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Strong generative capacity of RST, SDRT and discourse dependency DAGSs

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Abstract

The aim of this paper[0] is to compare the discourse structures proposed in RST, SDRT and dependency DAGs which extend the semantic level of MTT for discourses. The key question is the following: do these formalisms allow the representation of all the discourse structures which correspond to felicitous discourses and exclude those which correspond to infelicitous discourses? Hence the term of "strong generative capacity" taken from formal grammars.

1 Introduction

RST [Mann and Thompson1988] and SDRT [Asher and Lascarides2003] are quite different discourse theories, however they both rely on discourse relations and postulate an asymmetry: some parts of a text play a "subordinate" ("less important") role relative to other parts. This asymmetry is expressed in RST as a distinction between the arguments of discourse relations: arguments of type Nucleus are more important than arguments of type Satellite. This is expressed in SDRT as a distinction between the types of discourse relations: a coordinating relation links arguments of equal importance, while a subordinating relation links an important argument to a less important one. Since these distinctions come from the same idea, we use the following terminology for the two theories: a multi-nuclear or coordinating relation links two Nuclei[1], while a nucleus-satellite or subordinating relations links a Nucleus and a Satellite.

On the other hand, dependency DAGs for discourse [Danlos2004], which extend the sentential semantic level of MTT (Meaning-Text Theory) [Mel'cuk1988] to the discourse level, relies on discourse relations but not on the distinction Nucleus/Satellite or coordinating/subordinating. This formalism only calls upon constraints coming from the semantic behavior of discourse connectives. These constraints are extrapolated to

[0] A French version of this paper is published in *Revue TAL*, Volume 47 Numéro 1, pp 169-198, 2006.

[1] A coordinating relation may link more than two Nuclei, e.g. *Narration* or *Sequence*. However, I leave aside this case, which means that it is supposed that *all* discourse relations discussed in this paper have exactly two arguments.

discourse relations which are not lexicalized by a discourse connective. These (minimal) constraints are also respected in RST and SDRT (Section 4).

The aim of this paper is to compare RST, SDRT and discourse dependency DAGs with respect to the following question: do these formalisms allow the representation of all the discourse structures which correspond to felicitous discourses and exclude those which correspond to infelicitous discourses? By taking the term "strong generative capacity" from formal grammars, I reformulate this question as: what is the strong generative capacity of each of these three formalisms?

It will be shown that none of these formalisms has the appropriate strong generative capacity. RST, which imposes that discourse structures be tree shaped (among other constraints), is too restrictive (there exist some felicitous discourses whose structure is not controversial but not representable as an RST tree). At the opposite extreme, dependency DAG formalism, which only imposes constraints coming from the semantics of discourse connectives, is too powerful (there exist some dependency DAGs which respect these constraints, but which seem to correspond to no felicitous discourse). Finally, SDRT comes near to the appropriate strong generative capacity but still falls short.

This conclusion may sound negative, however we hope this study will shed new light on the constraints which must govern discourse structures and on the geometric properties of the graphs representing discourse structures.

Let us insist on the following point: this paper only focuses on discourse structures. Nothing is said about the processes that are or should be implemented to compute discourse structures from discourses.

The paper is organized as follows. Sections 2, 3 and 4 present the main features of the discourse structures proposed respectively in RST, SDRT and dependency DAGs. Section 5 concerns the strong generative capacity of these three formalisms. Section 6 concludes.

In sections 2 to 4, a reference discourse is used. This discourse, taken from [Asher and Lascarides2003], is given in (1).

(1) a. Fred 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.

This narrative discourse describes Fred's evening which is elaborated with two subevents, the meal and the dancing competition. The meal is itself elaborated with two courses, salmon and cheese. The discourse relations involved and their arguments are not controversial, they are the following:

- *Elaboration* holds between the first sentence (1a) and the rest of the discourse (1b-e),
- *Narration* (called *Sequence* in RST) holds between the meal and dancing competition sentences, i.e. (1b) and (1e),

- *Elaboration* holds between the meal sentence (1b) and the two next sentences, i.e. (1c) and (1d),
- *Narration* holds between the salmon and cheese sentences, i.e. (1c) and (1d).

Elaboration is a nucleus-satellite relation in RST and is subordinating in SDRT, while *Narration* is multinuclear in RST and coordinating in SDRT. This fits with the claim that nucleus-satellite/subordinating and multinuclear/coordinating are terminological variants.

2 RST

RST is a theory which dates back twenty years and which has been widely used in descriptive or computational linguistics as well as in NLP (both for text understanding and text generation). Therefore, the numerous authors working in this framework do not systematically share the same points of view. It is not in the scope of this paper to present the various points of view on RST, see [Taboada and Mann2006a] and [Taboada and Mann2006b] for a review. Thus, we limit ourselves in the next section to a particular interpretation of RST, that of Marcu which has had a strong impact in discourse analysis [Marcu2000a] and discourse annotation [Carlson et al.2003]. However, we discuss in Section 2.2 one of the issues which is debated within the RST community, namely the Nucleus/Satellite distinction.

2.1 Graphical representations and predicate-argument relations

The original graphical representation proposed in [Mann and Thompson1987] for discourse structures is illustrated in Figure 1, which shows the discourse structure for (1). In this diagram, the representation of the *ith* sentence is noted π_i. This notation comes from SDRT and not from RST where the notation C_i is preferred, see for example [Egg and Redeker2007] (this volume). This difference in notation is irrelevant since the representation of sentences is not discussed at all in this paper, which focuses on discourse structures annotated with discourse relations.

[Marcu1996] has proposed graphical representations which are equivalent to the original diagrams, but which do look like trees. For a discourse made up of two sentences (clauses) linked by a discourse relation R, the representation is a binary tree: the root is R, the edges are labelled N for Nucleus or S for Satellite, the (ordered) leaves are the representations of the two sentences. If R is a nucleus-satellite relation, the Nucleus (resp. Satellite) of R is the leaf on the edge labelled N (resp. S); the Nucleus precedes or follows the Satellite. If R is a multi-nuclear relation, both edges are labelled N.

Marcu has also proposed a principle, called "Nuclearity Principle" (or "Compositionality Principle"), which gives the predicate-argument relations when a *nucleus-satellite (subordinating)* relation is embedded in another discourse relation. I extend his principle to give the predicate-argument relations when a *multinuclear (coordinating)* relation is embedded in another one. This leads to the "Mixed Principle".

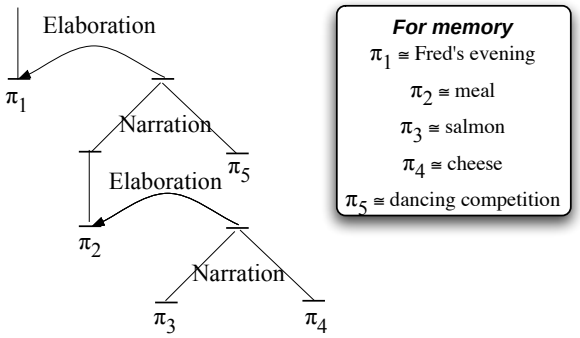

Figure 1: RST diagram for (1) in orthodox style

Mixed Principle: Let n_i be a non terminal node in an RST tree whose left (resp. right) daughter is n_j. The left (resp. right) argument of n_i is:

- if n_j is a leaf, n_j
- if n_j is a coordinating discourse relation, the sub-tree rooted at n_j
- if n_j is a subordinating discourse relation, the Nucleus argument of n_j (recursively given by the Mixed Principle).

This principle is case-based. The two first cases correspond to the standard interpretation of trees used in computer science; the third one corresponds to Marcu's Nuclearity Principle. The RST tree for (1), which must be interpreted with the Mixed Principle, is shown in Figure 2.

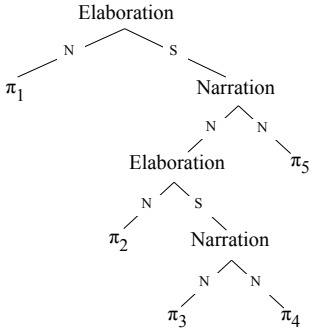

Figure 2: RST tree for (1) in standard style

In this tree, the right (Satellite) argument of the root - the topmost *Elaboration* - is the sub-tree rooted at the topmost coordinating relation *Narration*. In this sub-tree, the left argument of the root is π_2 (thanks to the Nuclearity Principle). π_2 is also the left

argument of the embedded *Elaboration*. In a nutshell, π_2 is argument of **two** discourse relations, although it has a **single** parent in the tree in Figure 2.

2.2 Nucleus/Satellite distinction

The criterion put forward by Marcu for the Nucleus/Satellite distinction is the fact that the satellites of a text can be deleted without harming its coherence. He used this criterion for text summarization: his strategy consists in deleting all the Satellites from the original text to keep only the Nuclei [Marcu2000b]. Along the lines of the theory as originally proposed in Mann and Thomson (1988), Marcu considers that only a few discourse relations are multi-nuclear (mainly *Sequence*, *Parallel Contrast*, *Joint* and *List*). He considers that all the other ones are nucleus-satellite relations, in particular all the relations that can be lexicalized by a subordinating conjunction (the main clause corresponding to the Nucleus, the subordinate clause to the Satellite) [Matthiessen and Thompson1988].

Marcu's position is not approved unanimously within the RST community. On the one hand, his criterion for the Nucleus/Satellite distinction has been criticized, for example, in [Stede2007] where it is proposed that the notion of salience should be taken into account to determine which elements can be qualified as Nuclei according to the context. Moreover, the direct mapping advocated by [Matthiessen and Thompson1988] between the linguistic structure and the type of a discourse relation (i.e. a subordinating conjunction lexicalizes a subordinating relation) has been widely criticized, recently in [Delort2006].

We will see in Section 3.3 that the distinction between coordinating and subordinating relations made in SDRT is also debated.

3 SDRT

3.1 Box representations and graphs for SDRSs

Originally, [Asher1993] designed SDRT as an extension of DRT - Discourse Representation Theory [Kamp and Reyle1993] - to account for specific properties of discourse. Thus, a discourse structure in SDRT, called an SDRS, gets a box representation à la DRT. In box representations, the distinction between coordinating and subordinating discourse relations is not taken into account. However, the theory, especially the ''logic of information packaging", makes heavy use of this distinction, which is crucial in order to give SDRSs hierarchical structures represented as graphs. Let us introduce this graphical representations.

For a discourse made up of two sentences (clauses) linked by a discourse relation R, the nodes of the SDRS graph are the labels π_1 and π_2 of the DRSs giving the semantic representations of the two sentences. They are linked by an arrow labelled by the discourse relation R. The arrow "is horizontal with the newer constituent to the right if R is coordinating, while it is vertical (oblique) with the newer constituent below if R is subordinating" [Asher and Vieu2005]. Taking into account the Nucleus/Satellite type of arguments, this means that a horizontal arrow links two Nuclei, while a vertical

arrow goes from a Nucleus down to a Satellite. It is supposed that the Nucleus of a subordinating relation always precedes the Satellite. We will come back on this simplification in Section 3.4.

In addition to nodes representing sentences (noted π_i and called "sentence nodes"), SDRS graphs include "scope nodes" (noted π', π'', ...). In the box representation scheme, a scope node labels a sub-SDRS. In the graph scheme, a scope node is linked by *lines* (and not arrows) to sentence nodes.

Figure 3 illustrates these two representation schemes for the SDRS of (1) (these diagrams are taken from [Asher and Lascarides2003]). The notation K_{π_i} stands for the DRS representing the *ith* sentence.

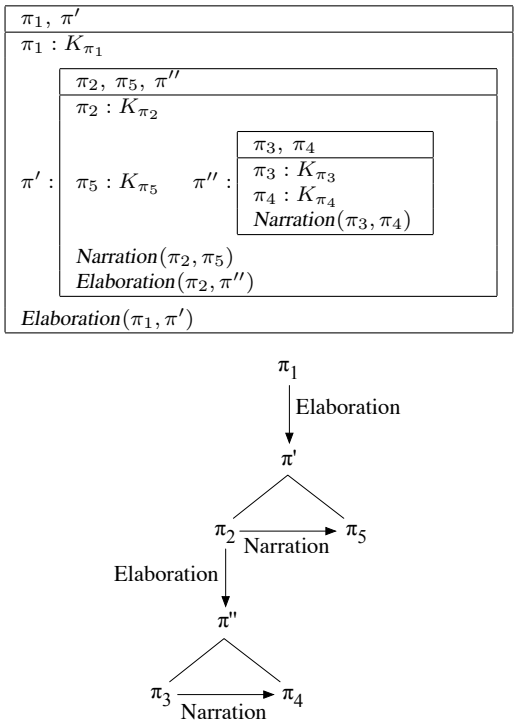

Figure 3: SDRS for (1) in a box representation and as a graph

It should be noted that *Narration*(π_2, π_5) and *Elaboration*(π_2, π'') are on an equal footing in the sub-SDRS labelled π' in the box representation, because no difference is made there between coordinating and subordinating discourse relations. However, this is not the case in the graph: the scope node π' immediately dominates the two Nuclei π_2 and π_5 of the coordinating relation *Narration*, while it immediately dominates only the Nucleus π_2 of the subordinating relation *Elaboration* (it dominates the Satellite π'' but does not immediately dominate it[2]). This asymmetry between coordi-

[2]Dominance is the transitive closure of immediate (direct) dominance.

nating and subordinating relations in SDRS graphs can be considered as equivalent to the asymmetry present in the Mixed Principle in the framework of RST (Section 2.2).

3.2 Topic nodes

In addition to sentence and scope nodes, an SDRS can also include "topic nodes" (noted $\pi^*, \pi^{**}, \ldots$) which are constructed nodes used for representing the theme of several constituents when this theme is not linguistically realized. These topic nodes are mainly introduced for constituents linked by a coordinating relation. As an illustration, consider the discourse obtained by deleting the first sentence of (1). Its SDRS graph is exactly like the one for (1) except that π_1 is replaced by a topic node π^*: the content of π^* is *Fred's evening*. The introduction of topic nodes is mainly motivated by the Right Frontier Constraint.

3.3 Right Frontier Constraint

The notion of "right frontier" was originally proposed by [Polanyi1988]. In an SDRS graph for a discourse with n sentences (clauses), the right frontier contains the node π_n representing the last sentence, and the sentence and topic nodes which are on the rightmost branch of the graph and dominate π_n. In the graph of Figure 3, the right frontier contains the nodes π_5 and π_1. In the dynamic construction of an SDRS, via an incremental update process, the discourse constituents on the right frontier are the only available sites for attachment of new information. This is known as the "Right Frontier Constraint". Moreover, this constraint states that the antecedent of an anaphoric expression must be ("DRS-accessible") on the right frontier.

The notion of right frontier is therefore crucial in SDRT. As it relies on the distinction between coordinating/subordinating relations, this distinction has been widely discussed [Asher and Vieu2005], [Prevot and Vieu2005]. It is not in the scope of this paper to present all these discussions. Let us just say that these authors consider that a given discourse relation may have only a type *by default* which can be revised in context. For example, [Asher and Vieu2005] propose that the relation *Result* is coordinating by default, but that it becomes subordinating in some contexts.

3.4 Subordinating conjunctions and linear order

Subordinate conjunctions have been largely ignored in SDRT, in which the focus has been put on inferring the discourse relations which are not lexicalized by a discourse connective. Thereby, preposed subordinate clauses which appear before the main clause, are ignored. Hence, the following simplification: it is assumed that the Nucleus always precedes the Satellite (see the quotation "vertical arrows for subordinating relation with the newer constituent below" in Section 3.1). This simplification is not made in RST: the Satellite of a subordinating relation follows or precedes the Nucleus. As we don't want to anticipate how preposed subordinated clauses should be handled in SDRT, we limit the rest of this study – the goal of which is to compare the generative capacity of RST and SDRT – to the cases where the Satellite of a subordinating relation follows the Nucleus.

3.5 Summary on RST and SDRT, discourses in the canonical order

From this short presentation of RST and SDRT, it should be clear that the two theories do not study exactly the same set of phenomena. To carry on the comparison between the discourse structures they propose, we must limit ourselves to discourses which have been studied in both theories. That is the reason why any discourse including a preposed subordinate clause is put aside, since we have just seen that such subordinate clauses are ignored in SDRT. So the rest of this paper concerns discourses in the "canonical order", i.e. discourses of the form S_1 $(Conn_1)$ $S_2 \ldots S_i$ $(Conn_i)$ $S_{i+1} \ldots S_n$, which count n sentences, in fact n clauses, noted S_i, and with no preposed subordinate clauses. The clauses are linked by optional discourse connectives noted $Conn_i$ which appear in the initial position of their host sentence. It is assumed that S_i includes no discourse connective: this means that cases with multiple discourse connectives are put aside (they are discussed in [Webber et al.2001]). Discourses in canonical order are also supposed to involve no discourse relation such as *Attribution*. This relation raises difficulties concerning the linear order of its arguments when one of them is embedded in the other one. It is discussed in [Redeker and Egg2006] in the framework of RST and in [Hunter et al.2006] in the framework of SDRT.

The representation of S_i, whatever it is, is noted π_i. A connector $Conn_i$ lexicalizes a discourse relation noted R_i. If $Conn_i$ is not present, it is all the same assumed that there is a discourse relation R_i. In fact, there could be several discourse relations between two constituents if they are of the same type, i.e. either all coordinating or all subordinating. This is authorized in SDRT but not in RST. It can easily be authorized in RST without any drastic change: a node noted R_i/R'_i in an RST tree can be used to indicate that the two relations R_i and R'_i hold between two constituents. As R_i and R'_i are of the same type, there is no problem with the Nucleus/Satellite type of their arguments. In SDRS graphs, a horizontal arrow can be labelled R_i/R'_i if R_i and R'_i are both coordinating, and a vertical arrow can be labelled R_i/R'_i if R_i and R'_i are both subordinating.

It is clear that the discourse structures proposed in RST and SDRT are quite different, however these two theories share the fact that they rely upon discourse relations and the distinction Nucleus/Satellite or coordinating/subordinating. Do they rely upon the same set of discourse relations and do they give them the same type? The answer to these two questions is roughly affirmative. In fact, [Asher1993] started from the discourse relations proposed in [Mann and Thompson1988] and even if there exist few differences in the set of discourse relations used in RST and SDRT, they are not relevant for the study proposed here. Concerning the type given to a discourse relation, it is the same in RST and SDRT in most cases. The well-known exception is the relation *Result* which is subordinating in RST and coordinating (by default) in SDRT. As a consequence, no example involving *Result* will be presented in the rest of this paper.

We are now going to present another mode of representation for discourse structures, which is inspired by dependency grammars and which doesn't rely upon the distinction between coordinating and subordinating relations.

4 Discourse dependency DAGs

Among dependency grammars, the most famous theory is probably MTT (Meaning-Text Theory) [Mel'cuk1988], designed for sentence generation but adapted to sentence analysis by [Kahane2001]. It involves three levels of representation: semantic, syntactic and morphologic. We propose below an extension of the semantic level for discourse, and compare the discourse structures obtained to those proposed in RST and SDRT.

The core of the semantic level in MTT is a directed labelled graph in which nodes are "semantemes", either lexical or grammatical. A lexical semanteme represents a meaning of a word (e.g. 'bake1' (a potato) and 'bake2' (a cake) are two lexical semantemes for the verb *bake*). A semanteme is viewed as a predicate which is linked to its arguments (if any) by arrows pointing towards them. These arrows are labelled with numbers which distinguish the arguments.

For discourse, it can be stated that discourse relations are semantemes when they are lexicalized by a discourse connective. In this perspective, a discourse relation corresponds to the meaning of a discourse connective or to one of its meanings. By extrapolation, discourse relations which are not lexicalized are also considered as semantemes. Two sentences linked by a discourse relation R receive thus the same representation as in RST, namely a binary tree whose root is R and whose leaves are the sentence representations. However, there is a crucial difference between semantic dependency graphs and RST representations, namely the tree structure of the graphs: a semantic dependency graph is not always tree shaped, while RST representations are compulsorily tree shaped (Section 2.1). This difference comes from the way predicate-argument relations are computed. In semantic dependency graphs, whether they represent a sentence as in MTT or a discourse in the MTT extension proposed here, predicate-argument relations are computed in a simple and standard way: the arguments of a predicate (e.g. a discourse relation) are always its daughters. There is no equivalent to the Nuclearity principle used in RST (Section 2.1). For example, the dependency graph for (1) – in fact a DAG, see below – is shown in Figure 4. In this graph, π_2 has two parents, which straightforwardly translates the fact that π_2 is argument of two discourse relations. On the other hand, it must be remembered that this fact is not graphically visible in the RST tree for (1) (see Figure 2); it requires the help of the Nuclearity Principle.

Convention: In this paper, any RST tree must be interpreted with the Mixed Principle, any dependency graph with the standard interpretation. To avoid confusion, edges are graphically represented as *lines* in RST trees and as *arrows* in semantic dependency graphs.

What are the constraints which govern dependency graphs representing discourse structures?

First, it is assumed that they are acyclic. Therefore, these dependency graphs are DAGs (Directed Acyclic Graphs). In these DAGs, it is assumed that the leaves, projected on a horizontal line, are ordered, as it is the case of the leaves of an RST tree. It is also assumed that any non terminal node has exactly two daughters, which comes from the fact that a non terminal node is a discourse relation with two arguments (see note 1).

Second, from our knowledge of the semantics of discourse connectives, two (minimal) constraints, noted C_1 and C_2, can be postulated for discourses in the canonical

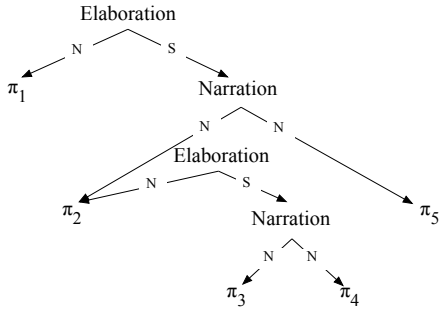

Figure 4: Dependency graph for (1)

order (in particular, without preposed subordinate clauses, see Section 3.5) of the form S_1 $(Conn_1)$ $S_2 \ldots S_i$ $(Conn_i)$ $S_{i+1} \ldots S_n$. Constraint C_1 states that the first argument of a discourse connective $Conn_i$ is on the left of $Conn_i$. Constraint C_2 states that a sentence S_{i+1} introduced by a discourse connective $Conn_i$ is under the semantic scope of this connective. By extrapolation, I postulate that these two constraints also hold when a discourse relation R_i is not lexicalized by a discourse connective. These constraints are formulated as follows in semantic dependency DAGs.

Constraint C_1: the first argument of R_i is the representation of a text span which appears on the left of $(Conn_i)$ S_{i+1}.

Constraint C_2: the second argument of R_i is the representation of a text span which starts at π_{i+1} (this text span can be reduced to π_{i+1}). In terms of dominance, C_2 means that R_i dominates π_{i+1}.

Let us show that constraints C_1 and C_2 are respected both in RST and SDRT, which is not a surprise since they are minimal. In RST, the "adjacency principle" is postulated. It states that the arguments of a discourse relation expressed through a discourse connective are given by continuous text spans which are *adjacent* to the discourse connective [Mann and Thompson1987]. The adjacency principle is also postulated when R_i is not lexicalized. This principle makes no distinction between the first and second argument of a discourse relation. More precisely, it is equivalent to constraints C_1' and C_2, in which C_1' mirrors C_2 (C_1' is thus a constraint which is stronger than C_1).

Constraint C_1': the first argument of R_i is the representation of a text span which ends at π_i (this text span can be reduced to π_i). In terms of dominance, C_1' means that R_i dominates π_i.

Constraints C_1' and C_2 are used in [Egg and Redeker2007] (this volume) for underspecified discourse representations in the framework of RST. For a discourse in the canonical order with n sentences, the underspecified representation they propose is given in Figure 5 (a dotted line represents dominance, a solid line immediate domi-

nance). This underspecified representation respects exactly constraints C_1' and C_2.

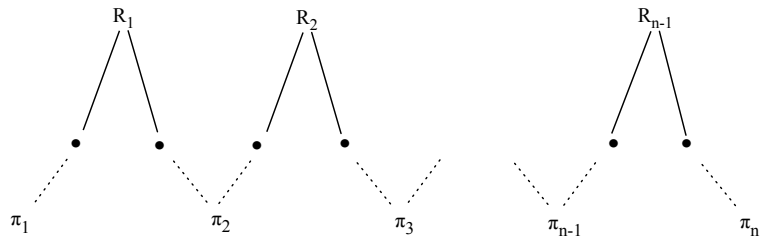

Figure 5: Underspecified RST representation from [Egg and Redeker2007]

In SDRT, constraints C_1'' (below) and C_2 can be inferred from the incremental updating process. In a simplified way, when dealing with the current sentence S_{i+1}, the underspecified condition $?R(\alpha, \pi_{i+1})$ holds, in which $?R$ is a discourse relation variable, which will be specified as R_i in our notation, and α is an attachment site which must be on the right frontier of the SDRS graph representing the left-context of $(Conn_i)S_{i+1}$ (Section 3.3). Therefore, a constraint stronger than C_1 holds for the first argument of R_i, namely C_1''.

Constraint C_1'': the first argument of R_i is a text span which appears on the right frontier of the SDRS graph representing the left context of $(Conn_i)$ S_{i+1}.

For the second argument of R_i, the underspecified condition $?R(\alpha, \pi_{i+1})$ states that π_{i+1} is the second argument of R_i. However, later on in the non-monotonous updating process, this condition may be revised so that R_i only dominates π_{i+1}. This means that C_2 is also respected in SDRT.

In conclusion, dependency graphs representing discourse structures are ordered DAGs, in which non-terminal nodes are discourse relations with two daughters. The predicate-argument relations respect a heavy constraint C_2 on the right argument and a weaker constraint C_1 on the left argument. RST and SDRT also respect C_2 for the second (right) argument, while these discourse theories respect respectively C_1' and C_1'' for the first (left) argument, these constraints being stronger than C_1.

From this data, one can expect dependency DAG formalism to be more powerful in strong generative capacity than RST and SDRT. This will indeed be shown in Section 5. Constraints C_1' and C_1'' cannot be directly compared without taking into account other RST or SDRT constraints (e.g. the constraint stating that RST structures must be tree shaped). However, it will be shown in Section 5 that RST is less powerful in strong generative capacity than SDRT.

Let us underline the following point: the only constraints which hold on discourse dependency DAGs are C_1 and C_2 which don't involve the coordinating/subordinating distinction, which is so crucial in RST and SDRT. The next section will examine the consequences of this fundamental difference.

To illustrate the constraints on dependency DAGs, let us examine what are the possible DAGs for discourses in the canonical order with three sentences, a case which

will be thoroughly studied in Section 5. The possible DAGs have three ordered leaves, $\pi_1 < \pi_2 < \pi_3$, two non terminal nodes R_1 and R_2. The heavy constraint C_2 means that the second argument of R_1 must start at π_2, and that π_3 is compulsorily the second argument of R_2. The weaker constraint C_1 means that π_1 is compulsorily the first argument of R_1. These constraints leave us with four possible non-labelled DAGs[3], which are shown in Figure 6. Two of them are non tree shaped (one in which π_1 has two parents, the other one in which π_2 has two parents), the two others are tree shaped.

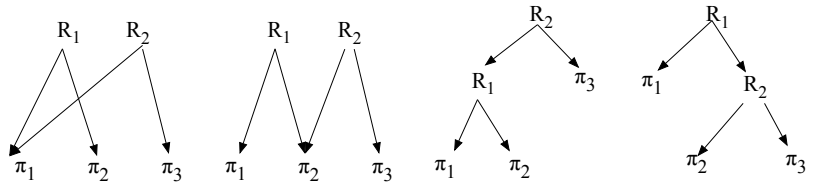

Figure 6: Non-labelled DAGs for a discourse with three sentences in the canonical order, respecting constraints C_1 and C_2

A crucial point is that constraint C_2 excludes the non tree shaped DAG in which π_3 has two parents, namely the DAG in Figure 7. This DAG is excluded since the second argument of R_1 does not start at π_2 (in other words R_1 does not dominate π_2), and so constraint C_2 is not respected. There seems to exist no felicitous discourse whose structure is the DAG in Figure 7. As explained in [Danlos2004], this is justified on psycho-linguisitic grounds: what would be a discourse in which the second sentence is not linked at all to the first one?[4]

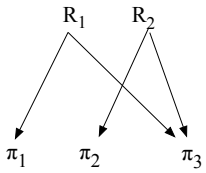

Figure 7: Non-labelled DAG which does not respect constraint C_2

Summary of the representations for discourse structures: Taking as illustration the discourse in (1), we have examined three representations for discourse structures: RST trees, SDRT graphs and dependency DAGs.

[3]Non-labelled graphs do not take into account the labels (N or S) on the edges.

[4]The link between the first two clauses of a discourse can be given by a third sentence, as in (i) below in which S_3 establishes a joint link between S_1 and S_2 through its plural subject. See also (ii) in which the first two sentences establish the setting for the third sentence. These discourses must be orally uttered with a special intonation.

(i) It is raining. Fred arrived late. These two facts irritated Mary.

(ii) The sun was shining. Nice music was playing on the radio. Fred woke up in a good mood that day.

We are going to compare the strong generative capacity of these three formalisms.

5 Strong generative capacity

To compare the strong generative capacity of the three formalisms under study, I start with quite a simple case of discourses in the canonical order, namely discourses with three sentences (clauses) noted here as S_1 $(Conn_a)$ S_2 $(Conn_b)$ S_3. Their discourse structures involve three sentence representation nodes noted π_i and two discourse relations noted R_a and R_b. The methodology is the following: I begin with RST trees, since RST is the most constraining formalism. Next I move to semantic dependency DAGs, since this formalism is the least constraining one. This will allow me to situate SDRT in between these two formalisms.

5.1 RST trees and their equivalents in the other representations

For discourses in the canonical order of the form S_1 $(Conn_a)$ S_2 $(Conn_b)$ S_3, RST trees must have three ordered leaves ($\pi_1 < \pi_2 < \pi_3$) and two internal nodes (R_a and R_b). To respect the tree structure, one internal node must be the daughter of the other one. Therefore, there exist only two non-labelled binary trees[5], namely either $R_b(R_a(\pi_1, \pi_2), \pi_3)$ or $R_a(\pi_1, R_b(\pi_2, \pi_3))$. These two trees lead to eight RST trees with the edges labelled. First, the four cases with an embedded *subordinating* discourse relation are examined, next the four other cases - with an embedded *coordinating* relation - are examined.

Cases with an embedded subordinating relation: In Table 1, the first row shows the four RST trees with an embedded satellite-nucleus relation, namely (Ia)-(IVa). The second row shows the equivalent dependency DAGs, namely (Ib)-(IVb). None of these DAGs is tree shaped. This comes from the fact that the Nuclearity Principle is involved to compute the predicate-argument relations in the RST trees (Ia)-(IVa) since the embedded relation is subordinating. For example, in (Ia), the Nucleus of R_b is π_1, which is also the Nucleus of R_a; hence the dependency DAG (Ib), in which π_1 has two parents.

The third row in Table 1 shows the equivalent SDRT graphs. Let us describe the SDRT graph in (Ic) with the help of the predicate-argument relations visible in (Ib): starting from π_1, there is a vertical arrow pointing towards π_2 and labelled with the subordinating relation R_a. Next, from π_1, there is a horizontal arrow pointing towards π_3 and labelled with the coordinating relation R_b. The scope label π' immediately dominates π_1 and π_3, and dominates π_2.

The four discourse structures (I)-(IV) given in Table 1 can all be linguistically realized in felicitous discourses, for example in the discourses given in (2).

(2) a. Fred was badly sick last week. He had a bad flu. However, he is in good shape this week
Structure (I) with R_a = Elaboration and R_b = Contrast

[5] As explained in note 3, non-labelled graphs don't take into account the labels N and S on the edges, that is the coordinating vs subordinating nature of discourse relations.

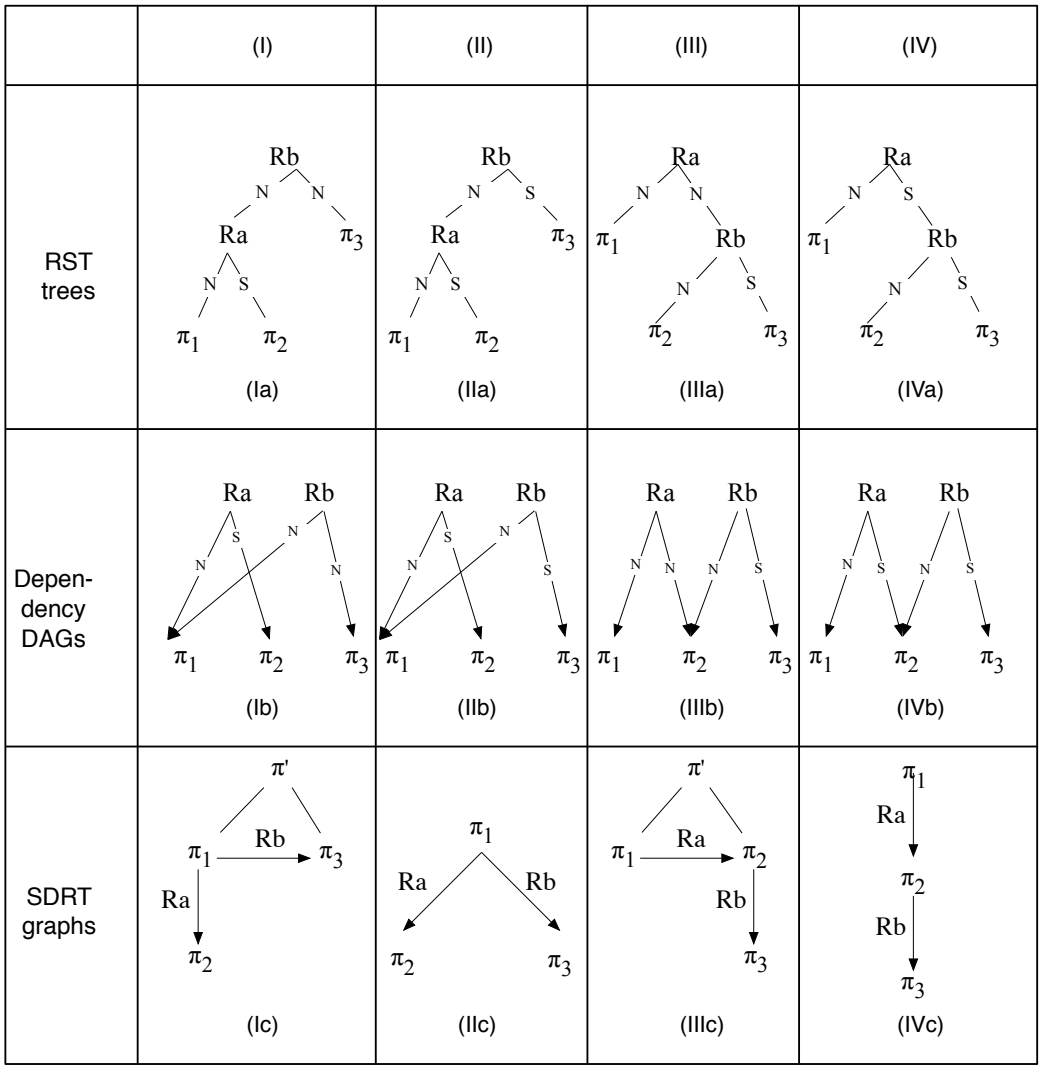

Table 1: RST trees for S_1 $(Conn_a)$ S_2 $(Conn_b)$ S_3 with an embedded *subordinating* relation, and their equivalent dependency DAGs and SDRT graphs.

b. Fred is badly sick. He probably has the flu. He took a walk in the rain yesterday.
Structure (II) with R_a = Elaboration and R_b = Explanation

c. Fred is in good shape. However, Mary is badly sick. She has a bad flu.
Structure (III) with R_a = Contrast and R_b = Elaboration

d. Fred was in a foul mood. He hadn't slept well that night. His electric blanket hadn't worked.[6]
Structure (IV) with R_a = Explanation and R_b = Explanation

Cases with an embedded coordinating relation: In Table 2, the first row shows the four RST trees with an embedded multi-nuclear relation, namely (Va)-(VIIIa). The second row shows the equivalent dependency DAGs, namely (Vb)-(VIIIb), which are all tree shaped. The RST trees and dependency DAGs are quite similar: graphically, they differ only by the edges which are lines in RST trees and arrows in dependency DAGs, according to the convention presented in Section 4. This similarity comes from the fact that the predicate-argument relations in the RST trees (Va)-(VIIIa) are computed in the standard way (i.e. without involving the Nuclearity Principle). For example, in (Va), the Nucleus of R_b is the sub-tree rooted at R_a, hence the dependency DAG (Vb). The third row in Table 2 shows the equivalent SDRT graphs. In these graphs, the topic nodes are omitted for the sake of simplicity: the scope nodes are supposed to play their roles on the right frontier for the attachment of new information.

The four discourse structures (V)-(VIII) given in Table 2 can all be linguistically realized in felicitous discourses, for example in (3).

(3) a. Fred ate a big salmon. He also devoured a lot of cheese. On the other hand, Mary missed her diner.
Structure (V) with R_a = Parallel/Narration[7] *and R_b = Contrast*

b. Fred ate a big salmon. He also devoured a lot of cheese. This was a fantastic meal.
Structure (VI) with R_a = Parallel/Narration and R_b = Comment[8]

c. Fred missed his diner. On the other hand, Mary ate a big salmon. She also devoured a lot of cheese.
Structure (VII) with R_a = Contrast and R_b = Parallel/Narration

d. Fred had a fantastic meal. He ate a big salmon. He also devoured a lot of cheese.
Structure (VIII) with R_a = Elaboration and R_b = Parallel/Narration

In conclusion, for discourses in the canonical order of the form S_1 $(Conn_a)$ S_2 $(Conn_b)$ S_3, RST allows exactly eight discourse structures. These eight RST trees correspond to dependency DAGs and SDRT graphs which are authorized in these two formalisms. They can all be linguistically realized in felicitous discourses.

[6] This discourse is taken from [Hobbs1979].

[7] The notation R_a = *Parallel/Narration* has been introduced in Section 3.5. It means that the two coordinating relations *Parallel* and *Narration* can be inferred to link π_1 and π_2.

[8] *Comment* is subordinating both in RST and SDRT.

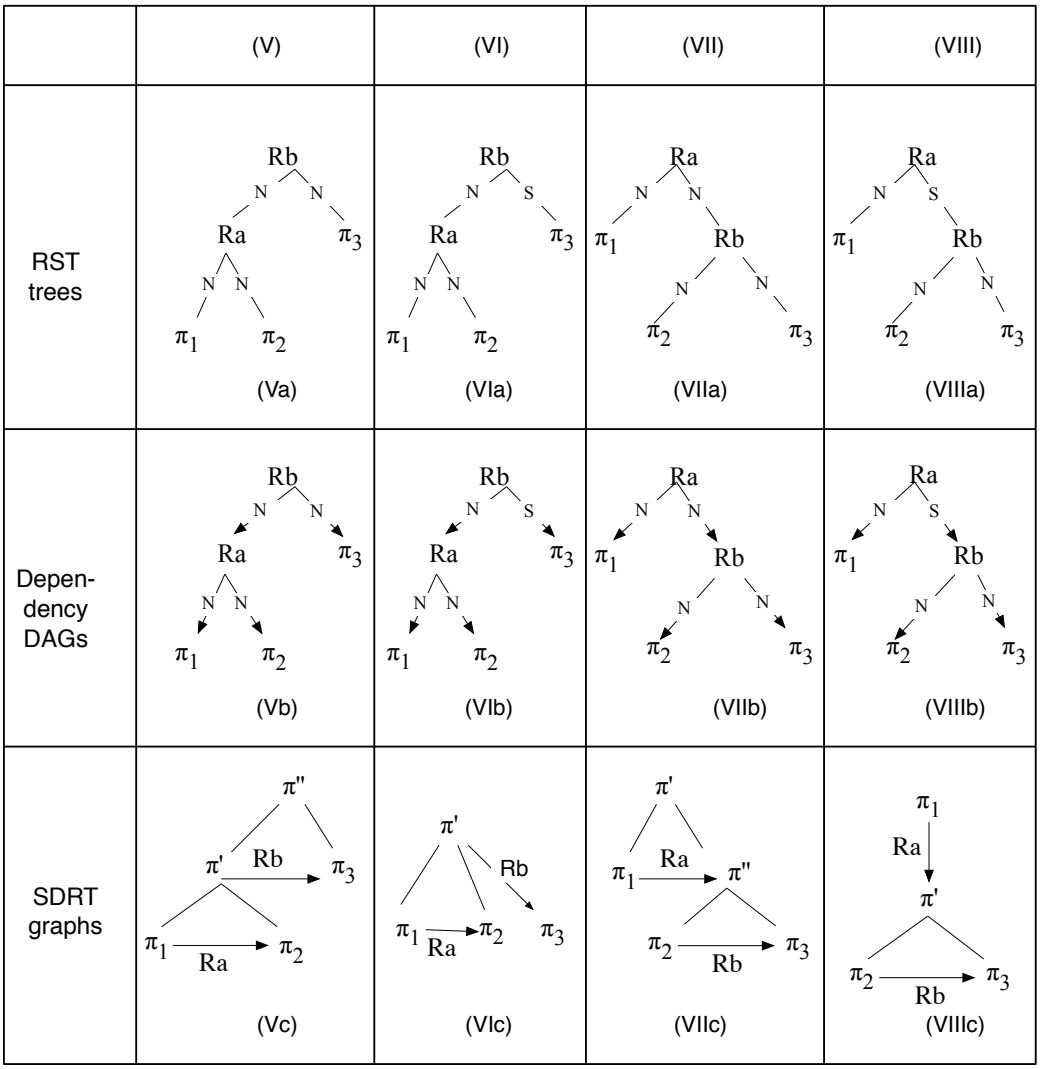

Table 2: RST trees for S_1 $(Conn_a)$ S_2 $(Conn_b)$ S_3 with an embedded *coordinating* relation, and their equivalent dependency DAGs and SDRT graphs.

5.2 Dependency DAGs without any equivalent RST tree

We have shown in Section 4 that there are four non-labelled DAGs for discourses in the canonical order of the form S_1 $(Conn_a)$ S_2 $(Conn_b)$ S_3, respecting constraints C_1 and C_2. When the edges are labelled, sixteen DAGs are obtained (four for each non-labelled DAG). Eight of these DAGs have already been examined in the previous section: DAGs (Ib)-(VIIIb) in Tables 1 and 2 with an equivalent RST tree. We are left with the eight other DAGs without any equivalent RST tree, which thus correspond to discourse structures excluded in RST. We are going to examine whether these discourse structures are also excluded in SDRT or not, and study their linguistic realization. We start with the four non tree shaped DAGs.

5.2.1 Non tree shaped DAGs without any equivalent RST tree

Non tree shaped DAGs in which π_1 has two parents: DAGs (IXb) and (Xb) in Table 3 differ from DAGs (Ib) and (IIb) in Table 1 by the fact that R_a is *coordinating* (and not subordinating). Hence the impossibility of obtaining RST trees (interpreted with the Mixed Principle) with the same predicate-argument relations.

These DAGs convert into the SDRT graphs (IXc) and (Xc), which are excluded by the Right Frontier Constraint (Section 3.3): π_3 cannot be attached to π_1 which is not on the right frontier.

Non tree shaped DAGs in which π_2 has two parents: DAGs (XIb) and (XIIb) in Table 3 differ from DAGs (IIIb) and (IVb) in Table 1 by the fact that R_b is *coordinating* (and not subordinating). In structure (XII), it is assumed that $R_a \neq R_b$. In other words, this discourse structure does not involve a unique discourse relation linking three constituents.

SDRT graph (XIc) is excluded by the "Continuing Discourse Pattern Constraint" which states that "coordinated constituents of a substructure must behave in a homogeneous fashion with respect to a dominating constituent", [Asher and Vieu2005][9]. In the non-monotonous updating process of SDRT, graph (XIc) is compulsorily transformed into graph (VIIIc) in Table 2, in which the two coordinated constituents are dependent on π_1.

On the other hand, SDRT graph (XIIc) is not excluded by any constraint.

Remark on the arborescence of SDRT graphs and their projectivity: SDRT graphs never look like trees since they contain horizontal arrows (for coordinating relations). Nevertheless, one can disregard these horizontal arrows and examine the arborescence of SDRT graphs focusing on the relations between a mother and a daughter coming from a subordinating relation (graphically a vertical or oblique arrow) or a scope relation (graphically an oblique line). In this perspective, SDRT graphs (Ic)-(IXc) look like trees with a single root and a single parent for each node. However, this is not the case for (Xc)-(XIIc): in each of these graphs, one node has two parents - π_1 in (Xc), π_2 in

[9] A similar constraint has been put forward in syntax for coordination: [Sag et al.1985], for example, state that two constituents can be coordinated only if they have the same syntactic function.

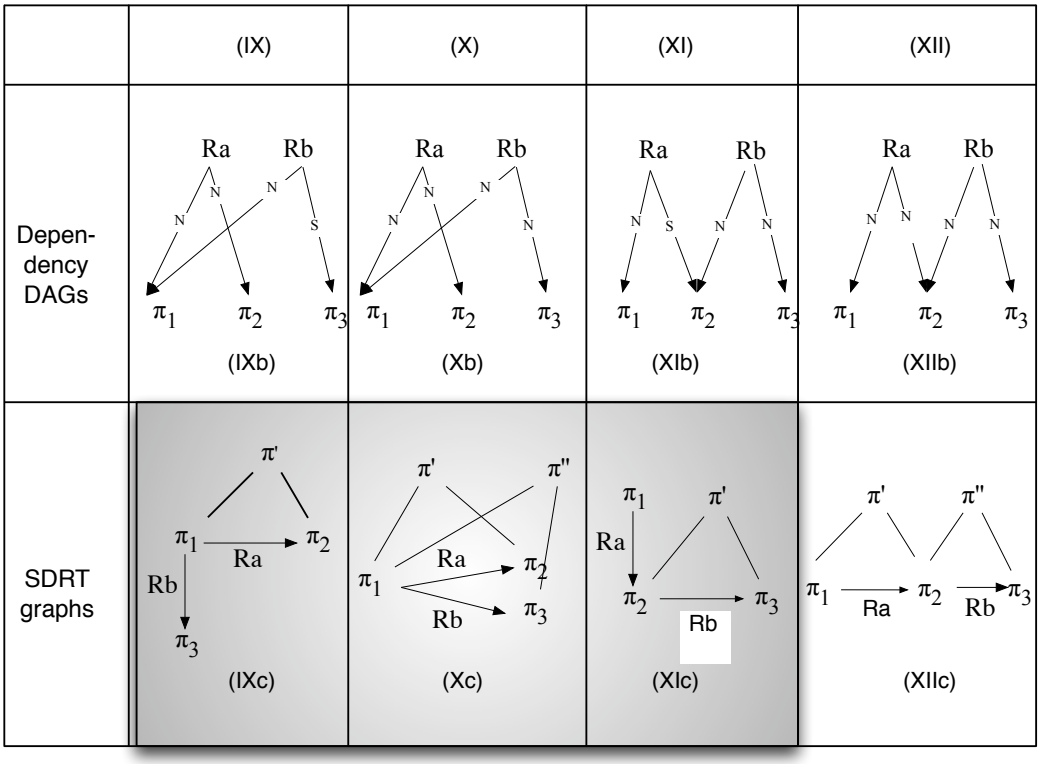

Table 3: Non tree shaped dependency DAGs without any equivalent RST tree, and their equivalent SDRT graphs (on a shaded background for those which are excluded by the theory)

(XIc) and (XIIc). The fact that (XIIc) is not excluded means that an SDRT graph can be non tree shaped.

SDRT graph (IXc) is tree shaped (disregarding horizontal arrows) but it doesn't respect the Right Frontier Constraint. Let us show that this SDRT tree is not "projective"[10]. The notion of projectivity has been introduced in dependency grammars for syntax. First a definition: in a tree, the (maximal) *projection* of a node x, noted $Proj(x)$, is the set of nodes dominated by x, x included. A syntactic dependency tree for a sentence is *projective* iff all the projections of words are continuous segments of the sentence [Lecerf1961]. Lecerf proved that a dependency tree is projective iff dependencies never cross each other and no dependency covers the root. As an illustration, if w_1, w_2, w_3, and w_4 are four words occurring in a projective dependency tree with the linear order $w_1 < w_2 < w_3 < w_4$, then it is not possible that w_1 be linked to w_3 and w_2 to w_4 (such a case is known as "crossing dependencies"). The notion of projectivity can be straightforwardly extended to SDRT trees (i.e. SDRT graphs which are tree shaped disregarding horizontal arrows). The reader can check, for example, that the SDRT graph for (1) in Figure 3 is a projective tree. The SDRT graphs (Ic)-(VIIIc) are also projective trees. On the other hand, this is not the case for (IXc) which is not projective: Proj(π_1) $= \{\pi_1, \pi_3\}$ does not form a continuous segment since there is π_2 which intervenes between π_1 and π_3. In summary, (Ic)-(VIIIc) are projective trees and they respect the Right Frontier Constraint, while (IXc) is not projective and doesn't respect the Right Frontier Constraint. More generally, it is possible to show that an SDRT tree is projective iff it respects the right frontier constraint (Sylvain Kahane, pc)[11].

We are now going to examine how the discourse structures (IX)-(XII) given in Table 3 are linguistically realized. We start with structure (IX), which raises questions on the status of anaphoric relations in discourse structures.

Linguistic realization of (IX): The discourse (4) involves an anaphoric link between an indefinite NP (*a salmon*) in the first sentence and a definite NP in the third sentence (*the salmon*). It can be given structure (IX), represented as the dependency DAG (IXb), with R_a = *Parallel/Narration* and R_b = *Elaboration/Comment*. This discourse is felicitous, and numerous examples following this pattern, in which the third sentence elaborates/comments an entity occurring in the first sentence, can be found in corpora.

(4) Fred ate a big salmon. He also devoured a lot of cheese. The salmon came from Norway.

As structure (IX) does not correspond to any RST tree (because of the Mixed Principle) and is excluded in SDRT (because of the Right Frontier Constraint), other analyses for (4) are proposed in these discourse theories. In the framework of RST, [Egg and Redeker2007] (this volume) would give (4) the tree shaped structure (VIa) in Table 2, with again R_a = *Parallel/Narration* and R_b = *Elaboration/Comment*. In this tree, the Nucleus of R_b is

[10] I thank Sylvain Kahane for drawing my attention to projectivity issues.

[11] This rule is valid only for SDRT trees such that the Nucleus of any subordinating relation occurs before the Satellite. This is the case for the SDRT trees studied here, which represent discourses in the canonical order (Section 3.5).

the sub-tree rooted at R_a. This means that the anaphoric link between *a salmon* and *the salmon* is ignored in the discourse structure. More generally, Egg and Redeker claim that "anaphora can create relations between sentences that are not directly linked by discourse structure". This position is not adopted by [Wolf and Gibson2005]: although these authors work in the RST framework, they would give (4) structure (IX) and use such examples as evidence against the arborescence of discourse structures.

In the framework of SDRT, the anaphoric definite expression *the salmon* in (4) violates the constraint stating that the antecedent of an anaphoric expression must be on the right frontier (Section 3.3). However, [Asher2007] (this volume) claims that such a definite NP, which has presuppositional content, is accommodated with the following consequence: the referent for *a salmon* is introduced in the topic π^* of π_1 and π_2 (see Section 3.2 for the notion of topic). π^* is on the right frontier and π_3 is attached to π^*. The SDRT graph for (4) is shown in Figure 8, with R_a = *Parallel/Narration* and R_b = *Elaboration/Comment*. It respects the Right Frontier Constraint both for the attachment of π_3 and for the antecedent of *the salmon*. As explained in Section 5.2, topic nodes are omitted in the diagrams of Table 2 for the sake of simplicity. If it were not the case, the diagram (VIc) in Table 2 would be replaced by the one in Figure 8. This amounts to saying that [Asher2007] gives (4) structure (VI) (disregarding topic nodes), which is the structure advocated in [Egg and Redeker2007] in the framework of RST.

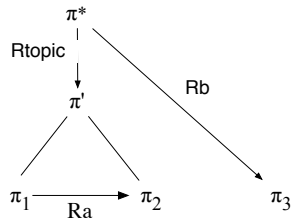

Figure 8: SDRT graph proposed in [Asher2007] for discourse (4)

To sum up, (4) is given either structure (VI) or (IX) according to the positions adopted for the status of anaphoric relations in discourse structures.

We have seen that (IXc) is not projective. In syntax, it is well-known that most structures for English (or French) sentences are projective, but not all of them. If (4) is given structure (IX), then it can be stated that most structures for English (or French) discourses are projective, but not all of them.

What can be said about crossing dependencies in discourse? Consider discourses with four sentences (clauses) in which the third sentence elaborates an entity occurring in the first one (or elaborates the first one) and the fourth sentence elaborates an entity occurring in the second one (or elaborates the second one). Such discourses, which have been examined by [Stede1999], [Wolf and Gibson2005] and [Egg and Redeker2007] (this volume), are illustrated in (5), with the anaphoric links *a big salmon/the salmon* and *a lot of cheese/the cheese*.

(5) Fred ate a big salmon. He also devoured a lot of cheese. The salmon came from

Norway. The cheese came from France.

If anaphoric links are taken into account in discourse structure - Wolf and Gibson's position - then the dependency DAG for (5) includes crossing dependencies, namely $Elaboration(\pi_1, \pi_3)$ and $Elaboration(\pi_2, \pi_4)$. On the other hand, Egg and Redeker (this volume) and Asher (pc.) would give (5) a structure which doesn't reflect the anaphoric links[12].

In conclusion, a definite anaphoric NP can have its antecedent *a priori* anywhere in its left context (as long as binding constraints are respected). Taking into account anaphoric links in discourse structures raises a problem for the arborescence of RST structures and for the Right Frontier Constraint in SDRT, and leads to crossing dependencies in dependency DAGs. Another solution, advocated by Egg in RST and Asher in SDRT, consists in not systematically representing anaphoric links in discourse structures. I have no conclusive argument to decide between these two solutions.

Linguistic realization of (X): Structure (X) in Table 3, in which two coordinating relations have the same constituent as first argument, violates the SDRT Right Frontier Constraint for the attachment of π_3. It turns out that it is hard to imagine an example with this structure. Nevertheless, let us examine the discourse in (6a). It is a priori of structure (X) with *also* lexicalizing R_a = *Parallel* and *next* lexicalizing R_b = *Narration*. However, one can argue that the second sentence (*Mary did too*) is perceived as secondary information, which amounts to demoting the coordinating relation *Parallel* down to a subordinating relation, and therefore to giving (6a) structure (I) in Table 1 instead of structure (X). We are left with the cases where (6a) is part of a longer discourse in which Fred and Mary are on an equal footing, for example (6b).

(6) a. Fred ordered salmon. Mary did too. Next, he had an apple pie.
Structure (X) with R_a = Parallel and R_b = Narration

b. Fred and Mary went to a fancy restaurant last night. *Fred ordered salmon. Mary did too. Next, he had an apple pie.* On the other hand, Mary had cheese cake.

In (6b), the narrative of Fred and Mary's dinner is organized following the dishes they ordered: first the main course, next the dessert. This narrative structure can be reflected in an SDRT graph in which the topic π^* of the second and third sentences is *Fred and Mary's main course* to which is attached the topic π^{**} of the fourth and fifth sentences defined as *Fred and Mary's dessert*. This discourse structure is given in Figure 9. In this structure, the sub-discourse (6a) is not given structure (X).

In a nutshell, since (6a) illustrates the only pattern of felicitous discourses with structure (X) I can imagine, it would seem that this structure cannot be linguistically realized, provided that it is accepted that the coordinating/subordinating type of a discourse relation changes according to the context (for example, provided that it is accepted that the coordinating relation *Parallel* can be demoted down to a subordinating relation in context).

[12] In this structure, the third and fourth sentences form a complex constituent which elaborates/comments the complex constituent made up of the first and second sentences (which are linked by the relation *Parallel/Narration*).

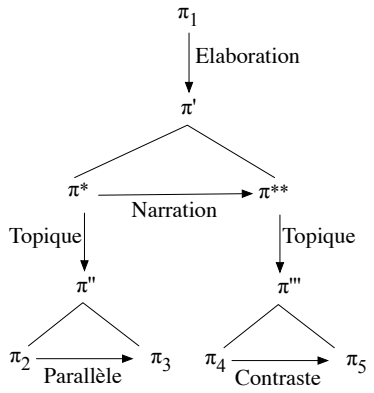

Figure 9: SDRT graph for the discourse in (6b)

Linguistic realization of (XI) and (XII): discourses (7a) and (7b) illustrate respectively structures (XI) and (XII).

(7) a. Mary is worrying because her eldest son has bad marks. Her youngest son also has bad marks (but she doesn't care).
Structure (XI) with R_a = Explanation and R_b = Parallel

b. Fred tidied up his bedroom this afternoon. Mary did too. Next she went to the movies.
Structure (XII) with R_a = Parallel and R_b = Narration

In SDRT, the discourse in (7a) cannot be given structure (XI): SDRT graph (XIc) is transformed into graph (VIIIc) in Table 2 by the Continuing Discourse Pattern Constraint (see above). For (7a), this constraint amounts to inferring that Mary is also worrying about the bad marks of her youngest son, although this may be wrong (as suggested by the element we put into brackets *but she doesn't care*). These data lead us to state that the Continuing Discourse Pattern Constraint could be maintained when the subordinating relation R_a is *Elaboration*, but should not be maintained when R_a is *Explanation*. This allows (7a) to be analyzed as (XIc).

We have seen that (XIc) and (XIIc) are not tree shaped (disregarding horizontal arrows) since the node π_2 has two parents. The felicitous examples in (7) show that non tree shaped SDRT graphs must be authorized.

5.2.2 Tree shaped DAGs without any equivalent RST tree

In the four tree shaped dependency DAGs in Table 2, namely (Vb)-(VIIIb), the embedded relation is *coordinating*. What can be said about the discourse structures corresponding to the four other tree shaped DAGs with an embedded *subordinating* relation? Consider DAG (XIIIb) in Figure 10 (this figure also includes the equivalent SDRT graph which is commented below). The Nucleus argument of R_b in this DAG is the sub-tree

rooted at R_a. This predicate-argument relation is not possible in (Marcu's version of) RST because of the Nuclearity Principle which states that the Nucleus argument of R_b is π_1.

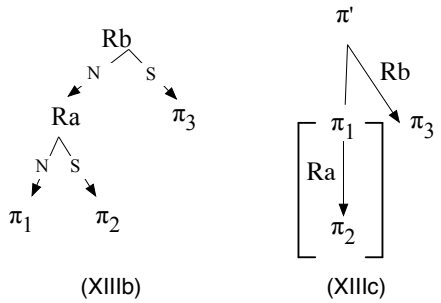

Figure 10: DAG (XIIIb) and its equivalent SDRT graph

The discourse structure (XIIIb) can be felicitously realized, for example in discourse (8), in which the antecedent of *this* is the interpretation of its left context, namely the causal relation linking the interpretations of the two first sentences.

(8) Fred is upset because his wife is abroad for a week. This proves that he does love her.
Structure (XIIIb) with R_a = Explanation and R_b = Comment

The discourse structure for (8) is not controversial. In the framework of RST, Egg (pc.) indeed does analyze (8) as (XIIIb) and acknowledges that this is a clear counter-example to the systematic applicability of the Nuclearity Principle. In SDRT, Asher (pc.) analyzes (8) as (XIIIc), i.e. as a graph including brackets around π_1, π_2 and the arrow labelled R_a. These brackets mean that (XIIIc) must be interpreted as including a complex constituent formed by π_1 and π_2 linked by R_a. This is not yet formalized in the theory, in which only complex constituents formed around a coordinating discourse relation are formally handled in the present state of the formalism.

In summary, neither RST nor SDRT can accurately handle the structure of (8). This is explained by the fact that (8) does not fit with the basic principles of these theories which rely heavily on the coordinating/subordinating distinction and consider the relation *Explanation* as subordinating and the explanation of a fact as a satellite of lower importance. Yet, in (8), the explanation given for Fred's being upset is essential for the interpretation of the third sentence[13].

The only formalism in which the structure of (8) does not raise any problem is the dependency DAG formalism, which goes along with the fact that this formalism does not make any use of the coordinating/subordinating distinction.

[13]Nevertheless, neither Egg nor Asher contemplate the solution consisting in promoting *Explanation* as a coordinating relation in an example such as (8).

The three other tree shaped DAGs with an embedded *subordinating* relation raise the same questions as (XIIIb). So I will not comment on them in detail and I consider that they can all be linguistically realized in a felicitous way.

6 Summary and Conclusion

First, we give an assessment on the strong generative capacity of RST, SDRT and dependency DAG formalism, for discourses in the canonical order with three sentences.

There exist sixteen dependency DAGs which respect the minimal constraints C_1 and C_2 exposed in Section 4.

RST – in the version presented in Section 2 – authorizes only eight discourse structures, namely structures (I)-(VIII) in tables 1 and 2. These discourse structures can all be realized in felicitous discourses. However, RST is too restrictive: it excludes discourse structures which can be realized in felicitous discourses, as described below.

SDRT authorizes the eight discourse structures admitted by RST and the two structures (XI)[14] and (XII), which are realized in felicitous discourses, cf. (7).

SDRT excludes structures (IX) and (X) because of the Right Frontier Constraint. The question of whether structure (IX) can be realized in felicitous discourses depends (at least) upon the status that should be given to anaphoric links: should they be systematically reflected in discourse structures or not (cf. the discussion of examples (4) and (5))? Concerning structure (X), it seems hard to find a felicitous discourse realizing it (see the discussion of (6)). If it turns out that this structure cannot indeed be realized in felicitous discourses, this is a strong argument in favor of the Right Frontier Constraint for the attachment of new information and, thereby, a strong argument against the dependency DAG formalism which cannot exclude structure (X).

We are left with structure (XIII) and the three other structures in which a subordinating relation forms a complex constituent. These structures can be realized in felicitous discourses, see (8). Only dependency DAG formalism authorizes them[15].

In conclusion, none of the three formalisms under study – RST, SDRT, and dependency DAG formalisms – has the appropriate strong generative capacity. These formalisms are either too restrictive or too powerful. This conclusion may sound negative, however we hope this study will shed new light on the constraints which must hold on discourse structures and on the following open questions: should the distinction between the coordinating/subordinating type of discourse relations be kept? Should the type of a given discourse relation be fixed in a static way – which is easy to implement – or computed in a dynamic way according to the context - which is hard to implement and may give rise to vicious circles?

What can be expected about the strong generative capacity of these formalisms for discourses in the canonical order with more than three sentences? The same results as those obtained for discourses in the canonical order with three sentences. This is because constraints are too restrictive in RST, not restrictive enough in DAG formalism, and not totally adequate in SDRT, whatever the number of sentences.

[14] If the Continuous Discourse Pattern Constraint is applied in a limited way, which means that (XIc) is not excluded.

[15] SDRT is ready to authorize them, but does not yet have the formal mechanism to do it

On the other hand, there is an unknown factor, namely the number of discourse structures which can be realized in felicitous discourses. Consider discourses in the canonical order with four sentences. There exist five non-labelled RST trees and twenty-five non-labelled dependency DAGs respecting constraints C_1 and C_2 for these discourses. This leads to forty labelled RST trees and two hundred labelled dependency DAGs. We cannot tell where the number of felicitous discourses stands between forty and two hundred.

Future research is needed for discourses which are not in canonical order, for example, for discourses with preposed subordinate clauses or discourses with multiple discourse connectives in the same clause.

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