  $\langle\alpha,\beta\rangle \wedge fall(x, me(\alpha)) \wedge push(y, x, me(\beta)) > cause(me(\beta), me(\alpha))$

This represents a mixture of WK and linguistic knowledge (LK), for it asserts that given the sentences are discourse-related somehow, and given the kinds of events that are described by these sentences, the second event described caused the first, if things are normal.

The logical forms for (3a) and (3b) are the same as (7) and (8), save that *standup* and *greet* are replaced respectively with *fall* and *push*. Upon interpreting (3), the reader believes all defeasible WK and LK together with (3a), (3b) and $\langle 3a, 3b\rangle$. Hence the antecedents to two defeasible laws are satisfied: Narration and Causal Law 3. Moreover, the antecedent of Law 3 entails that of Narration, and the laws conflict because of the axiom on Narration and the axiom that causes precede effects:

- **Causes Precede Effects**
  $\Box(\forall e_1 e_2)(cause(e_1, e_2) \rightarrow \neg e_2 \prec e_1)$

The result is a 'Complex' Penguin Principle: it is complex because the consequents of the two defeasible laws are not ζ and $\neg\zeta$, but instead the laws conflict in virtue of the above axioms. MASH supports the more complex Penguin Principle:

- **Complex Penguin Principle**
  $\Box(\phi \rightarrow \psi), \psi > \chi, \phi > \zeta, \Box(\chi \rightarrow \theta),$
  $\Box(\zeta \rightarrow \neg\theta), \phi \approx\!\!| \zeta$
  but not: $\Box(\phi \rightarrow \psi), \psi > \chi, \phi > \zeta,$
  $\Box(\chi \rightarrow \theta), \Box(\zeta \rightarrow \neg\theta), \phi \approx\!\!| \chi$

Therefore there is a defeasible inference that the pushing caused the falling from the premises, as required.

The use of the discourse relation *Explanation* is characterised by the following rule:

- **Explanation**
  $\langle\alpha,\beta\rangle \wedge cause(me(\beta), me(\alpha)) > Explanation(\alpha,\beta)$

In words, if α and β are discourse-related and the event described in β caused the event described in α, then $Explanation(\alpha,\beta)$ normally holds. Furthermore, Explanation imposes a certain temporal structure on the events described so that if β is a causal explanation of α then β's event doesn't precede α's:

- **Axiom on Explanation**
  $\Box(Explanation(\alpha,\beta) \rightarrow \neg me(\alpha) \prec me(\beta))$

The antecedent to Narration is verified by the reader's beliefs, and given the results of the Complex Penguin Principle above, the antecedent to Explanation is also verified. Moreover, the antecedent to Explanation entails that of Narration, and these laws conflict because of the above axioms. So there is another complex Penguin Principle, from which $Explanation(3a, 3b)$ is inferred.

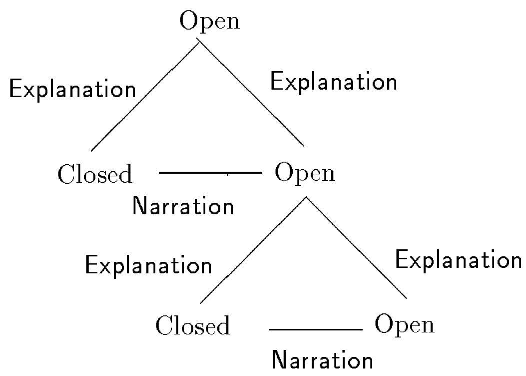
The second application of the Penguin Principle in the above used the results of the first, but in nonmonotonic reasoning one must be wary of dividing theories into 'subtheories' in this way because adding premises to nonmonotonic deductions does not always preserve conclusions, making it necessary to look at the theory as a whole. (Lascarides & Asher, 1991) shows that the predicates involved in the above deduction are sufficiently independent that in MASH one can indeed divide the above into two applications of the Penguin Principle to yield inferences from the theory as a whole. Thus our intuitions about the kind of reasoning used in analysing (3) are supported in the logic. We call this double application of the Penguin Principle where the second application uses the results of the first the *Cascaded Penguin Principle*.[8]

[7] This law may seem very 'specific'. It could potentially be generalised, perhaps by re-stating e_1 as x moving and e_2 as y applying a force to x. For the sake of brevity we ignore this generalisation.

[8] On a general level, MASH is designed so that the con-

Distinct Discourse Structures

Certain constraints are imposed on discourse structure: Let R be *Explanation* or *Elaboration*; then the current sentence can be discourse related only to the previous sentence α, to a sentence β such that $R(\beta, \alpha)$, or to a sentence γ such that $R(\gamma, \beta)$ and $R(\beta, \alpha)$. This is a simpler version of the definition for possible attachment sites in Asher (forthcoming). Pictorially, the possible sites for discourse attachment in the example structure below are those marked open:



There are structural similarities between our notion of openness and Polanyi's (1985). The above constraints on attachment explain the awkwardness of text (9a-f) because (9c) is not available to (9f) for discourse attachment.

(9) a. Guy experienced a lovely evening last night.
b. He had a fantastic meal.
c. He ate salmon.
d. He devoured lots of cheese.
e. He won a dancing competition.
f. ?He boned the salmon with great expertise.

According to the constraint on attachment, the only available sentence for attachment if one were to add a sentence to (1) is *John greeted him*, whereas in (3), both sentences are available. Thus although the sentences in (1) and (3) were assigned similar structural semantics, they have very different discourse structures. The events they describe also have different causal structures. These distinctions have been characterised in terms of defeasible rules representing causal laws and pragmatic maxims. We now use this strategy to analyse the other texts we mentioned above.

flict between defeasible laws whose antecedents are such that one of them entails the other is resolvable. Thus unwanted irresolvable conflicts can be avoided.

Elaboration

Consider text (2).

(2) a. The council built the bridge.
b. The architect drew up the plans.

We conclude *Elaboration*(2a, 2b) in a very similar way to example (3), save that we replace $cause(me(\beta), me(\alpha))$ in the appropriate defeasible rules with $prep(me(\beta), me(\alpha))$, which means that $me(\beta)$ is part of the preparatory phase of $me(\alpha)$. In Law 2 below, $Info(\alpha, \beta)$ is a gloss for "the event described in α is the council building the bridge, and the event described in β is the architect drawing up the plans", and the law represents the knowledge that drawing plans and building the bridge, if connected, are normally such that the former is in the preparatory phase of the latter:

- **Elaboration**
  $\langle \alpha, \beta \rangle \wedge prep(me(\beta), me(\alpha)) >$
  $Elaboration(\alpha, \beta)$
- **Axiom on Elaboration**
  $\Box(Elaboration(\alpha, \beta) \rightarrow \neg me(\alpha) \prec me(\beta))$
- **Law 2**
  $\langle \alpha, \beta \rangle \wedge Info(\alpha, \beta) > prep(me(\beta), me(\alpha))$

The inference pattern is a Cascaded Penguin Principle again. The two resolvable conflicts are Law 2 and Narration and Elaboration and Narration.

Background

Intuitively, the clauses in (4) are related by *Background*.

(4) Max opened the door. The room was pitch dark.

The appropriate reader's belief state verifies the antecedent of Narration. In addition, we claim that the following laws hold:

- **States Overlap**
  $\langle\alpha,\beta\rangle \wedge state(me(\beta)) >$
  $overlap(me(\alpha), me(\beta))$

- **Background**
  $\langle\alpha,\beta\rangle \wedge overlap(me(\alpha), me(\beta)) >$
  $Background(\alpha,\beta)$

- **Axiom on Background**
  $\Box(Background(\alpha,\beta) \rightarrow$
  $overlap(me(\alpha), me(\beta)))$

States Overlap ensures that when attached clauses describe an event and state and we have no knowledge about how the event and state are connected, gained from WK or syntactic markers like *because* and *therefore*, we assume that they temporally overlap. This law can be seen as a manifestation of Grice's Maxim of Relevance as suggested in (Lascarides, 1990): if the start of the state is not indicated by stating what caused it or by introducing an appropriate syntactic marker, then by Grice's Maxim of Relevance the starting point, and is irrelevant to the situation being described. So the start of the state must have occurred *before* the situation that the text is concerned with occurs. As before, we assume that unless there is information to the contrary, the descriptive order of eventualities marks the order of their discovery. This together with the above assumption about where the state starts entail that unless there's information to the contrary, the state *temporally overlaps* events or states that were described previously, as asserted in States Overlap.

We assume that the logical form of the second clause in (4) entails $state(me(\beta))$ by the classification of the predicate *dark* as stative. So *Background* is derived from the Cascaded Penguin Principle: the two resolvable conflicts are States Overlap and Narration and Background and Narration. States Overlap and Narration conflict because of the inconsistency of $overlap(e_1, e_2)$ and $e_1 \prec e_2$; Background and Narration conflict because of the axioms for Background and Narration.

Result

(5) has similar syntax to (4), and yet unlike (4) the event causes the state and the discourse relation is *Result*.

(5) a. Max switched off the light.
    b. The room was pitch dark.

Let $Info(\alpha,\beta)$ be a gloss for "$me(\alpha)$ is Max switching off the light and $me(\beta)$ is the room being dark". So by the stative classification of *dark*, $Info(\alpha,\beta)$ entails $state(me(\beta))$. Then Law 5 reflects the knowledge that the room being dark and switching off the light, if connected, are normally such that the event causes the state:[9]

- **Causal Law 5**
  $\langle\alpha,\beta\rangle \wedge Info(\alpha,\beta) > cause(me(\alpha), me(\beta))$

The use of the discourse relation of Result is characterised by the following:

- **Result**
  $\langle\alpha,\beta\rangle \wedge cause(me(\alpha), me(\beta)) > Result(\alpha,\beta)$

- **Axiom on Result**
  $\Box(Result(\alpha,\beta) \rightarrow me(\alpha) \prec me(\beta))$

The reader's beliefs in analysing (5) verify the antecedents of Narration, States Overlap and Law 5. Narration conflicts with States Overlap, which in turn conflicts with Law 5. Moreover, the antecedent of Law 5 entails that of States Overlap, which entails that of Narration. So there is a 'Penguin-type' conflict where Law 5 has the most specific antecedent. In MASH Law 5's consequent, i.e. $cause(me(5a), me(5b))$, is inferred from these premises. The antecedent of Result is thus satisfied, but the antecedent to Background is not. Result does not conflict with Narration, and so by Defeasible Modus Ponens, both $Result(5a, 5b)$ and $Narration(5a, 5b)$ are inferred.

Note that thanks to the axioms on *Background* and *Result* and the inconsistency of $overlap(e_1, e_2)$ and $e_1 \prec e_2$, these discourse relations are inconsistent. This captures the intuition that if a causes b, then b could not have been the case when a happened. In particular, if Max switching off the light caused the darkness, then the room could not have been dark when Max switched off the light.

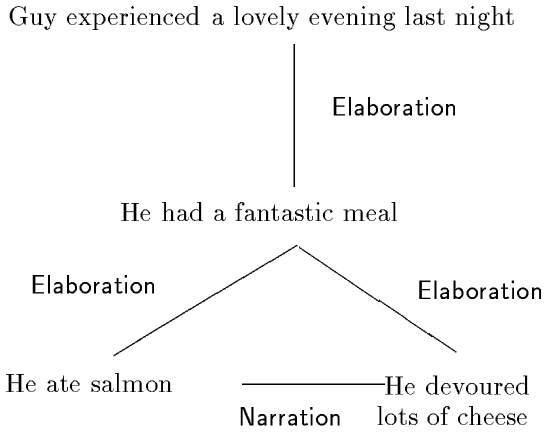
Discourse Popping

Consider text (9a-e):

[9] For the sake of simplicity, we ignore the problem of inferring that the light is in the room.

(9) a. Guy experienced a lovely evening last night.
b. He had a fantastic meal.
c. He ate salmon.
d. He devoured lots of cheese.
e. He won a dancing competition.

The discourse structure for (9a-d) involves Cascaded Penguin Principles and Defeasible Modus Ponens as before. Use is made of the defeasible knowledge that having a meal is normally part of experiencing a lovely evening, and eating salmon and devouring cheese are normally part of having a meal if these events are connected:



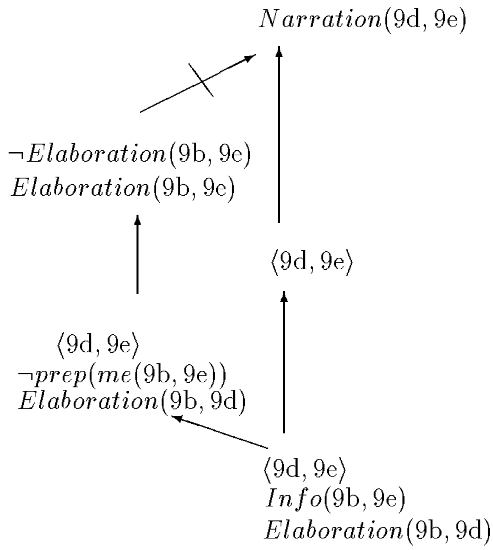
We study the attachment of (9e) to the preceding text in detail. Given the concept of openness introduced above, the open clauses are (9d), (9b) and (9a). So by the assumptions on text processing, the reader believes $\langle 9d, 9e\rangle$, $\langle 9b, 9e\rangle$ and $\langle 9a, 9e\rangle$. $\langle 9d, 9e\rangle$ verifies the antecedent to Narration, but intuitively, (9d) is not related to (9e) at all. The reason for this can be explained in words as follows:

- (9d) and (9e) don't form a narrative because:
  - Winning a dance competition is normally not part of a meal;
  - So (9e) doesn't normally elaborate (9b);
  - But since (9d) elaborates (9b), (9e) can normally form a narrative with (9d) only if (9e) also elaborates (9b).

These intuitions can be formalised, where $Info(\alpha, \beta)$ is a gloss for "$me(\alpha)$ is having a meal and $me(\beta)$ is winning a dance competition":

- **Law 9**
  $\langle \alpha, \beta\rangle \wedge Info(\alpha, \beta) > \neg prep(me(\beta), me(\alpha))$
- **Defeasibly Necessary Test for Elaboration**
  $\langle \alpha, \beta\rangle \wedge \neg prep(me(\beta), me(\alpha)) > \neg Elaboration(\alpha, \beta)$
- **Constraint on Narration**
  $Elaboration(\alpha, \beta_1) \wedge \neg Elaboration(\alpha, \beta_2) > \neg Narration(\beta_1, \beta_2)$

The result is a 'Nixon Polygon'. There is *irresolvable* conflict between Narration and the Constraint on Narration because their antecedents are not logically related:



The above in MASH yields $\not\mid\!\approx Narration(9d, 9e)$ and $\not\mid\!\approx \neg Narration(9d, 9e)$. We assume that believing $\langle 9d, 9e\rangle$ and *failing* to support *any* discourse relation between (9d) and (9e) is incoherent. So $\langle 9d, 9e\rangle$ cannot be believed. Thus the Nixon Diamond provides the key to discourse 'popping', for (9e) must be related to one of the remaining open clauses; i.e. (9b) or (9a). In fact by making use of the knowledge that winning a dance competition is normally part of experiencing a lovely evening if these things are connected, $Elaboration(9a, 9e)$ and $Narration(9b, 9e)$ follow as before, in agreement with intuitions.

Conclusion

We have proposed that distinct natural interpretations of texts with similar syntax can be explained in terms of defeasible rules that represent causal laws and Gricean-style pragmatic maxims. The distinct discourse relations and event relations arose from intuitively compelling patterns of defeasible entailment. The Penguin Principle captures the intuition that a reader never ignores information salient in text that is relevant to calculating temporal and discourse structure. The Nixon Diamond provided the key to 'popping' from subordinate discourse structure.

We have investigated the analysis of texts involving only the simple past tense, with no other temporal markers present. Lascarides & Asher (1991) show that the strategy pursued here can be applied to the pluperfect as well. Future work will involve extending the theory to handle texts that feature temporal connectives and adverbials.

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