Document Structure

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We argue the case for abstract document structure *as a separate descriptive level in the analysis and generation of written texts. The purpose of this representation is to mediate between the message of a text (i.e., its discourse structure) and its physical presentation (i.e., its organization into graphical constituents like sections, paragraphs, sentences, bulleted lists, figures, and footnotes). Abstract document structure can be seen as an extension of Nunberg's "text-grammar"; it is also closely related to "logical" markup in languages like HTML and LaTeX. We show that by using this intermediate representation, several subtasks in language generation and language understanding can be defined more cleanly.*

1. Introduction

When language is written, it appears as a collection of words set out on one or more (actual or virtual) pages. In fact, much of what we tend to call "text" has a strong graphical component (Schriver 1997; Scott and Power 2001). Not only are the words often accompanied by conventional graphics such as pictures or diagrams, but they themselves form graphical elements such as titles, headings, chapters, sections, captions, paragraphs, and bulleted lists.

The overlay of graphics on text is in many ways equivalent to the overlay of prosody on speech. Just as all speech has prosody (even if it is a monotone), so too do all texts have layout (even if it is simple wrapped format, in a single face and font, and makes rudimentary use of white space). And just as prosody undoubtedly contributes to the meaning of utterances, so too does a text's graphical presentation contribute to its meaning. However, although there is a long tradition and rich linguistic framework for describing and representing speech prosody (e.g., Halliday 1967; Chomsky and Halle 1968; Crystal 1969; Bolinger 1972; Pierrehumbert 1980; 't Hart, Collier, and Cohen 1990; Ladd 1996), the same is not true for text layout. Perhaps not surprisingly, therefore, few natural language understanding (NLU) systems use graphical presentational features to aid interpretation, and few natural language generation (NLG) systems attempt to render the output texts in a principled way.

Of course, since all texts have a graphical dimension, all NLG systems will, by definition, produce laid-out texts. In all but a few recent cases (the ICONOCLAST system (Power 2000; Bouayad-Agha, Power, and Scott 2000; Bouayad-Agha, Scott, and Power 2001; Bouayad-Agha 2001) and the DArt$_{bio}$ system (Bateman et al. 2001)), this is achieved by mapping directly from the underlying discourse structure (Arens and

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Hovy 1990; DiMarco et al. 1995; Paris et al. 1995; Power and Cavallotto 1996; Lavoie and Rambow 1997; Mittal et al. 1998). In other cases, the text is mapped onto predetermined genre-specific layout patterns—for example, for verbalizing mathematical proofs (Huang and Fiedler 1997) or producing letters for customers (Coch 1996). If we take, as most do, the level of discourse structure as representative of the underlying *message* of a text, such systems are subject to a fundamental limitation. Simply put, for each message there will be but one possible form of presentation.

As an illustration let us briefly consider the well-known consensus architecture for NLG systems proposed by Reiter (1994). This architecture, based on a survey of NLG systems from the 1980s and early 1990s, takes the form of a "pipeline" in which five modules are applied in sequence: content determination, sentence planning, surface generation, morphology, and formatting. Sentence planning maps "conceptual structures into linguistic ones ... grouping information into clauses and sentences" (Reiter 1994, page 164), but formatting (specified, for example, by LaTeX markup) occurs only in the final formatting stage. In consequence, the organization of material into paragraphs, bulleted lists, etc., is considered only after the wording has been fixed.

Graphical presentation, however, clearly interacts with wording. For example, the section of a message that, at the level of discourse, is composed of a LIST relation, will be expressed differently depending on whether, at the presentational level, it is mapped onto a vertical or horizontal list. Consider a simple example like the following, taken from a patient information leaflet (PIL):

(1) Are you taking any of the following:

- Anticoagulants?
- Lithium?
- Methotrexate?
- Any other medicines which your doctor does not know about?

(Voltarol leaflet, Geigy; from APBI 1997)

If the very same content were presented instead as a horizontal list, we would expect to get something like:

(2) Are you taking anticoagulants, lithium, methotrexate, or any other medicines which your doctor does not know about?

Now all the information is packed into one sentence, with some missing and additional words, wildly different punctuation, and less generous use of upper-case letters.[1] Mapping directly from discourse structure to graphical presentation during generation therefore limits not only the choice of possible layout, but also the choice of possible wording.

There have been some recent attempts to develop NLG systems that generate *documents* rather than just *texts*. Instead of producing *text plans*, they produce *document plans*. Typically these are the text plans of old (i.e., structures of ordered content elements represented in terms of rhetorical structure theory (Mann and Thompson 1986, 1987)), but extended to include pictures or diagrams as content elements, and with additional annotations for metalevel elements such as paragraph or sentence boundaries. Figure 1 shows the type of document plan proposed by Reiter and Dale (2000).

[1] Indeed, it appears to be the case that the more graphical the presentation is, the greater the difference in wording is likely to be over the unmarked case of plain text (Bouayad-Agha, Scott, and Power 2000).

Weather Summary for July 1996

The month was slightly warmer than average with almost exactly the average rainfall, but rainfall for the year is still very depleted. Heavy rain fell on the 27th and 28th.

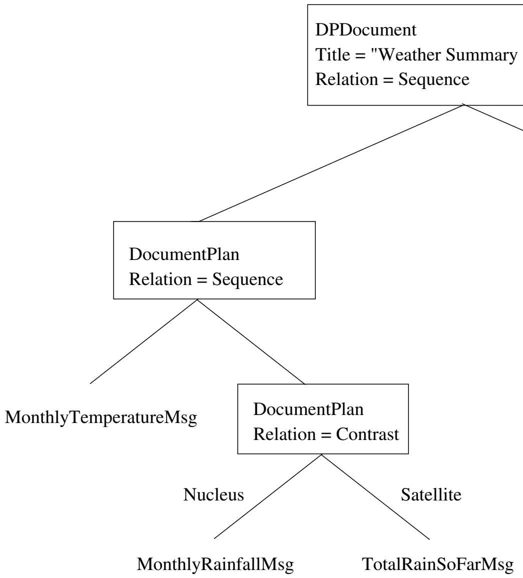


Figure 1
A document plan and associated text (Reiter and Dale 2000).

Although this approach allows for a more reasoned presentational format, by conflating discourse and presentational features into one structure, the possible generated expressions of any given message are once again strongly limited relative to the set of all possible *valid* expressions.

We wish to argue the case for a separate descriptive level in the analysis and generation of written texts, which we will call **document structure**. Informally, document structure describes the organization of a document into graphical constituents like sections, paragraphs, sentences, bulleted lists, and figures; it also covers some features within sentences, including quotation and emphasis. Although document structure applies equally to NLU and NLG, we will focus our attention here on its role in the generation of appropriate presentations (both wording and layout) of texts. As we will try to show, texts (unless they are fairly simple) cannot be produced to a satisfactory standard unless document structure is specified earlier in the process than suggested in previous works (e.g., Reiter 1994; Reiter and Dale 2000), so that interactions with meaning and wording are taken into account.

The plan of the article is as follows. In section 2 we explain more fully what we mean by *document structure*, acknowledging its origins in Nunberg's (1990) work and text markup languages such as LaTeX and HTML. Section 3 discusses the relationship of document structure to rhetorical organization and syntax. Section 4 presents the formal theory of document structure, and Section 5 shows how it is applied in the ICONOCLAST system. Finally, Section 6 summarizes the argument and discusses some other approaches to the representation and generation of layout.

2. Defining Document Structure

2.1 Nunberg's Text Grammar

Our point of departure has been the theory of text structure proposed by Nunberg (1990) in *The Linguistics of Punctuation*. This book introduces two crucial clarifications. First, it distinguishes **text structure**,[2] which is realized by punctuation and layout, from **syntactic structure**. Second, it distinguishes **abstract** features of text structure from the **concrete** (or graphical) features through which they are expressed.

The distinction between text structure and syntax can best be explained by considering two interpretations of the word *sentence*. In linguistics, *sentence* is used mainly as a syntactic category, defined by phrase structure rules such as $S \rightarrow NP + VP$. However, a sentence can also be viewed orthographically as a portion of text starting with a capital letter and ending in a period; to distinguish this from the syntactic category, Nunberg calls it a **text-sentence**. Sometimes the two categories of sentence coincide, but often they do not. Thus in the following passage:

(3) He entered the office. Disaster. The safe was open and the money had gone.

the first text-sentence is also a syntactic sentence, but the second is merely a noun, and the third comprises two syntactic sentences (or three, if we count the whole as well as its parts). Nunberg argues that if we have two kinds of category, then we need *two kinds of grammar*: he calls them the **lexical grammar** (we prefer **syntactic grammar**) and the **text-grammar**. In addition to text-sentence, the text-categories include **text-clause**, **paragraph**, and **section**, and the text-grammar allows us to formulate constituent structure rules such as

$$S_t \rightarrow C_t{}^{+}$$

meaning that a text-sentence comprises one or more text-clauses.

In introducing the concepts *text-sentence*, *text-clause*, etc., it is convenient to explain them in terms of their realization in punctuation and layout: thus a text-sentence starts with a capital letter and ends in a period; a text-clause ends in a semicolon; a paragraph begins on a new line with a tab. However, this is not strictly correct. In Nunberg's theory, these concepts represent *abstract* structural properties of the text that may be realized differently according to context or convention. In the case of *paragraph* this distinction is obvious, since we are all familiar with several devices for expressing paragraph boundaries: instead of a new line with a tab, for example, an editor might prefer two new lines (or some other vertical space) with no tab. However, the abstract/concrete distinction also applies to the other text-categories. For example, the passage:

(4) The safe was open; the money had gone.

contains two text-clauses, but the second has no semicolon because its ending coincides with the closure of a larger unit, a text-sentence, which is marked by a period. Similarly, the stop at the end of a text-sentence is often dropped when the sentence is an item

[2] This should not be confused with the use of this term within the NLG literature to refer to the discourse structure of a text.

in a vertical list, for instance, in a sequence of instructions:

(5) To save the file:
1. Open the Save dialogue-box
2. Enter the filename
3. Click on the Save button

Thus text structure is *realized* by punctuation (and layout), but the two are not equivalent.

2.2 Markup Languages

Nunberg's notion of text structure, or our wider notion of document structure, has an obvious connection to the markup languages (e.g., LaTeX, SGML) now in common use as a method for specifying layout in an ASCII source file. The common philosophy of these languages is that markup should abstract from the visual appearance of the document, using concepts like *paragraph* that might be realized graphically in different ways, depending on a separate style definition.

This approach has several advantages, of which the most obvious is flexibility. An exact specification of the desired spatial layout can yield only one printed form of the document; by employing abstract categories, definitions using LaTeX or SGML can produce a range of printed forms, depending on which style file is used. Less obviously, the markup language can be tailored to the genre of the document, so that, for example, a poem may have a constituent marked *stanza*, whereas a letter may have one marked *address*.

In practice, this separation of abstract structure from visual realization is not carried through consistently; for reasons of convenience, authors sometimes prefer to have direct control over appearance. Thus LaTeX, for example, allows both the abstract tag `em`, meaning *emphasis*, and the visual tag `it`, meaning *italic face*. Vertical separation is usually achieved through abstract tags like `section` and `itemize` but may also be imposed directly using `vspace`. All these devices have counterparts in HTML: thus a typical reference guide to HTML (Ford and Dixon 1996) explicitly distinguishes "logical" tags such as `<EM>` from "visual" tags such as `<I>`.

More subtly, the markup languages in common use do not attempt to cover structural units that are realized through *punctuation* rather than layout. Paragraphs may be marked (albeit implicitly in LaTeX), but lower units such as text-sentence and text-clause are not. No doubt there are good practical reasons for this approach, but some opportunities for stylistic variation are thereby lost. Consider, for example, the simple case of reported speech in example (6a). If this were marked up as a sentence containing a quotation, it could be punctuated differently, with the period outside the closing quotation mark (6b), perhaps, or using double quote (6c), or even using a dash with no quotation marks at all (6d) (as in James Joyce's *Ulysses*):

(6)
(a) She said 'Come up and see me sometime.'
(b) She said 'Come up and see me sometime'.
(c) She said "Come up and see me sometime."
(d) She said—Come up and see me sometime.

Thus although markup languages provide some guidance toward a formal treatment of document structure, they often deviate, for practical reasons, from the philosophical ideal of separating abstract structure from visual presentation. On the one hand, some tags (e.g., italic face) are clearly visual and should not be included in abstract document structure at all. On the other hand, some abstract categories (e.g., text-sentence, quoted speech) are omitted from the tag set and thus cannot be realized in a range of different graphical styles.

Despite these compromises, markup languages are based on a key insight that is highly relevant to natural language analysis and generation: *layout can be matched to wording through the mediation of abstract document structure*. Consider the following three versions of a passage adapted from a patient information leaflet:

(7)

(a) **Elixir** is a white cream.
It is used in the treatment of cold sores.
It contains aliprosan. This is effective against a range of viral skin disorders.
It should be used **only** on your lips and face.

(b) **Elixir** is a white cream.

It is used in the treatment of cold sores.

It contains aliprosan. This is effective against a range of viral skin disorders.

It should be used ONLY on your lips and face.

(c) **Elixir** is a white cream. It is used in the treatment of cold sores. It contains aliprosan. This is effective against a range of viral skin disorders. N.B. **Elixir** should be used only on your lips and face.

Suppose that example (7a) has been produced by author *A*, a novice in document design, and passed to a more experienced designer *B* for revision. The passage looks odd because it has four very short paragraphs, but short paragraphs are common in this genre, and *B* decides that the ugly appearance can be corrected simply by realizing paragraphs through a vertical space with no tab. In addition, *B* notices that boldface has been used for two different purposes: highlighting the product name and emphasizing *only*; this ambiguity is removed by changing emphatic boldface to small caps. Both these revisions, shown in version (7b), concern realization rather than abstract structure, and consequently they do not affect the validity of the wording.

For final checking the passage is then passed to a senior expert *C*, whose preferences are more traditional: in particular, *C* dislikes short paragraphs and variations in typeface. Glaring at the waste of space in version (7b), *C* takes out the paragraph boundaries and removes the emphasis on *only*. These are not merely changes in graphical realization: they also affect the abstract document structure. In general, *such changes endanger the validity of the wording*. Reading through the new version, *C* notices that the pronoun *it* in the final sentence now seems to refer to aliprosan, not Elixir, so it has to be replaced by the product name. To reinstate the emphasis in this sentence, *C* also inserts the expression *N.B.* These changes lead to version (7c).

In summary, abstract document structure interacts with wording, whereas visual realization does not. This principle explains why abstract markup is useful; it also shows where the boundary should be drawn. By applying this principle, we might discover that a category previously treated as visual should be reclassified as abstract. If, for example, the change in the realization of paragraph boundaries in examples like version (7b) required a rewording of the text, we would have to extend our set of abstract document categories so that there were two types of paragraph instead of one.

3. Document Structure and Rhetorical Structure

3.1 Form and Meaning

Logically there are four possible relationships between document structure (DS) and rhetorical structure (RS): either DS is part of RS, or RS is part of DS, or they partially overlap, or they are distinct from one another. Our view is that they should be distinct, just as syntax is distinct from semantics. Document structure, like syntax, describes the form of a (mainly) linguistic product. Rhetorical structure, like semantics, describes meaning, interpreting *meaning* in a broad sense that includes pragmatic features.

As an example, suppose that $approve(fda, elixir)$ is a semantic formula meaning that the Food and Drug Administration (FDA) approves the medicine Elixir. This semantic formula can be *realized* (in English) through a range of syntactic forms, including

$$[_{\textsc{s}}\,[_{\textsc{np}}\,[_{\textsc{det}}\,the][_{\textsc{n}}\,FDA]][_{\textsc{vp}}\,[_{\textsc{v}}\,approves][_{\textsc{np}}\,Elixir]]]$$

which would yield 'the FDA approves Elixir'; alternative syntactic forms could be obtained by replacing descriptions with pronouns, or by putting the whole sentence into the passive (e.g., 'it is approved by the FDA'). Now, suppose that we add a second semantic formula *contain(elixir, gestodene)*, and suppose that the author knows that gestodene is a controversial ingredient. On this basis, a rhetorical relation of CONCESSION might be applied to the two formulas:

$$concession(contain(elixir, gestodone), approve(fda, elixir))$$

where the second argument of CONCESSION is the central one and is supported by the first argument.[3] To realize this more complex message, we may need a linguistic form that cannot be described only by a syntactic phrase marker. In other words, we need to consider document structure as well as syntax. Ignoring possibilities for variations in the wording of the constituent propositions and assuming that CONCESSION may be marked with the discourse connectives *although* and *however*, we can choose among the following realizations of the whole message:

(8)

(a) Although Elixir contains gestodene, it is approved by the FDA.

(b) The FDA approves Elixir although it contains gestodene.

(c) Elixir contains gestodene; however, it is approved by the FDA.

(d) Elixir contains gestodene. However, it is approved by the FDA.

(e) Elixir contains gestodene.
However, it is approved by the FDA.

In versions (8a) and (8b), the rhetorical relationship is realized within a single syntactic sentence, although before adding punctuation we need to know that this syntactic sentence is also a text-sentence. In versions (8c)–(8e), the arguments of the CONCESSION relation are expressed in separate syntactic sentences, so that the relationship is realized through document structure as well as syntax. In each case, the

[3] These are termed *nucleus* and *satellite* in RST (Mann and Thompson 1987).

units realizing the arguments are coordinated in document structure, satellite precedes nucleus, and the discourse connective *however* is placed within the nucleus.

Our claim, then, is that document structure combines with syntax in the realization of the meaning of a document, and that rhetorical structure should be regarded as part of meaning, not part of document structure. However, as we will now show, this principle of clear separation of meaning and form has not always been observed.

3.2 Rhetorical Structure Theory

Rhetorical structure theory (Mann and Thompson 1986, 1987) was developed as a method of analyzing the rhetorical organization of texts. Formally, the theory is remarkably simple. It proposes that a text can be analyzed, by rhetorical function, into a set of nested spans, each span being represented by a node on an ordered tree. Each nonterminal node on this tree is labeled with a single term describing the relationship that holds among its constituents. These constituents may have equal importance, in which case the relation is said to be **multinuclear**, or one may be rhetorically subordinated to the other, in which case they are said to fulfill the roles of **satellite** and **nucleus**. Although this scheme is obviously intended as a first approximation, it has been widely adopted, not only by literary analysts, but also by computational linguists, especially in the NLG community.

One aspect of RST, perhaps more presentational than substantial, has led, in our view, to confusion: both in the text of their article and the accompanying diagrams, Mann and Thompson seem to assert that rhetorical relations hold between spans of text, rather than between the meanings of these texts. In other words, they treat rhetorical structure as part of document structure. Mann and Thompson assert this explicitly (1987, page 4):

> Relations are defined to hold between two non-overlapping text spans,
> here called the *nucleus* and the *satellite*, denoted by N and S.

where

> A *text span* is an uninterrupted linear sequence of text.

However, it is unclear whether their claim is intentional or simply the result of an informal style of presentation.

Would it make any sense to treat rhetorical relations as holding literally between text spans? For clearly pragmatic relations, such as RESTATEMENT, this seems a possible position. A text span, after all, is an instrument of the writer, so it makes sense to make a statement about the function that the instrument is supposed to serve. For clearly semantic relations, such as NONVOLITIONAL-CAUSE, the position is harder to maintain. In a text like 'Mary was sad because she lost her doll', the causal relation plainly holds between two events, not between two spans of text.

Leaving aside intuitive plausibility, the crucial question, we think, is whether the argument in a document can be formalized without reference to the particular text spans through which it is realized. Could the same argument be realized by two English texts with a different structure, or by an English text and a French text? Could someone forget a text but remember its argument? If so, it must be possible to treat relations like CONCESSION and NONVOLITIONAL-CAUSE as holding between ideas rather than units of text. Rather than creating two kinds of rhetorical relation, it seems more parsimonious to treat the relation between ideas as primary, so that the argument of

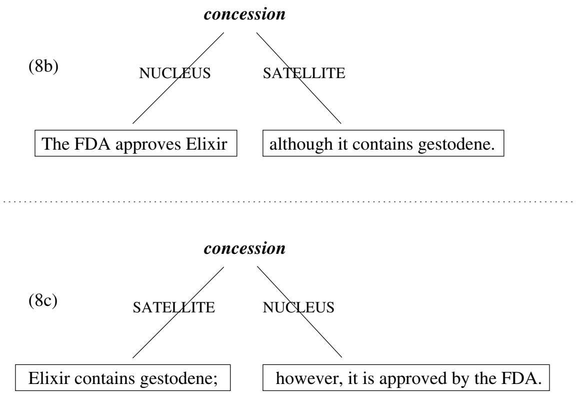

concession
(8b)
NUCLEUS
SATELLITE
The FDA approves Elixir
although it contains gestodene.
concession
(8c)
SATELLITE
NUCLEUS
Elixir contains gestodene;
however, it is approved by the FDA.

Figure 2
RST analysis.

a document can be planned before the writer (or NLG system) has considered issues of wording or linear order.[4]

To illustrate this point, let us go back to example (8). Suppose that we want to show that versions (8b) and (8c) express the same argument.

(8b) The FDA approves Elixir although it contains gestodene.

(8c) Elixir contains gestodene; however, it is approved by the FDA.

Figure 2 shows RST annotations for these texts, on the assumption that rhetorical relations hold between text spans; note, incidentally, that since related spans must be consecutive, the discourse connectives *although* and *however* have to be included somewhat arbitrarily in one span or the other. These annotations fail to bring out that the two texts express the same argument, since at a textual level the spans in (8b) and (8c) are simply different, both in wording and position.

In Figure 3, instead, different document structures are specified for versions (8b) and (8c) and linked to a common rhetorical structure; the dotted arrows express the relation *realizes*, so that, for example, each text-sentence realizes the whole rhetorical structure governed by the CONCESSION relation. Note that rhetorical structures are always unordered, whereas document structures are ordered trees. Thus the two unordered propositions in the rhetorical structure of Figure 3 are realized in different orders in the two document structures.

This distinction between rhetorical structure and document structure accounts for some of the difficulties encountered when RST is applied as an analytic tool. The core of the problem is that when faced with a text to analyze, the analyst applies the principles of RST analysis to the text itself rather than to the message underlying the text. What the analyst really needs to do is, in some way, to "get behind the text" to its constituent propositions and the rhetorical relations that hold between them (Scott and Paris 1995). But instead, by applying relations to text-spans, he or she is heavily constrained by the evident document structure of the text, and the result is a rhetorical structure that is isomorphic to the document structure. However, as we have

[4] This proposal was first made by Scott and Souza (1990).

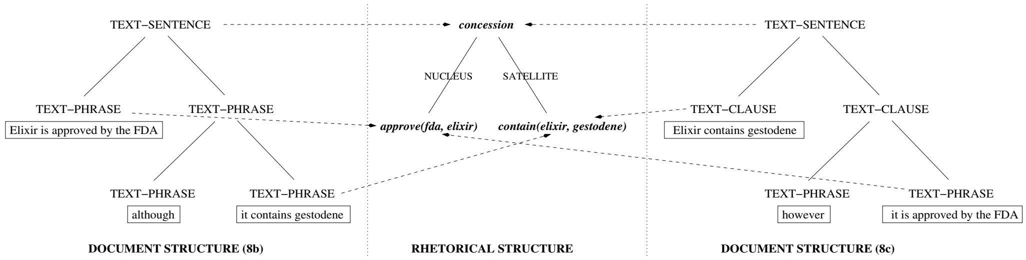


Figure 3
Document structure realizes rhetorical structure.

seen from the above example, the underlying rhetorical structure is not necessarily isomorphic to the document structure;[5] this means that the analysis obtained in this way is not necessarily an accurate representation of the *actual* discourse structure of the text. Consider, for example, the following excerpt from a patient information leaflet:

(9) IF you find your condition gets worse during treatment$_A$ you may be allergic to the cream$_D$ or have a skin infection$_E$.
STOP USING THE CREAM$_B$ AND TELL YOUR DOCTOR AS SOON AS POSSIBLE$_C$
(Betnovate leaflet, Glaxo; from APBI 1997)

Careful reading of the text, combined with world knowledge, suggests that the following logical condition holds between the propositional content of *A* and the pair *B* and *C*:

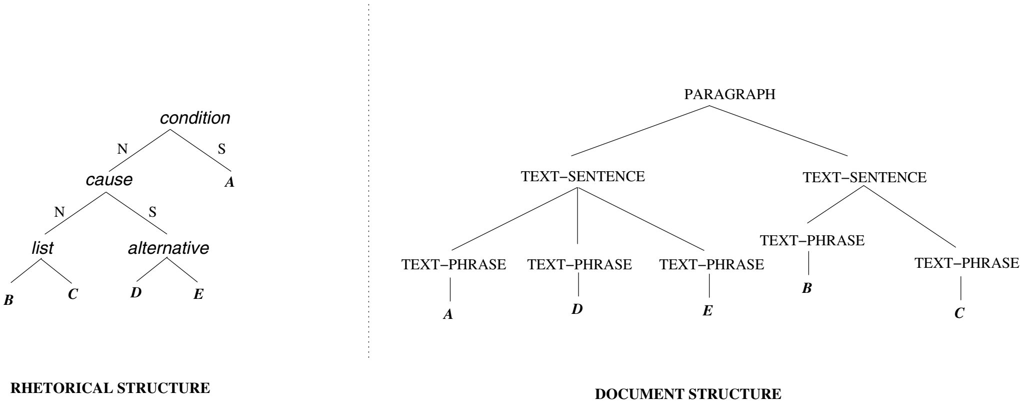
```
IF <condition of patient worsens during treatment>
   THEN <patient must stop taking cream>
    AND <patient must tell patient's doctor>
ENDIF
```

In other words, the rhetorical relation of CONDITION holds between *A* as satellite and the complex of *B* and *C* (joined by a LIST relation) as nucleus. We learn additionally that the reason why the patient must carry out the imperative actions of *B* and *C* is that he or she may be either allergic to the cream (*D*) or have a skin infection (*E*). In other words, there is a causal relation between the complex of *B* and *C* (the effect) and complex of *D* and *E* (the cause). Representing all this in RST would yield the structure in Figure 4.

Most people would probably agree that what is depicted in the RST structure shown in Figure 4 captures the intended meaning of the text in the example, and that the text itself is of reasonable quality. However, a traditional RST analysis (i.e., of the text itself, as opposed to its underlying meaning) would not be able to produce the structure shown here. To explicate, let us go through what the typical RST analyst would do with this text.

The analyst would probably start by segmenting the text into elementary "text spans" (i.e., clauses); this would lead to the same assignment of *A*–*E* given above. The next step would focus on the first sentence: the discourse marker *if* clearly suggests the CONDITION relation; similarly, the marker *or* suggests the ALTERNATIVE relation. So far so good. However, the next step would be to find a relation that holds among

[5] This is discussed in more detail in Bouayad-Agha, Power, and Scott (2000) and Bouayad-Agha (2001) and in section 5.3.



RHETORICAL STRUCTURE

DOCUMENT STRUCTURE

Figure 4
Document structure is not always isomorphic with rhetorical structure.

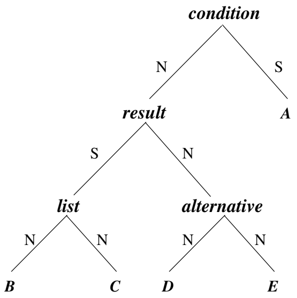


Figure 5
Analysis when RST is applied directly to text.

the text spans in the sentence; if this cannot be done, then according to the tenets of RST, the text is not coherent. Following this rule, the analyst is likely to make *D* and *E* the components of the identified (multinuclear) ALTERNATIVE relation. Next he would attempt to assign the satellite and nucleus of the identified CONDITION relation; the choice would be between *A* and the complex of *D* and *E*. Since the marker *if* must attach to the satellite of CONDITION, the answer seems clear:

condition(*alternative*(D,E),A)

(corresponding to the RST structure shown in Figure 5). But it is also clearly wrong, since we know from our semantic analysis that what really holds is that shown in Figure 4:

condition(*list*(B,C),A)

Indeed, even the layout of the text reinforces, through the use of capital letters, the strong relationship between *A* and the pair *B* and *C*.

In principle, an RST structure that is derived from the analysis of a given text should, when used as the input to an NLG system, produce the very same text and other *semantically equivalent* versions of it. By separating rhetorical structure from document structure, we can now provide a coherent framework for achieving this result.

For instance, we can now produce not only the original text of example (9) (shown here with neutral layout):

(9b) If you find your condition gets worse during treatment, you may be allergic to the cream or have a skin infection. Stop using the cream and tell your doctor as soon as possible.

but also the following (in some contexts perhaps better) variant

(9c) If you find your condition gets worse during treatment, stop using the cream and tell your doctor as soon as possible; you may be allergic to the cream or have a skin infection.

Of course, NLG systems that ignore the level of document structure would still be able to produce the text in version (9b) from the RST structure in Figure 5, but they would not be able to produce version (9c). Moreover, they could also end up producing the following incorrect text:[6]

(9c) # Stop using the cream and tell your doctor as soon as possible because you may be allergic to the cream or have a skin infection if your condition gets worse during treatment.

A number of other researchers have identified cases in which "orthodox" RST analysis of a text is problematic (e.g., Moore and Pollack 1992; Moser and Moore 1996; Knott et al. 2001). For example, Knott et al. (2001) report on texts from a corpus of museum labels that violate the RST principle of **continuous constituency** (i.e., adjacent units must be linked by a relation) but are nonetheless coherent. These are cases in which the satellite of a relation is not adjacent to its own nucleus in the text. In all the texts that Knott et al. discuss, the "dislocated" relation is ELABORATION, and they attribute the source of the problem to the relation itself: ELABORATION is not, they claim, a proper relation; it is a very weak relation that commands a different treatment from the other stronger ones.

Although there may well be a strong case to be made for the "demotion" of ELABORATION and for a special treatment of it in NLG systems, the phenomenon of dislocated satellites that Knott et al. (2001) describe is not, in fact, confined to ELABORATION. Indeed, it corresponds precisely to the problem we have just seen with example (9), which involves not ELABORATION, but CONDITION. We have also reported elsewhere other similar examples of nonisomorphic rhetorical and document structures (Bouayad-Agha, Power, and Scott 2000). In all cases that we have seen, the principles of RST (e.g., compositionality, nuclearity, continuous constituency) appear to be violated only because they are being applied (in the orthodox manner) to the surface text (i.e., at the level of document structure) rather than more properly to the underlying propositional structure of the text (i.e., at the level of rhetorical structure).

But why would one want to produce a text whose document structure is not isomorphic with its rhetorical structure? One rather practical reason is that as a rhetorical structure becomes more complex, it becomes increasingly difficult for the writer to produce a text that satisfies both the demands of coherence (as defined by theories such

[6] This text would result from systems that treat the leaves of a rhetorical or text plan as ordered.

as RST) and those of syntax. This happens quite frequently, for example, with conditionals: syntax dictates that expressions using the subordinating discourse marker *if* must have the antecedent and consequent in the same sentence. For example:

(10) If you eat too many sweets, you will become ill.

but not

(11) # If you eat too many sweets. You will become ill.

As the consequent or its antecedent becomes more complex, the chances of satisfying the syntactic constraints are reduced. Here is a typical example from a PIL:

(12) **If you get any of the following:**

> Stomach pain, indigestion, heartburn or feeling sick for the first time.
> Any sign of bleeding in the stomach or intestine, for example, passing black stools.
> . . .
> An unexpected change in the amount of urine produced and/or its appearance.

STOP taking the tablets and tell your doctor.

(Voltarol leaflet, Geigy; from APBI 1997)

Here the conditional is expressed within one big sentence that itself contains several other sentences—indeed, paragraphs—each describing a set of symptoms organized around areas of the body. In writing this text, the author has clearly chosen to remain faithful to the rhetorical structure at the expense of syntax.

At other times, such as the example in Figure 6, taken from Knott et al. (2001), it is the rhetorical structure that loses out. In this case, the author has decided that the content of the satellite associated with (9) warrants its own paragraph (perhaps for reasons to do with its size).

4. Formal Theory of Document Structure

We will describe here the formal theory of document structure that we have developed as part of the ICONOCLAST system (Power 2000; Bouayad-Agha, Power, and Scott 2000; Bouayad-Agha 2000; Bouayad-Agha, Scott, and Power 2001), which generates multiple versions of the same message in different styles (i.e., with different wording and layout). In describing the theory, we will concentrate on units above the level of text-sentence; our treatment of the lower levels varies only slightly from that in Nunberg's theory, which is described in great detail in Nunberg (1990).

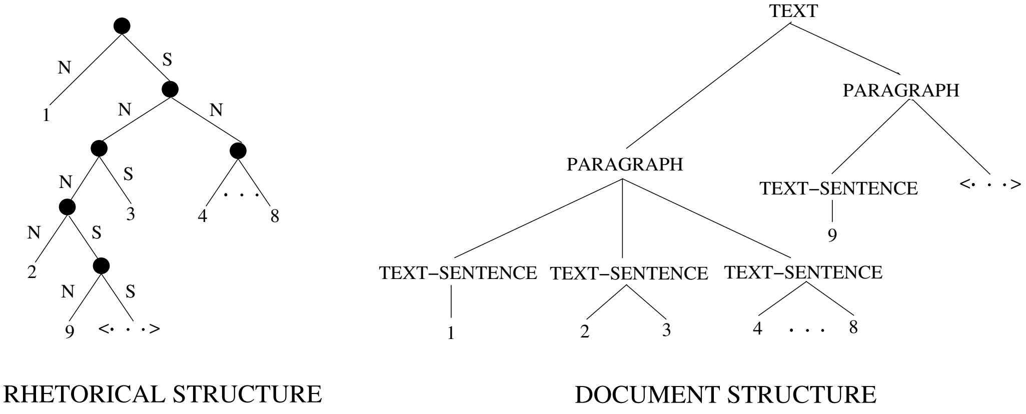
4.1 Basic Hierarchy of Document Units

Informally it seems clear that units of document structure are ranked: sentences are grouped into paragraphs, paragraphs into sections, sections into chapters, and so forth. The hierarchy of categories differs from one document type to another, but there is always *some* hierarchy;[7] there might for instance be subsubsections and subsections

[7] Exceptionally, some elements—in particular, footnotes and pictures—will be "floating."

(1) In the women's quarters the business of running the household took place.
(2) Much of the furniture was made up of chests (3) arranged vertically in matching pairs. ... (4) Female guests were entertained in these rooms, (5) which often had beautifully carved wooden toilet boxes (6) with fold–away mirrors and sewing boxes, (7) and folding screens, (8) painted with birds and flowers.

(9) Chests were used for storage of clothes. ...



RHETORICAL STRUCTURE DOCUMENT STRUCTURE

Figure 6
Another example of nonisomorphic rhetorical and document structures.

between paragraphs and sections. As a basis for discussion, let us assume a hierarchy of six levels, which we will number from 0 (assumed to be the lowest possible level of document structure) to 5:[8]

0	text-phrase
1	text-clause
2	text-sentence
3	paragraph
4	section
5	chapter

The fundamental organizing principle of document structure is that a unit of a given level is composed of one or more units of the next level down. This observation could be expressed by a set of constituent structure rules, one for each level:

$$\begin{aligned} \textit{chapter} &\rightarrow \textit{section}^{+} \\ \textit{section} &\rightarrow \textit{paragraph}^{+} \text{ (etc.)} \end{aligned}$$

Alternatively, we could generalize over this set of rules by introducing the symbol L_N to denote a unit of level N (so that L_0 means text-phrase, L_1 means text-clause, etc.). A single rule will now cover units of all levels:

$$L_N \rightarrow {L_{N-1}}^{+} \quad (N > 0)$$

[8] We use *text-sentence* and *text-clause* in Nunberg's sense, as units typically marked by a period and a semicolon. However, unlike Nunberg, we use *text-phrase* for any constituent of a text-clause, whether it is marked by a comma or not.

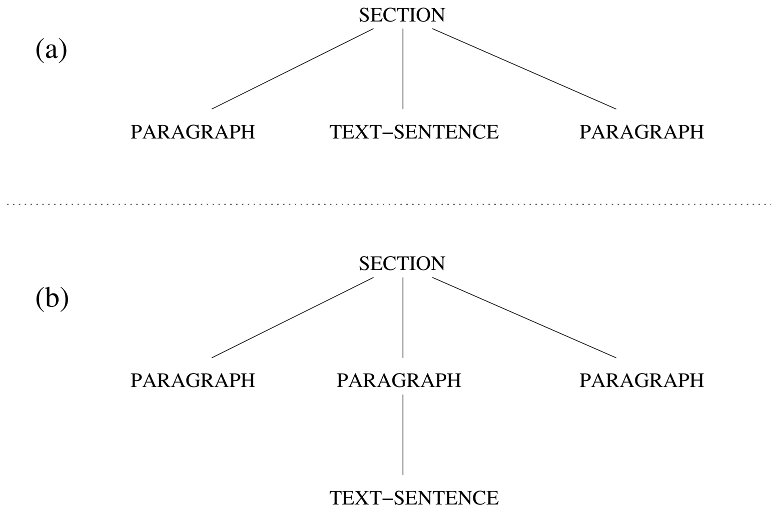


Figure 7
Ill-formed (a) and well-formed (b) document structures.

Two consequences of this rule should be noted. First, it disallows document structures in which a unit contains a subunit of higher level—for instance, a text-sentence may not contain a paragraph. Second, it disallows document structures in which coordinated units have different levels. A section, for example, may not be formed by coordinating two paragraphs and a text-sentence, as in Figure 7(a); the sentence should be the only constituent of a further paragraph unit, as in Figure 7(b), so that when the abstract document structure is realized graphically, the sentence will be formatted with a paragraph break as well as with a capital letter and a period.

This deals with the basic organization of text into hierarchical document units; however, a full description should take account of many other patterns including headings, bulleted lists, footnotes, and figures. We cannot deal with all these patterns here, so we focus on what is probably the most complex problem: the treatment of indented structures such as quotations, bulleted lists, and enumerated lists.

4.2 Indented Document Units

At first sight it might seem that indentation is a feature of graphical realization rather than underlying structure: in other words, that it belongs to concrete rather than abstract document structure. We have several reasons for rejecting this view. First, it is at least suggestive that both LaTeX and HTML include tags for indented structures:

Pattern	**HTML tag**	**LaTeX** tag
Quotation	`<QUOTE>`	`\begin{quote}`
Bulleted list	`<UL>`	`\begin{itemize}`
Enumerated list	`<OL>`	`\begin{enumerate}`
Description list	`<DL>`	`\begin{description}`

Second, one can find examples of vertical lists that seem structurally equivalent to (say) a bulleted list but are presented without item markers and without the use of horizontal indentation. Here is a case in point, taken from a PIL with formatting exactly preserved:

(13) If you experience any of the following or any other unusual effects,
tell your doctor:

Poor appetite or a slight sick feeling
Mild abdominal pains or fullness
Alterations in your sense of taste
Diarrhoea
Itching or rash
Pain in your muscles or joints

If you notice yellowing of the skin or eyes, tell your doctor
straight away.
(Lamisil, Sandoz; from APBI 1997)

Third, and most important of all, indented structures may introduce apparent violations of the hierarchical ranking described in the last section: for instance, a sentence may contain a paragraph, *provided that the paragraph is indented*. We have already seen this in the case of complex conditionals in example (12). However, the phenomenon is much more widespread:

(14) In rare cases the treatment can be prolonged for another week; however, this is risky since

- The side-effects are likely to get worse. Some patients have reported severe headache and nausea.
- Permanent damage to the liver might result.

(15) The opening of *Pride and Prejudice*

> It is a truth universally acknowledged, that a single man in possession of a good fortune, must be in want of a wife. However little known the feelings or views of such a man may be on his first entering a neighbourhood, this truth is so well fixed in the minds of the surrounding families, that he is considered as the rightful property of some one or other of their daughters.

is one of the most famous paragraphs in English literature.

In these examples, too, note that the important issue is not graphical indentation, but what we might call **logical indentation**. Thus in the case of the quotation, the logical indentation of the quoted paragraph might be shown without graphical indentation (e.g., by using a distinctive font or character size):

(16) The opening of ‘Pride and Prejudice’

It is a truth universally acknowledged, that a single man in possession of a good fortune, must be in want of a wife. However little known the feelings or views of such a man may be on his first entering a neighbourhood, this truth is so well fixed in the minds of the surrounding families, that he is considered as the rightful property of some one or other of their daughters.

is one of the most famous paragraphs in English literature.

How can the formation rules for document structure be extended so as to accommodate these patterns? Our main proposal, implemented in the ICONOCLAST document planner, is that a document unit should be defined by (at least) two features: its level and its indentation. The level is the usual ranking from L_0 (text-phrase)

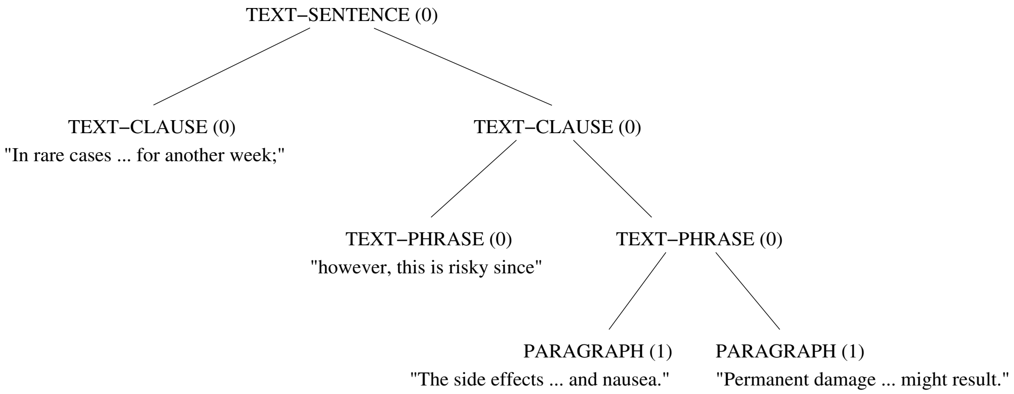

TEXT–SENTENCE (0)
TEXT–CLAUSE (0)
"In rare cases ... for another week;"
TEXT–CLAUSE (0)
TEXT–PHRASE (0)
"however, this is risky since"
TEXT–PHRASE (0)
PARAGRAPH (1)
"The side effects ... and nausea."
PARAGRAPH (1)
"Permanent damage ... might result."

Figure 8
Indented document structure (example (14)).

to L_5 (chapter) or whatever hierarchy of units the author decides to employ; the indentation is a value in the range $I_0 \dots I_{\text{Max}}$, where I_0 means that the unit is not indented at all, I_1 means it is indented one place, and so forth, with I_{Max} representing the deepest embedding that the author is prepared to contemplate. The passages in examples 14–16 can then be described formally as unindented text-sentences (i.e., units with the category $[L_2, I_0]$), which have among their constituents indented paragraphs (units with the category $[L_3, I_1]$). Such structures can be permitted if we change the basic rule of the last section so that a unit of indentation I_N always outranks a unit of indentation I_{N+1}, no matter what their respective levels may be. Instead of one general rule, we now need two: the first for unindented constituents, the second for indented ones.

Unindented constituents $[L_N, I_M] \rightarrow [L_{N-1}, I_M]^+$

Indented constituents $[L_A, I_M] \rightarrow [L_B, I_{M+1}]^+$

In the second rule, L_A and L_B are unrelated, so L_B could represent a higher level than L_A (e.g., a paragraph inside a text-sentence). For most document types one would presumably prefer to set an upper limit on the level of an indented constituent (e.g., an indented chapter seems ridiculous); this could be done for instance by adding the constraint $B < 4$.

Figures 8 and 9 give document structures for examples (14) and (15), respectively; the latter also describes example (16), which differs from (15) only in the graphical realization of the indented paragraph. One feature of these analyses might at first sight appear strange: they assign the minimal text level L_0 to the node representing the quotation or the bulleted list. How, one might ask, can a paragraph, or indeed a list of paragraphs, be regarded as a text-phrase? Should it not be a unit *higher* than the paragraph, perhaps some kind of section, or better, a new text category *vertical list*?

On first tackling indented structures, we followed precisely this reasoning, introducing *vertical list* as a text category. However, despite its initial plausibility, this decision has several irritating consequences. First, the concept *vertical list* has no relationship to the text-level hierarchy. Does it belong between text-sentence and paragraph, or perhaps between paragraph and section? Any placement seems arbitrary. Second, since the vertical list in a document structure like that in Figure 8 is clearly coordinated with a text-phrase, such an analysis would violate the rule that coordinated constituents have the same level. Third, and perhaps most persuasively of all,

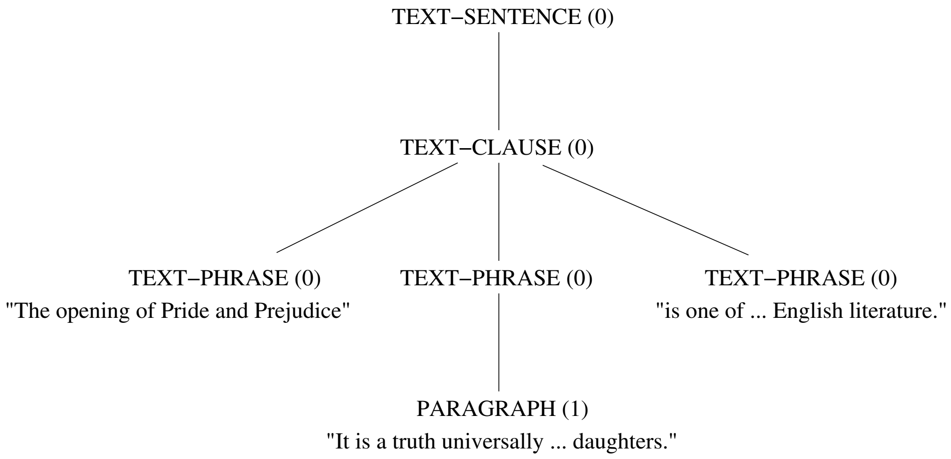

TEXT−SENTENCE (0)
TEXT−CLAUSE (0)
TEXT−PHRASE (0)
"The opening of Pride and Prejudice"
TEXT−PHRASE (0)
TEXT−PHRASE (0)
"is one of ... English literature."
PARAGRAPH (1)
"It is a truth universally ... daughters."

Figure 9
Indented document structure (examples (15) and (16)).

it turns out that in their interactions with discourse connectives, vertical lists *behave like text-phrases*, not like sentences, paragraphs, or higher units. Thus the vertical list in Figure 8 is coordinated with the discourse connective *since*, which would not normally link constituents higher than text-phrases (we will discuss this constraint more fully in the next section).[9]

All these difficulties are removed by denying appearances and assigning the vertical-list node a text-level of L_0. With this treatment, no new arbitrary level in the hierarchy of units is needed, the basic rule of document structure holds (i.e., coordinated constituents have the same level), and the interaction of the unit with discourse connectives can be described using the same rules that hold for nonindented structures. Note also that the difference in indentation between the node and its daughters is sufficient to identify it as a vertical list; any extra feature (such as a new value in the text-level hierarchy) would be redundant.

5. Methods of Document Structuring

5.1 Defining the Task

The aim of **document structuring** within NLG is to create a document structure that satisfactorily realizes a particular rhetorical structure. This can be achieved through a variety of architectures, as reflected in the RAGS framework.[10] For example, systems aimed at generating technical abstracts or captions for graphics would probably need to specify a "one paragraph only" limit quite early on in the process; in such cases, document structuring would start before any rhetorical or syntactic decisions were made (e.g., the RAGS reimplementation of the Caption Generation System [Mellish et al. 2000]). Alternatively, systems that need to generate texts with rich layout might prefer to interleave document structuring with rhetorical structuring (e.g., Cahill et al. 2001).

[9] Note that a vertical list can also be coordinated with units larger than text-phrases, such as text-sentences or paragraphs. The formal rules allow this because a text-phrase can be the only constituent of a text-clause, which can in turn be the only constituent of a text-sentence, and so forth.

[10] See *The* RAGS *Reference Manual*, http://www.itri.bton.ac.uk/projects/rags/RefMan/refman.ps.

For simplicity of presentation, we will assume here an NLG architecture in which a preliminary module selects simple propositions from a knowledge base and organizes them into some kind of argument; the document structurer distributes the various parts of this argument among units like paragraphs and text-sentences; a syntactic realizer takes over in order to determine the wording of the propositions; finally, a formatter decides how the abstract categories and features of document structure will be realized graphically (e.g., whether paragraphs will be marked by a tab on a new line, or by a vertical space). In the context of such an architecture, two issues are crucial: what input does the document structurer receive from the earlier planning module, and how does the output of the document structurer guide syntactic realization?

In ICONOCLAST, our initial assumption, following Scott and Souza (1990), was that the rhetorical structure would take the form of a graph in which terminal nodes represent simple propositions and nonterminal nodes represent rhetorical relationships. By organizing all propositions into a single hierarchy, such an input simplifies the task of the document structuring module; indeed, it could be argued that part of the work has been done already. An alternative assumption is that the rhetorical structure takes the form of a set of assertions, each describing a rhetorical relationship between two propositions (Marcu 1997). With this flat representation, the document structurer must take more responsibility for grouping the propositions. In this article, we will focus on the first of these methods (i.e, starting from a hierarchical rhetorical input). The second method (starting from a flat rhetorical input) is described in Bouayad-Agha (2001).

Regarding the interface between document structuring and syntax, the difficult issue is where the boundary should be drawn. Above the level of text-clause, it seems clear that syntax plays little part; however, at the level in which text-phrases combine to form text-clauses, there is an interplay between the "syntactic" grammar and the "text" grammar, as Nunberg (1990) has shown. As an example, consider the simple rhetorical structure discussed earlier (example (8) and Figure 2):

$$concession(contain(elixir, gestodene), approve(fda, elixir))$$

As mentioned earlier, this rhetorical-semantic input could be realized through a text-sentence comprising two text-clauses:

(8c) Elixir contains gestodene; however, it is approved by the FDA.

In this case it seems clear where the boundary should lie: the document structurer decides that *approve(fda, elixir)* should be expressed in the first text-clause, and that *contain(elixir, gestodene)* should be expressed in the second, along with the connective *however*. It might also impose constraints on the clauses that will realize these propositions, for instance, by requiring declarative clauses rather than imperative or interrogative ones. The rest is left to the syntactic realizer, which must decide how the two propositions should be worded, and how the second clause should be combined with the connective. Several alternative versions might result, each having exactly the same document structure:

(8′) Elixir contains gestodene; the FDA, however, approves it.

(8″) Elixir contains gestodene; however, the FDA approves it.

(8‴) Gestodene is an ingredient of Elixir; Elixir is approved, however, by the FDA.

Suppose, however, that the document structurer decides to realize the two propositions within the same text-clause, as in the following version:

(8⁗) Elixir is approved by the FDA although it contains gestodene.

Where now does the boundary lie? Should the document structurer create a text-sentence containing a single text-clause, leave instructions that this text-clause should express the whole concession relationship, and then wash its hands of the affair, leaving everything else to the syntactic realizer? Or should it trespass into the domain of syntactic realization by constructing a syntactic clause of the form S_1 *although* S_2, with instructions that a subclause realizing *approve*(*fda*, *elixir*) should be inserted in position S_1 and a second subclause realizing *contain*(*elixir*, *gestodene*) in position S_2?

In ICONOCLAST we have found it more convenient to adopt the latter policy. The linguistic structure of a document is represented using a single tree in which nodes may be labeled both with document structure features and with syntactic features. The document structurer's task is to build the upper part of this tree, extending from the root all the way down to the nodes that express simple propositions. In the upper reaches of the tree, nodes will be labeled with units like *section* and *paragraph*, and syntactic features will be irrelevant; lower down, the document structure may have to assign some syntactic features when constructing compound clauses. To simplify, we assume that conjunctive adverbs like *however* will always be placed at the beginning of a clause; this means that discourse connectives can be placed into the tree by the document structurer, thereby limiting the task of the syntactic realizer to the wording of the simple clauses that realize propositions.

Having clarified the document structurer's task, we posed the following question: given a well-formed rhetorical structure, together with a set of formation rules for document structure and a set of discourse connectives for realizing rhetorical relations, can we enumerate all document structures that correctly realize the rhetorical structure—and further, can we evaluate these document structures by some metric so that we can choose the best? The generation of many alternative solutions was essential to the project, which focused on the problem of controlling style in an NLG system: by varying a set of stylistic parameters, the user of the system can influence the evaluation metric that is applied to the set of potential solutions and so influence the type of solution that will be preferred.

As mentioned above, we have explored two methods of enumerating and evaluating document structures, one (the focus of this article) assuming a hierarchical input, the other (described in Bouayad-Agha [2001]) assuming a nonhierarchical input. The two methods have much in common: they share the same formation rules for document structure, the same discourse connectives, and (mainly) the same constraints on the correct realization of rhetorical relationships. Before describing the hierarchical method in detail, it will be useful to review the constraints that they share; these constraints will be needed, in some form or other, in any system that performs document structuring.

5.2 Constraints on Realizing Rhetorical Structure

In order to realize a rhetorical structure $R(A_1, A_2)$ as a document structure, several decisions must be made:

- What should be the level (e.g., section, paragraph, text-sentence) of the document unit that realizes the whole relationship $R(A_1, A_2)$?
- What should be the levels of the units realizing the arguments A_1 and A_2?
- Should the units realizing A_1 and A_2 be indented items, or should they have the same indentation as the unit realizing $R(A_1, A_2)$?
- In what linear order should the units realizing A_1 and A_2 occur?
- Should the rhetorical relation R be expressed using a discourse connective or left implicit?
- If a discourse connective is used, should it be linked to the span realizing A_1 or the span realizing A_2?

These decisions are closely related, as the following examples show:

- If $R(A_1, A_2)$ is realized through a text-sentence, then the arguments A_1 and A_2 cannot be realized through a higher unit, such as a paragraph, unless they are indented one place further than $R(A_1, A_2)$. (This follows from the formation rules for document structure.)
- If R is a nucleus-satellite relation rather than a multinuclear one, the arguments A_1 and A_2 should not be realized through indented items.[11]
- If a subordinating conjunction like *although* is used to express the relation R, the arguments A_1 and A_2 should be realized within the same syntactic clause; hence they should be text-phrases, rather than text-clauses or some higher unit. Moreover, *although* should be attached to the clause expressing A_1 (assuming this is the satellite).

Constraints arising from the formation rules for document structure have already been covered; we will therefore focus here on constraints that concern the realization of rhetorical relations.

Leaving aside quotations for the time being, our first suggestion is that indentation should be employed only for the arguments of a *multinuclear* relation. Vertical lists are typically used when the items in the list play the same role in the discourse—for instance, they might be symptoms of a disease or potential side effects of a medicine. By definition, the arguments of a nucleus-satellite relation have different purposes; the nucleus makes the main point, whereas the satellite's role is supportive. Consider, for example, the following rhetorical structure:

$$\mathit{justify}(\mathit{list}(\mathit{tested}(\mathit{elixir}), \mathit{approve}(\mathit{fda}, \mathit{elixir})), \mathit{safe}(\mathit{elixir}))$$

which gives two reasons why Elixir is safe to use. The LIST relation is multinuclear, whereas JUSTIFY is nucleus-satellite; according to our rule, then, the document structures in (17) and (18) should be avoided, whereas those in (19) and (20) should be

[11] This constraint is based on the intuition that the items in a vertical list should have parallel roles in the argument, a condition that clearly fails to hold for a nucleus-satellite relation.

acceptable:

(17)
- Elixir is safe to use
- because it has been carefully tested and is approved by the FDA.

(18)
- Elixir has been carefully tested and is approved by the FDA,
- therefore, it is safe to use.

(19) Elixir is safe to use because
- it has been carefully tested
- it is approved by the FDA

(20)
- Elixir has been carefully tested
- Elixir is approved by the FDA

Therefore, it is safe to use.

Note that when the arguments of a multinuclear relation are presented within a text-clause, syntax requires a connective like *and* or *or*. When they are presented as indented items, the connective is instead often omitted, leaving the relation implicit; the reader has to use common sense to divine whether the list represents a conjunction or a disjunction.

5.2.1 Discourse Connectives. A comprehensive treatment of discourse connectives will not be attempted here, but we will cover the three main categories identified by Knott (1996): subordinating conjunctions, coordinating conjunctions, and conjunctive adverbs.

The properties of a discourse connective can be fully specified by four features: MEANING, SYNTAX, LOCUS, and SPELLING. As examples, here are three definitions for the CONCESSION relation:

MEANING	`concession`
SYNTAX	`subordinating conjunction`
LOCUS	`satellite`
SPELLING	'although'

MEANING	`concession`
SYNTAX	`coordinating conjunction`
LOCUS	`nucleus`
SPELLING	'but'

MEANING	`concession`
SYNTAX	`conjunctive adverb`
LOCUS	`nucleus`
SPELLING	'however'

The LOCUS specifies which argument of the relation carries the discourse connective. For a nucleus-satellite relation, the argument is identified either by `nucleus` or `satellite`; for a multinuclear relation it is identified by an ordinal specification such as `initial` or `final`.

For each type of discourse connective, it is possible to state specific constraints on the order of arguments, and on the document units that express them.[12]

[12] Some of these are also mentioned by Scott and Souza (1990) and Rosner and Stede (1992).

5.2.1.1 Subordinating Conjunction. The spans linked by a subordinating conjunction can be arranged in either order (nucleus first or satellite first) but must be expressed within the same text-clause. For example:

(21) Although it has no significant side effects, never give Elixir to other patients.

(22) Never give Elixir to other patients, although it has no significant side effects.

(23) # Although it has no significant side effects; never give Elixir to other patients.

(24) # Although it has no significant side effects. Never give Elixir to other patients.

(25) # Never give Elixir to other patients; although it has no significant side effects.

(26) # Never give Elixir to other patients. Although it has no significant side effects.

5.2.1.2 Coordinating Conjunction. Spans linked by a coordinating conjunction can occur in the same text-clause or in different text-clauses (or higher units) but must be ordered so that the discourse connective is located in the final span (i.e., the second span in the case of a nucleus-satellite relation):

(27) Elixir has no significant side effects, but never give it to other patients.

(28) # But never give Elixir to other patients, it has no significant side effects.

(29) Elixir has no significant side effects; but never give it to other patients.

(30) # But never give Elixir to other patients; it has no significant side effects.

(31) Elixir has no significant side effects. But never give it to other patients.

(32) # But never give Elixir to other patients. It has no significant side effects.

Of course examples (28), (30), and (32) are prohibited only as a means of realizing a CONCESSION relation between the two propositions. They might be acceptable in a text realizing a different rhetorical structure in which the satellite had already been expressed.

5.2.1.3 Conjunctive Adverb. Spans linked by a conjunctive adverb can occur in different text-clauses (or higher units), but not in the same text-clause. For a nucleus-satellite relation they must be ordered so that the discourse connective is located in the second span:

(33) # Elixir has no significant side-effects, however, never give it to other patients.

(34) # However, never give Elixir to other patients, it has no significant side-effects.

(35) Elixir has no significant side-effects; however, never give it to other patients.

(36) # However, never give Elixir to other patients; it has no significant side-effects.

(37) Elixir has no significant side-effects. However, never give it to other patients.

(38) # However, never give Elixir to other patients. It has no significant side-effects.

Again, examples (33), (34), (36), and (38) would be acceptable in realizations of different rhetorical structures in which the satellite had already been presented.

5.3 Planning Document Structure Using Hierarchical Input

Using the hierarchical method, the input rhetorical structure is a tree in which the terminal nodes are formulas representing elementary propositions (i.e., propositions having no internal rhetorical complexity), whereas the nonterminal nodes are labeled with rhetorical relations (see, for example, Figure 10). This tree is unordered: the roles

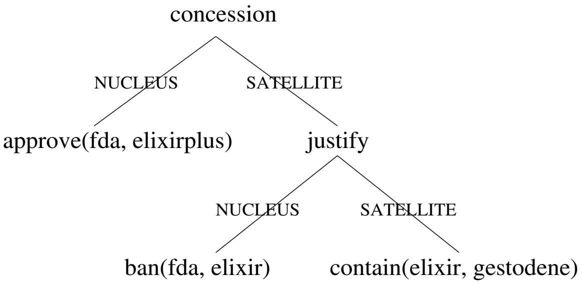


Figure 10
Example of rhetorical structure.

of daughter nodes are shown by labels on the arcs (NUCLEUS or SATELLITE in the case of a nucleus-satellite relation, or an integer greater than zero in the case of a multinuclear relation).

The output is a linguistic structure, represented formally by an ordered tree in which each node corresponds to a span of the document. Nodes are labeled with document structure features (e.g., the level and indentation of the unit) and also with syntactic features, which usually become relevant only at the level of text-clause or below. Discourse connectives are already selected and positioned correctly in the tree; the only task left to the syntactic realizer is to elaborate the tree further by generating clauses that express the elementary propositions.

Our aim in ICONOCLAST has been to find a document-structuring method that will generate *all* document structures that correctly realize an input rhetorical structure, given certain simplifying assumptions about the composition of the document structure and the discourse connectives available in the lexicon. During this initial enumeration of potential solutions, we are not concerned with good style: the procedure should generate clumsy realizations as well as elegant ones. But we do require a minimal standard of correctness. There is no point in considering solutions that leave propositions in the rhetorical structure unexpressed in the document structure or group them wrongly. The strategy is first to define a procedure that generates all solutions that are worth considering at all; using this minimally correct set as a basis, we can then posit further constraints that impose particular stylistic preferences.

We assume that a minimally correct solution must satisfy three conditions:

1. The terminal nodes of the document structure must express all the propositions in the rhetorical structure.
2. In addition to satisfying the document structure formation rules, the solution must conform to correct syntax within text-clauses. For example, two elementary propositions within a text clause must be linked by a conjunction placed in the right position.
3. The document structure must be structurally compatible with the rhetorical structure.

The first two of these conditions are obvious, but the third needs clarification. What exactly is meant by “structurally compatible”?

We have explored two definitions of structural compatibility that are closely related to the mathematical notions of **isomorphism** and **homomorphism** (Landman

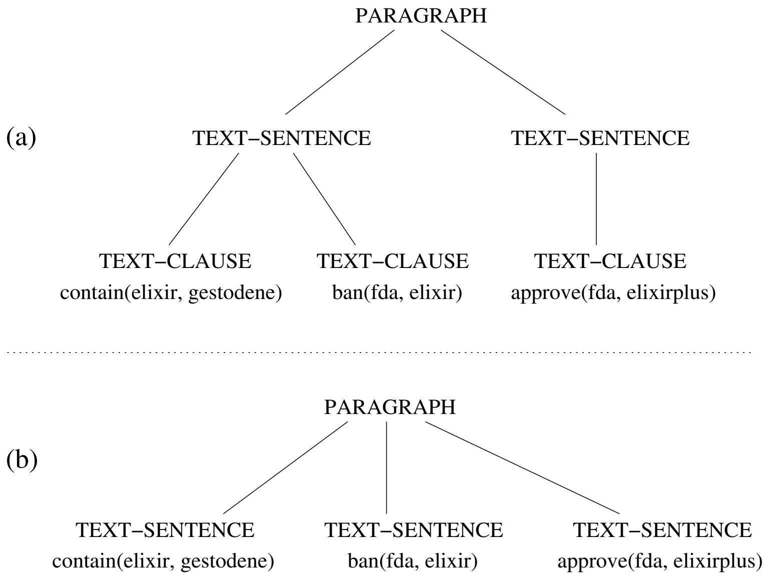


Figure 11
Isomorphic (a) and homomorphic (b) document structures.

1991; Bouayad-Agha, Power, and Scott 2000). Each notion can be conveniently expressed in terms of groupings of propositions in the rhetorical structure and the discourse structure. For an isomorphism (the strongest definition of compatibility), two conditions must hold:

1. If a node in the document structure represents a span in which the set of propositions expressed is *P*, there must be a corresponding node in the rhetorical structure that dominates exactly the same set *P* of propositions.
2. If a node in the rhetorical structure dominates a set *P* of propositions, there must be a node in the document structure representing a span in which exactly this set *P* is expressed.

Informally, for an isomorphism, all groupings of propositions in the rhetorical structure must be transmitted faithfully to the document structure, and no new groupings should be introduced. For a homomorphism from rhetorical structure to document structure, only the first condition is required to be fulfilled. Any grouping found in the document structure must correspond to a grouping in the rhetorical structure, but the document structure may "flatten out" the rhetorical structure by leaving some groupings unexpressed.

These two kinds of compatibility, isomorphism and homomorphism, are illustrated by document structures (a) and (b), respectively, in Figure 11, which are alternative realizations of the rhetorical structure in Figure 10; to simplify, discourse connectives have been left out. Solution (a) is isomorphic with the rhetorical structure, since the propositions dominated by the JUSTIFY relation are grouped together in a separate text-sentence. Solution (b) is homomorphic only with the rhetorical structure, since the propositions are expressed in three separate text-sentences, the internal grouping remaining implicit. Here are two texts that might result:

(39)

(a) Elixir contains gestodene; therefore, it is banned by the FDA. However, the FDA approves ElixirPlus.

(b) Elixir contains gestodene. Therefore, it is banned by the FDA. However, the FDA approves ElixirPlus.

Note that by losing a grouping from the rhetorical structure, (39b) introduces an ambiguity: its form would also be consistent with an alternative rhetorical structure in which the relation JUSTIFY dominated CONCESSION. From the point of view of expressing the rhetorical input precisely, the isomorphic solution is always better. However, when the resulting document structure is complex, or when the correct interpretation can be inferred easily from the content, there might be stylistic reasons for preferring a looser homomorphic solution. As a criterion for generating all minimally correct solutions, therefore, we believe the homomorphic definition of compatibility is more appropriate.[13]

Having decided what counts as a correct solution, our next task is to find an efficient algorithm that will generate all and only these solutions. In ICONOCLAST, this is accomplished through a constraint-solving method that formalizes the options for realizing each part of the rhetorical structure, then eliminates those combined choices that violate constraints. The technique has been explained fully elsewhere (Power 2000), so we will confine ourselves here to a sketch of the main points.

For each node N_R on the rhetorical structure, we can lay out some options on how the rhetorical fragment dominated by this node will be realized in the document structure. The crucial choices are as follows:

- What should be the level and indentation of the document structure node that realizes the proposition or relationship N_R?
- If N_R is a nonterminal node, labeled with a rhetorical relation, what discourse connective (if any) should express this relation in the document structure?
- If N_R is nonterminal, in what linear order should its daughter nodes be realized in the document structure?

These decisions can be formalized by associating with each node four variables that we will call LEVEL, INDENTATION, CONNECTIVE, and POSITION. The potential values of these variables represent options for realizing the relevant part of the rhetorical structure, and these options will be reduced by considering constraints on which *combinations* of values are allowed. Initially, the possibilities are as follows:

LEVEL**:** The level of the document structure unit realizing N_R will be a document unit along the hierarchy from text-phrase to chapter. In the program, it

[13] We actually believe that even the less strict requirement of a homomorphism from RS to DS is too strong, because one occasionally finds natural texts that violate it. For example, in Figure 4, RS and DS are not only nonisomorphic, but nonhomomorphic, because there is a grouping in the DS (propositions *A*, *D*, *E*) that is not found in the RS (no node in the RS dominates just these three propositions). This raises the question of how one can distinguish nonhomomorphic solutions that are acceptable (like that in Figure 4) from ones that are unacceptable (probably the great majority). To defer this difficult issue, we have preferred in this article to confine our attention to homomorphic solutions. For further discussion see Bouayad-Agha, Power, and Scott (2000).

is convenient to represent this with an integer, so that constraints on a higher or lower level can be implemented using the operations $>$ and $<$; we will here continue the notation introduced in Section 4.1, in which L_0 means text-phrase, L_1 means text-clause, and so forth.

INDENTATION**:** The indentation of the document structure unit will be a value in the range I_0 to I_{Max}, as explained in Section 4.2. Again, in the implementation, it is convenient to use an integer.

CONNECTIVE**:** The value of this variable is either $\emptyset$, meaning that no connective should be used, or a word from the lexicon. Thus if the node N_R has the label CONCESSION, the potential values might be $\emptyset$, *although*, *but*, and *however*.

POSITION**:** This variable represents the order in which N_R will be realized in the document structure, in comparison with its sisters. The value must lie in the range $1 \ldots S$, where S is the total number of sisters (including N_R). Thus if N_R is an argument in a nucleus-satellite relation, the range will be $1 \ldots 2$; if it is an argument in a multinuclear relation, the range may be larger.

The solution process consists in determining the set of options for each variable (these are known in constraint logic programming as the **domain** of the variable), then imposing constraints on combinations of values, then enumerating all combinations that satisfy the constraints. Each admissible combination of values can then be used as a blueprint for building one of the document structures that may realize the input rhetorical structure. The constraints imposed during the second phase of this algorithm are essentially those described in the last section.

6. Examples of Document Structuring

We now give two examples of the document-structuring method outlined in the last section. First, we look in detail at a very simple task, to make it clear how the method works. Then we show some output for a more complex task, for which the program will generate dozens of solutions even if the wording of individual propositions is held constant.

6.1 Simple Example

To view the document-structuring method from close up, we will use a simplified version of the task discussed in the last section. The rhetorical structure will comprise just two propositions linked by a CONCESSION relation:

$$concession(ban(fda, elixir), approve(fda, elixirplus))$$

The method works by computing the options for realizing each constituent of the rhetorical structure, where a **constituent** is any node in the rhetorical structure tree along with its descendents. Thus in the present example there are three constituents—the two propositions and the whole relationship—and for convenience we will label them as follows:

A: $approve(fda, elixirplus)$
B: $ban(fda, elixir)$
C: $concession(ban(fda, elixir), approve(fda, elixirplus))$

We can now begin to characterize the units in the document structure that will realize the rhetorical constituents A, B, and C. For each unit, four choices must be made: its *level*, its *indentation*, its *position* in relation to its sisters, and its *connective*. We therefore have a total of twelve variables. Any combination of values that satisfies the constraints (as discussed in the last section) will serve as the blueprint for a solution.

Following the usual technique for solving constraint satisfaction problems (Hentenryck 1989), we assign to each variable a domain of potential values:

Constituent	**Level**	**Indentation**	**Position**	**Connective**
A (*approve*)	$\{L_0 \ldots L_3\}$	$\{I_0, I_1\}$	$\{P_1, P_2\}$	C_0
B (*ban*)	$\{L_0 \ldots L_3\}$	$\{I_0, I_1\}$	$\{P_1, P_2\}$	C_0
C (*concession*)	$\{L_0 \ldots L_3\}$	$\{I_0, I_1\}$	P_1	$\{\mathrm{C}_0, \mathrm{C}_{\mathrm{alt}}, \mathrm{C}_{\mathrm{but}}, \mathrm{C}_{\mathrm{how}}\}$

Some of these assignments require some explanation:

- We make the simplifying assumption that the highest unit required will be the paragraph (formalized as level L_3), and that the maximum indentation will be one place (formalized as I_1).
- Since constituents A and B are sisters in the rhetorical structure, their relative order is formalized by a choice between two positions, P_1 and P_2. Constituent C, in contrast, has no sister in the rhetorical structure, so as an "only child," it can have only one position value.
- Constituents A and B are not associated with a discourse connective, because they are elementary propositions, so their value for the *connective* variable is $C_\emptyset$ (meaning *no connective*). Constituent C is instead associated with the CONCESSION relation, for which we assume that the lexicon offers three connectives: *although* (C_{alt}), *but* (C_{but}), and *however* (C_{how}). The initial domain for the variable *connective*(C) therefore comprises these three possibilities along with $C_\emptyset$, the option of leaving the relation implicit.

Having assigned the initial domains, we next proceed to apply some constraints; these will have the effect of reducing some of the domains. First of all, there are some constraints applicable to the unit that will serve as the root of the whole document structure:

Root Level: In a document generation task, we usually have some preconception about the size of the whole document (e.g., it might be a chapter, or a section). Since this is a small rhetorical structure, we might decree that the whole text should consist of a paragraph, so that *level*$(C) = L_3$.

Root Indentation: It makes no sense for a whole document to be an indented item, so to realize the root constituent C we may stipulate that *indentation*$(C) = I_0$.

Having applied these constraints to the variables realizing C, we can impose some further constraints that arise from the relationship between C and its direct constituents A and B:

Argument Indentation: As pointed out in the last section, it is permissible to indent the arguments of a multinuclear relation, but not a nucleus-satellite relation. Therefore, given that the indentation of C has been fixed as I_0, the indentations of A and B must also be I_0.

Parental Domination: Since A and B are constituents of C in the rhetorical structure, the units realizing A and B in the document structure will occur within the constituent realizing C. Given that all indentations have been set to I_0, this means that $level(C)$ should outrank both $level(A)$ and $level(B)$, and that consequently the option L_3 should be removed from the domains of the last two variables.

Sister Equality: Because A and B are sisters in the rhetorical structure (i.e., arguments of the same relation), it is appropriate that they should be realized in the document structure by units of the same level. We can therefore impose the constraint $level(A) = level(B)$. This does not immediately affect the domains of these variables, but it does mean that as soon as one is fixed, so is the other.

Sister Position: The units realizing the sisters A and B must occur in one of two linear orders in the document structure—they cannot both come first, or both second. We may therefore set the constraint $position(A) \neq position(B)$. Again this has no immediate effect on the domains, but as soon as one value is fixed, so is the other.

Obligatory Connective: As Scott and Souza (1990) point out, an NLG system is ill-equipped to judge when a rhetorical relation may be left implicit, so it makes sense to play safe by *always* realizing the relation using a discourse connective. Following this policy, we can remove C_0 from the domain of $connective(C)$.

Through applying these constraints, the domains of the variables have been reduced as follows:

Constituent	**Level**	**Indentation**	**Position**	**Connective**
A (*approve*)	$\{L_0 \ldots L_2\}$	I_0	$\{P_1, P_2\}$	C_0
B (*ban*)	$\{L_0 \ldots L_2\}$	I_0	$\{P_1, P_2\}$	C_0
C (*concession*)	L_3	I_0	P_1	$\{C_{\text{alt}}, C_{\text{but}}, C_{\text{how}}\}$

Before enumerating solutions, we need to impose a final set of constraints that are conditional on the choice of discourse connective for C. These constraints have been explained fully above, so here we only point out how they are stated in terms of our variables.

Subordinating Conjunction: The units connected by *although* may occur in any order, but they must be text-phrases. Therefore, if $connective(C) = C_{\text{alt}}$, then $level(A) = level(B) = L_0$.

Coordinating Conjunction: We will assume that a coordinating conjunction like *but* may link spans within a text-clause, or across text-clauses and text-sentences, so that no constraint on the levels of A and B results. However, the satellite must precede the nucleus, so we have $position(B) = P_1$ (and hence, by Sister Position, $position(A) = P_2$).

Conjunctive Adverb: A conjunctive adverb like *however* should link spans in units of text-clause or higher,[14] so we can impose the constraints $level(A) > L_0$ and $level(B) > L_0$. (Note that in the implementation, only one of these need be applied, since the other results from Sister Equality.) For *however*, the satellite must precede the nucleus, so again we have $position(B) = P_1$ and $position(A) = P_2$.

With all potential interactions among decisions taken care of, enumeration can proceed. In an implementation in constraint logic programming, this is accomplished through a method called *labeling*, in which the remaining possible values for each variable are tried one by one, with backtracking, until all permitted combinations have been produced. For this example, this process can be understood most easily if we explore in turn the possible values for $connective(C)$.

Suppose first that $connective(C) = C_{alt}$ (i.e., that we try *although*). Through the constraint Subordinating Conjunction, this choice immediately fixes all values of *level*, yielding the following domains:

Constituent	**Level**	**Indentation**	**Position**	**Connective**
A (*approve*)	L_0	I_0	$\{P_1, P_2\}$	C_0
B (*ban*)	L_0	I_0	$\{P_1, P_2\}$	C_0
C (*concession*)	L_3	I_0	P_1	C_{alt}

The only remaining issue is the relative orders of the spans realizing A and B. Enumerating arbitrarily on $position(A)$, we first try the value P_1; by Sister Position this immediately yields $position(B) = P_2$, whereupon all values in the table are fixed. We therefore have our first complete solution:

Constituent	**Level**	**Indentation**	**Position**	**Connective**
A (*approve*)	L_0	I_0	P_1	C_0
B (*ban*)	L_0	I_0	P_2	C_0
C (*concession*)	L_3	I_0	P_1	C_{alt}

This is still only a blueprint for a document structure, but with these specifications the rest can be inferred. First, since the units realizing A and B are text-phrases, whereas the root unit realizing C is a paragraph, the program can interpolate the units needed to make a well-formed document structure: the paragraph has a single text-sentence, which has a single text-clause, which comprises the two text-phrases. Next, since *although* attaches to the satellite, the program coordinates it with the clause that will syntactically realize B. The document structure is now complete, and after syntactic realization of the two propositions we might obtain the following paragraph:

Solution 1: The FDA approves ElixirPlus, although it bans Elixir.

Backing up, the program can now try the alternative order in which $position(A) = P_2$. After inferring the complete document structure in the same way, we thereby obtain a second solution:

Solution 2: Although the FDA bans Elixir, it approves ElixirPlus.

[14] As Oates (2001) has shown, this is not true if *multiple* discourse connectives are allowed: For instance, one might say “The FDA bans Elixir but, however, it approves ElixirPlus.” But in the present example, we assume, for simplicity, that only single discourse connectives are used.

Having fully explored the possibilities with $connective(C) = C_{alt}$, we back up and try the next value, namely, C_{but}. This time the constraint Coordinating Conjunction applies, fixing the *position* values but leaving several possiblities for *level*:

Constituent	Level	Indentation	Position	Connective
A (*approve*)	$\{L_0 \ldots L_2\}$	I_0	P_2	C_0
B (*ban*)	$\{L_0 \ldots L_2\}$	I_0	P_1	C_0
C (*concession*)	L_3	I_0	P_1	C_{but}

Enumerating on one of the *level* variables, for instance, $level(A)$, we can now try in turn the values L_0, L_1, and L_2 (text-phrase, text-clause, and text-sentence); by Sister Equality, any choice will be copied across to $level(B)$, so that we obtain only three further solutions rather than nine:

Solution 3: The FDA bans Elixir, but it approves ElixirPlus.

Solution 4: The FDA bans Elixir; but it approves ElixirPlus.

Solution 5: The FDA bans Elixir. But it approves ElixirPlus.

Finally, we try the remaining option, for which $connective(C) = C_{how}$. The constraint Conjunctive Adverb now applies, fixing the order of *A* and *B* and ruling out solutions for which these propositions are realized by text-phrases:

Constituent	Level	Indentation	Position	Connective
A (*approve*)	$\{L_1, L_2\}$	I_0	P_2	C_0
B (*ban*)	$\{L_1, L_2\}$	I_0	P_1	C_0
C (*concession*)	L_3	I_0	P_1	C_{how}

It remains to enumerate (as before) on $level(A)$, trying in turn the values L_1 and L_2 (text-clause and text-sentence). Sister Equality again copies any selected value across to $level(B)$, so that we obtain just two more solutions:

Solution 6: The FDA bans Elixir; however, it approves ElixirPlus.

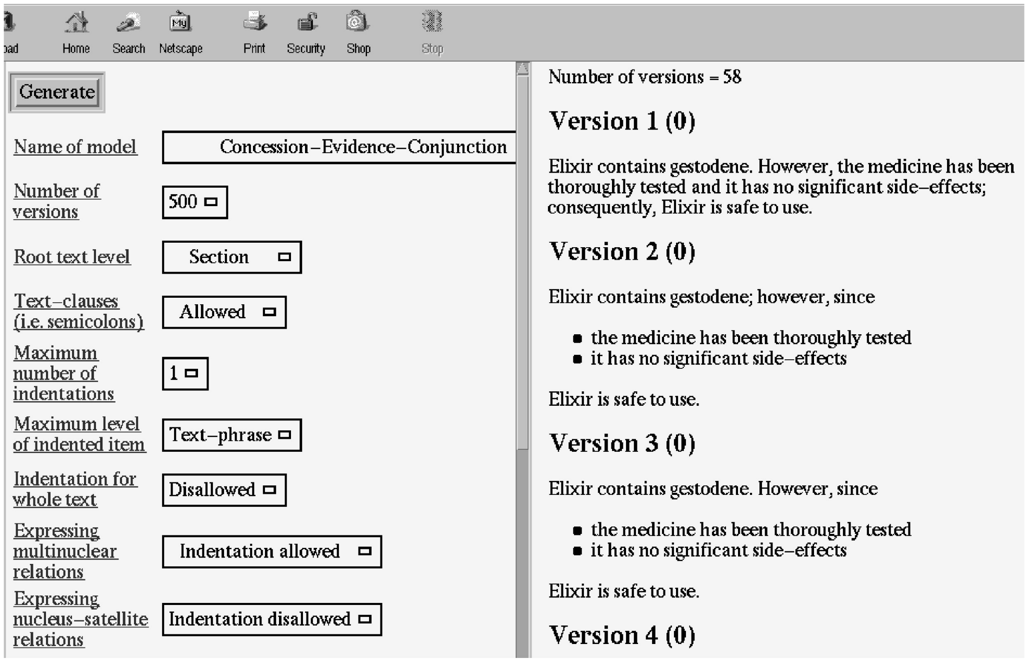
Solution 7: The FDA bans Elixir. However, it approves ElixirPlus.

Obviously further texts could be obtained by different wordings of the propositions or different placements of *however* (e.g., "The FDA bans Elixir; the FDA approves ElixirPlus, however"). But these variations do not concern us here, since we assume they are introduced during syntactic realization, not during document structuring.

6.2 Complex Example

To examine a more complex example, it is convenient to use a version of ICONOCLAST in which the wording of individual propositions is prespecified, so that the program's only task is to explore the set of possible document structures. The input to this program is provided in the form of an XML file using the tags `RhetRep` (for rhetorical relationships) and `SemRep` (for propositions) (Cahill et al. 1999). The roles of satellite and nucleus are distinguished implicitly by the order of the elements (satellite precedes nucleus). Thus the example discussed in the last section

$$concession(ban(fda, elixir), approve(fda, elixirplus))$$



Name of model: Concession–Evidence–Conjunction

Number of versions: 500

Root text level: Section

Text–clauses (i.e. semicolons): Allowed

Maximum number of indentations: 1

Maximum level of indented item: Text–phrase

Indentation for whole text: Disallowed

Expressing multinuclear relations: Indentation allowed

Expressing nucleus–satellite relations: Indentation disallowed

Number of versions = 58

Version 1 (0)

Elixir contains gestodene. However, the medicine has been thoroughly tested and it has no significant side–effects; consequently, Elixir is safe to use.

Version 2 (0)

Elixir contains gestodene; however, since

- the medicine has been thoroughly tested
- it has no significant side–effects

Elixir is safe to use.

Version 3 (0)

Elixir contains gestodene. However, since

- the medicine has been thoroughly tested
- it has no significant side–effects

Elixir is safe to use.

Version 4 (0)

Figure 12
Running the document planner.

could be encoded as follows:

```
<RhetRep relation=concession>
  <SemRep prop="the FDA bans Elixir"/>
  <SemRep prop="the FDA approves ElixirPlus"/>
</RhetRep>
```

Obviously this will sometimes lead to some clumsy wording (e.g., through inappropriate decisions on whether to use pronouns), but we can try to ignore this when evaluating the generated document structures.

As a more complicated example we will consider a rhetorical structure with two nucleus-satellite relations (EVIDENCE, CONCESSION) and one multinuclear relation (LIST):

```
<RhetRep relation=concession>
  <SemRep prop="Elixir contains gestodene"/>
  <RhetRep relation=evidence>
    <RhetRep relation=list>
      <SemRep prop="the medicine has been thoroughly tested"/>
      <SemRep prop="it has no significant side effects"/>
    </RhetRep>
    <SemRep prop="Elixir is safe to use"/>
  </RhetRep>
</RhetRep>
```

The main idea here is that Elixir is safe to use although it contains gestodene; the claim that Elixir is safe is supported by evidence comprising two conjoined facts: It has been thoroughly tested, and it has no significant side effects.

Figure 12 shows a snapshot of the program running on this example. Through the control panel on the left, the user can decide which XML model to use as input; in the figure, this is set to "Concession-Evidence-Conjunction," the name given to this input model. Using the button labeled "Number of versions," the user can determine the maximum number of versions that will be generated; since this has been set to 500, the program will return the first 500 solutions that it finds.[15] The other buttons control hard constraints and have been set deliberately to rather restrictive values (e.g., indented items have been allowed only to one level of indentation and may consist only of text-phrases, not larger units like text-sentences or paragraphs). Even with these restrictive settings, 58 solutions have been generated; they are presented in the pane on the right, ordered (partially) from best to worst. The scores in parentheses after the version number report the number of defects that the program detected for that particular version: thus for each of the solutions that appear in the snapshot, no defects were found.[16] As a comparison, here is version 58, which came up at the bottom of the class with six defects:

> **Version 58 (6)**
>
> Elixir contains gestodene.
>
> However, the medicine has been thoroughly tested.
>
> It has no significant side effects.
>
> Consequently, Elixir is safe to use.

The specific defects cited here were "Single-sentence paragraph" (occurring four times) and "Lost rhetorical grouping" (occurring twice). (The defects are explained below, and the full set of solutions is given in the Appendix.)

At present the program looks for six stylistic defects, which are formulated mainly by looking at generated solutions and making an intuitive judgment as to why they are bad. We have not tried to give the stylistic assessment a sound theoretical or empirical basis; the aim at this stage is to confirm that by applying some simple intuitive principles, we can separate reasonably good solutions from obviously horrible ones. The six defects are as follows (and we stress again that they are only provisional):

Nucleus precedes satellite: It is generally the case for English that the more important information is placed at the end of the sentence (i.e., *end focus* [Quirk et al. 1985]). For example, the rheme of a sentence comes after its theme, and new information is typically placed after given information (Halliday 1985; Givón 1988). There is also psycholinguistic evidence to suggest that sentences that conform to this general pattern are processed more easily (Yekovich, Walker, and Blackman 1979). Since by definition the nucleus is more important than the satellite (Mann and Thompson 1986, page 6), it thus makes sense to place the nucleus second. Obviously this principle is debatable, and the best order might differ from one relation to another, but we have noticed that for the very common relations such as CONCESSION and EVIDENCE, the order satellite-nucleus seems to work better. The program therefore scores a defect every time that a nucleus is placed before its satellite.

Left-branching structure: Fodor, Bever, and Garrett (1974) report that left-branching structures take more time to process and remember than right-branching

[15] Obviously, if there are fewer than 500 solutions, it will return all the solutions it finds.

[16] When it finds a defect in a version, the system also reports on the type of defect that it finds.

ones. We have also noticed that when a document structure coordinates two units of different sizes, it reads best when the smaller unit is placed first. We believe that this may be related to the more general organizational principle of **end weight** (Quirk et al. 1985). Thus in the program, when an elementary proposition is coordinated with a unit containing several propositions, a defect is scored whenever the elementary proposition is placed second.

Lost rhetorical grouping: As discussed, our method of document structuring does not demand an isomorphism between rhetorical structure and document structure; consequently, a grouping that is present in rhetorical structure may be left implicit in the document structure. Although we allow a grouping to be lost in this way, a defect is scored every time it is found to have occurred.

Single-sentence paragraph: Paragraphs containing a single text-sentence usually look strange, so they are scored as a defect.

Oversimple text-clauses: We noticed this subtle defect only as a result of experience with the program. In most cases it looks odd to compose a sentence from two text-clauses, each expressing a single proposition:

> Elixir contains gestodene; therefore, it is banned by the FDA.
> The FDA bans Elixir; however, it approves ElixirPlus.

Assuming it is agreed that these sentences are a little strange, why should this be so? We would suggest the following reason. The semicolon is a somewhat unusual device, more sophisticated than the comma, and one therefore expects it to be used only when ordinary methods are unsatisfactory. In these examples, containing only two propositions, a single text-clause using conjunctions (e.g., since, although) instead of adverbs would express the meaning equally clearly, so the semicolon seems unnecessary, and therefore distracting. A defect is therefore scored every time this is found to have happened.

Repeated discourse connective: If a rhetorical structure contains two relations of the same type, one dominating the other, a defect is scored if they are expressed using the same discourse connective. Here is a simple example of this defect (repetition of *although*), followed by an alternative solution that avoids the defect:

> The FDA approves ElixirPlus although it bans Elixir although Elixir has been thoroughly tested.
>
> The FDA approves ElixirPlus but it bans Elixir although Elixir has been thoroughly tested.

7. Discussion and Conclusion

Our main aim has been to introduce and motivate *abstract document structure* as an important representational level in natural language processing. This proposal rests on two separate claims: first, that it is useful to distinguish abstract document structure from concrete graphical realization; second, that abstract document structure should also be distinguished from rhetorical structure.

7.1 Abstract versus Concrete

We argue that the transition from a rhetorical-semantic message to a fully specified document can usefully be divided into two stages. During the first stage, the author puts the message into words and organizes the words into higher linguistic units like sentences, paragraphs, and bulleted lists. All decisions pertaining to the realization of literal content take place during this stage. During the second stage, detailed formatting takes place: quotations are realized either by single or double quotes (or some other method); emphasis is realized through italics, boldface, small capitals, or underlining; paragraphs are realized through an introductory tab or double line spacing; and so forth. Decisions about format do not affect the factual or logical content of the document, although they might convey "meanings" of a subtler sort, communicated through the typographical preferences of the authors (e.g., traditional versus trendy, ornamental versus puritanical, compact versus expansive).

It is worth noting that similar distinctions are made in other branches of linguistics. Thus in phonology, a distinction is made between a **phonemic** level and a **phonetic** level. The word *grass* has a single phonemic representation but will be pronounced differently by people from different regions or different social classes; these distinctions are phonetic, not phonemic. To refer to an area in the garden as *grass* rather than *lawn* is one kind of decision; to pronounce *grass* with a short or long vowel is another. A theory that mapped directly from the semantic concept to the phonetic form would miss a generalization that is not only obvious theoretically, but useful practically. The invention of writing provides additional support for an intermediate phonemic level, because the different pronunciations of *grass* are all written down in the same way; similarly, we would argue, the representational level of abstract document structure has received more recent support from the invention of markup languages like HTML and LaTeX.

The concept of abstract document structure is not linked to any particular architecture for natural language generation or understanding. In the RAGS "reference architecture" for NLG (Mellish et al. 2000; Cahill et al. 2001), document structure is distinguished from rhetorical structure as a data type, with no commitment as to when these two data structures are created during the generation process. The ICONOCLAST system, described in this article, assumes that rhetorical planning fully precedes document structuring: in other words, the RST tree has to be complete before the process of creating a document structure can begin. Such an architecture could be thought of as a refinement of the standard pipeline (Reiter 1994), with the document-planning phase divided into two parts (rhetorical planning and document structuring). However, the ICONOCLAST method would work equally well if a partial assignment of document structure was part of its input: This would be treated merely as a more specific set of constraints on possible solutions, which is precisely the arrangement that is used in the RAGS reimplementation of the Caption Generation System (Mellish et al. 2000).

7.2 Document Structure versus Rhetorical Structure

In the terminology of HTML and other mark-up languages, tags like `section` and `description list` are sometimes called *logical*, suggesting that they are rhetorical rather than linguistic categories. We have argued that this is a mistake, comparable to a confusion of syntax with semantics. In our view, the term *rhetorical structure* should properly be applied to the higher-level pragmatic and semantic organization of the message, with no commitment to the means by which this message will be expressed—whether by speech, or gesture, or diagram, or written document. By contrast, the categories `section` and `description list` are specific to a particular medium, the written document; hence the term *document structure*. The two levels are easily confused because we often refer to spans of a document using a noun that describes their rhetorical role (e.g., *summary* in an academic paper).

Some of the distinctions made in this article have parallels in work on document analysis. Various representations for document structure have been proposed in the document analysis community, of which the most developed is the Document Attribute Format Specification (DAFS) (Dori et al. 1997). In DAFS, the physical structure of a document is distinguished from its logical structure; typical physical units are block, frame, page, and page set, and typical logical units are sentence, paragraph, section, and header. More formally, the units of logical structure, called **textons**, are organized into levels from character (level 0), word (level 1), and sentence or phrase (level 2) up to sections and whole documents; the lower levels (up to paragraph) are called **simple textons**, and the higher levels are called **compound textons**. Simple textons are realized through blocks of text, whereas compound textons additionally have a heading and (optionally) a trailer. There is considerable overlap here with our distinction between concrete and abstract document structure; differences arise because the analysis community is concerned mainly with the relationship between logical structure and physical structure (to use that community's terminology), whereas the generation community, coming from the opposite direction, is concerned mainly with the relationship between logical structure (i.e., abstract document structure) and rhetorical structure.

Having drawn these distinctions, we have sketched a formal theory of abstract document structure and shown through an implemented NLG system that this theory allows us to enumerate systematically the high-level linguistic structures that can realize a given rhetorical-semantic input. The formal description of document structure is based on Nunberg's (1990) text-grammar, which we have extended in two ways. First, we introduce larger units such as sections and chapters; Nunberg instead focuses on the levels relevant for punctuation (i.e., text-sentence and below). Secondly, we introduce a second feature, abstract indentation. Whereas Nunberg categorizes units only according to the feature we have called LEVEL (the hierarchy from text-phrase, text-clause, etc., up to section and chapter), we categorize units according to two features, LEVEL and INDENTATION. This allows the generation of such patterns as bulleted lists, including more complex cases in which one list is embedded within another. Using this descriptive scheme, it has proved relatively easy to state constraints on the interaction between content, layout, and wording, especially as regards the use of discourse connectives.

By introducing a formal scheme for representing document structure, we have been able to define the task of document structuring in a simple and clear way. Following Scott and Souza (1990) and many other researchers on NLG, it is assumed that the rhetorical input takes the form of an RST tree; the output is a tree representing high-level linguistic structure, each node being labeled with a document structure category defined by the features LEVEL and INDENTATION. Our scheme is by no means complete (e.g., it has no treatment of tables, or figures, or text presented in boxes); however, it is sufficient to generate hundreds of alternative solutions even for a rhetorical structure containing only four or five elementary propositions. By clarifying the task of document structuring in this way, we have been able to define it as a constraint satisfaction problem and thus to implement a system in which the relevant constraints are defined declaratively; this means that constraints can be added or removed without changing the rest of the program. Such a system is useful not only as a module in an NLG architecture, but also as a tool for theoretical investigation: the results of any proposed combination of constraints can be quickly tested.

In pursuing this investigation, our methodology has been essentially the same as Nunberg's, relying largely on intuition as a means of separating the wheat from the chaff. Moreover, by implementing the theory in a system that can enumerate solutions systematically, we are able to test more thoroughly any proposed rule or constraint, at least for simple examples. This methodology assumes, first, that intuition is a reliable guide, and second, that constraints derived from small examples will apply also to full-scale examples. In the initial stages of an investigation, these assumptions seem reasonably safe. Many of the solutions generated by the program are so obviously good or bad that there is no point in submitting them to the judgment of literary experts or subjecting them to some other kind of empirical test. No doubt large-scale examples will require additional constraints, but much can still be learned from simple ones: an intrinsically bad paragraph will usually remain bad when placed into a larger context.

As a contrast, it is interesting to consider the investigation into layout by Bateman et al. (2001). Their approach could not be more different from ours. Instead of simple examples, they analyze (and regenerate) an exceedingly complicated page from a magazine. This page, which describes the game of hockey, includes several drawings, a photograph, diagrams of the pitch, boxes of text, two headers, and a glossary, all laid out in five different grids, each having a different division into columns. Their RST analysis of this page is correspondingly complex, with 45 elementary propositions and the same number of rhetorical relationships (the whole RST tree therefore has nearly 100 nodes). To analyze such an example informally may be a useful source of insights, but to attempt a complete formal analysis (and generation) of the page seems bold in the extreme. However, despite this difference in approach, the framework that emerges from Bateman et al.'s work is broadly similar to ours. First, a distinction is made between "layout structure" and "physical layout" (Bateman et al. 2001, section 3.1); although the discussion concerns boxes in a grid rather than more conventional linguistic units like section and paragraph, this distinction reflects the need for an abstract level of representation that can be related more easily to the rhetorical structure of the message. Secondly, in sections 4 and 5 of their article, Bateman et al. distinguish clearly between layout structure and rhetorical structure, pointing out that the two are not necessarily isomorphic and that constraints on the mapping must therefore be considered:

> Mapping is generally achieved by placing parts of the RST-structure in correspondence with particular nodes in layout structure. [. . .] As we have now seen, however, this correspondence is complicated by the fact that the layout structure and the RST tree need not remain congruent.
> (Bateman et al. 2001, page 430)

However, Bateman and his colleagues do not provide a detailed account of the formation rules for layout structure, or of the constraints on the mapping between the RST tree and the layout structure. We are unsure, for example, whether "layout structure" would include such patterns as sections, paragraphs, and bulleted lists. Nevertheless, the role played by these two abstract representations seems similar—they mediate between rhetorical structure and physical layout—so there is some reason to think that the two approaches are yielding results that are compatible.

Both in the Bateman et al. study and in our own work, a problem arises as to how the proposed representations and constraints should be validated. Our own approach, at least provisionally, has been that the theory should be embodied in a program that can generate many alternative solutions and rank them using some kind of cost function; at this point, we rely on intuition to judge whether the system has generated a plausible set of solutions and ranked them in an appropriate order. For the very complex examples considered by Bateman et al., the set of solutions could only be sampled: Even keeping the wording of individual propositions constant, they would number billions. Evaluation in this field has to take account of style as well as quality; in other words, it has a subjective side as well as an objective one. The problem is not just to generate a good solution, but to generate one that satisfies a set of subjective preferences, so that, for example, different documents produced for the same company will exhibit the desired consistency of style. Eventually, some kind of empirical investigation will be needed (e.g., an expert evaluation, or a study of the impression made on the intended readers). At the present state of knowledge, however, such refinements seem exaggerated: If we can separate the satisfactory from the barbaric, we will be more than content.

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Appendix. Solutions Found for the Example in Section 6.1

Number of versions = 58

Version 1 (0)
Elixir contains gestodene. However, the medicine has been thoroughly tested and it has no significant side effects; consequently, Elixir is safe to use.

Version 2 (0)
Elixir contains gestodene; however, since

- the medicine has been thoroughly tested
- it has no significant side effects

Elixir is safe to use.

Version 3 (0)
Elixir contains gestodene. However, since

- the medicine has been thoroughly tested
- it has no significant side effects

Elixir is safe to use.

Version 4 (0)
Elixir contains gestodene; however,

- the medicine has been thoroughly tested
- it has no significant side effects

so Elixir is safe to use.

Version 5 (0)
Elixir contains gestodene. However,

- the medicine has been thoroughly tested
- it has no significant side effects

so Elixir is safe to use.

Version 6 (0)
Elixir contains gestodene. However,

- the medicine has been thoroughly tested
- it has no significant side effects;

consequently, Elixir is safe to use.

Version 7 (1)
Elixir contains gestodene. However, the medicine has been thoroughly tested and it has no significant side effects. Consequently, Elixir is safe to use.

Lost rhetorical grouping

Version 8 (1)
Elixir contains gestodene. However, the medicine has been thoroughly tested and it has no significant side effects. Consequently, Elixir is safe to use.

Single-sentence paragraph

Version 9 (1)
Although Elixir contains gestodene since

- the medicine has been thoroughly tested
- it has no significant side effects

Elixir is safe to use.

Lost rhetorical grouping

Version 10 (1)
Although Elixir contains gestodene

- the medicine has been thoroughly tested
- it has no significant side effects

so Elixir is safe to use.

Lost rhetorical grouping

Version 11 (1)
Elixir contains gestodene but since

- the medicine has been thoroughly tested
- it has no significant side effects

Elixir is safe to use.

Lost rhetorical grouping

Version 12 (1)
Elixir contains gestodene but

- the medicine has been thoroughly tested
- it has no significant side effects

so Elixir is safe to use.

Lost rhetorical grouping

Version 13 (1)
Elixir contains gestodene; however, Elixir is safe to use since

- the medicine has been thoroughly tested
- it has no significant side effects.

Nucleus precedes satellite

Version 14 (1)
Elixir contains gestodene. However, since the medicine has been thoroughly tested and it has no significant side effects Elixir is safe to use.

Lost rhetorical grouping

Version 15 (1)
Elixir contains gestodene. However, Elixir is safe to use since

- the medicine has been thoroughly tested
- it has no significant side effects.

Nucleus precedes satellite

Version 16 (1)
Elixir contains gestodene; however, the medicine has been thoroughly tested and it has no significant side effects so Elixir is safe to use.

Lost rhetorical grouping

Version 17 (1)
Elixir contains gestodene. However, the medicine has been thoroughly tested and it has no significant side effects so Elixir is safe to use.

Lost rhetorical grouping

Version 18 (1)
Elixir contains gestodene; however, the medicine has been thoroughly tested and it has no significant side effects; consequently, Elixir is safe to use.

Lost rhetorical grouping

Version 19 (1)
Elixir contains gestodene; however,

- the medicine has been thoroughly tested
- it has no significant side effects;

consequently, Elixir is safe to use.

Lost rhetorical grouping

Version 20 (1)
Elixir contains gestodene; however, since the medicine has been thoroughly tested and it has no significant side effects Elixir is safe to use.

Lost rhetorical grouping

Version 21 (1)
Elixir contains gestodene. However,

- the medicine has been thoroughly tested
- it has no significant side effects.

Consequently, Elixir is safe to use.

Lost rhetorical grouping

Version 22 (1)
Elixir contains gestodene.
However,

- the medicine has been thoroughly tested
- it has no significant side effects.

Consequently, Elixir is safe to use.

Single-sentence paragraph

Version 23 (2)
Elixir contains gestodene but since the medicine has been thoroughly tested and it has no significant side effects Elixir is safe to use.

Lost rhetorical grouping
Lost rhetorical grouping

Version 24 (2)

- The medicine has been thoroughly tested
- it has no significant side effects

so Elixir is safe to use although Elixir contains gestodene.

Nucleus precedes satellite
Lost rhetorical grouping

Version 25 (2)
Elixir contains gestodene but the medicine has been thoroughly tested and it has no significant side effects so Elixir is safe to use.

Lost rhetorical grouping
Lost rhetorical grouping

Version 26 (2)
Elixir contains gestodene but Elixir is safe to use since

- the medicine has been thoroughly tested
- it has no significant side effects.

Nucleus precedes satellite
Lost rhetorical grouping

Version 27 (2)
Elixir contains gestodene; however, Elixir is safe to use since the medicine has been thoroughly tested and it has no significant side effects.

Nucleus precedes satellite
Lost rhetorical grouping

Version 28 (2)
Although Elixir contains gestodene since the medicine has been thoroughly tested and it has no significant side effects Elixir is safe to use.

Lost rhetorical grouping
Lost rhetorical grouping

Version 29 (2)
Elixir contains gestodene. However, Elixir is safe to use since the medicine has been thoroughly tested and it has no significant side effects.

> *Nucleus precedes satellite*
> *Lost rhetorical grouping*

Version 30 (2)
Elixir contains gestodene.

However, the medicine has been thoroughly tested and it has no significant side effects; consequently, Elixir is safe to use.

> *Single-sentence paragraph*
> *Single-sentence paragraph*

Version 31 (2)
Although Elixir contains gestodene the medicine has been thoroughly tested and it has no significant side effects so Elixir is safe to use.

> *Lost rhetorical grouping*
> *Lost rhetorical grouping*

Version 32 (2)
Elixir contains gestodene. However, the medicine has been thoroughly tested; it has no significant side effects; consequently, Elixir is safe to use.

> *Lost rhetorical grouping*
> *Oversimple text-clauses*

Version 33 (2)
Elixir contains gestodene.

However, since

- the medicine has been thoroughly tested
- it has no significant side effects

Elixir is safe to use.

> *Single-sentence paragraph*
> *Single-sentence paragraph*

Version 34 (2)
Elixir contains gestodene. However, the medicine has been thoroughly tested; it has no significant side effects. Consequently, Elixir is safe to use.

> *Lost rhetorical grouping*
> *Oversimple text-clauses*

Version 35 (2)
Elixir contains gestodene. However, the medicine has been thoroughly tested. It has no significant side effects. Consequently, Elixir is safe to use.

> *Lost rhetorical grouping*
> *Lost rhetorical grouping*

Version 36 (2)
Elixir contains gestodene.

However,

- the medicine has been thoroughly tested
- it has no significant side effects

so Elixir is safe to use.

Single-sentence paragraph
Single-sentence paragraph

Version 37 (2)
Elixir contains gestodene.

However, the medicine has been thoroughly tested; it has no significant side effects. Consequently, Elixir is safe to use.

Single-sentence paragraph
Oversimple text-clauses

Version 38 (2)
Elixir contains gestodene.

However, the medicine has been thoroughly tested. It has no significant side effects. Consequently, Elixir is safe to use.

Single-sentence paragraph
Lost rhetorical grouping

Version 39 (2)
Since

- the medicine has been thoroughly tested
- it has no significant side effects

Elixir is safe to use although Elixir contains gestodene.

Nucleus precedes satellite
Lost rhetorical grouping

Version 40 (2)
Elixir contains gestodene.

However,

- the medicine has been thoroughly tested
- it has no significant side effects;

consequently, Elixir is safe to use.

Single-sentence paragraph
Single-sentence paragraph

Version 41 (2)
Although Elixir contains gestodene Elixir is safe to use since

- the medicine has been thoroughly tested
- it has no significant side effects.

Nucleus precedes satellite
Lost rhetorical grouping

Version 42 (3)
Elixir contains gestodene.

However, Elixir is safe to use since

- the medicine has been thoroughly tested
- it has no significant side effects.

Single-sentence paragraph
Nucleus precedes satellite
Single-sentence paragraph

Version 43 (3)
Since the medicine has been thoroughly tested and it has no significant side effects Elixir is safe to use although Elixir contains gestodene.

Nucleus precedes satellite
Lost rhetorical grouping
Lost rhetorical grouping

Version 44 (3)
The medicine has been thoroughly tested and it has no significant side effects so Elixir is safe to use although Elixir contains gestodene.

Nucleus precedes satellite
Lost rhetorical grouping
Lost rhetorical grouping

Version 45 (3)
Elixir contains gestodene.

However, since the medicine has been thoroughly tested and it has no significant side effects Elixir is safe to use.

Single-sentence paragraph
Single-sentence paragraph
Lost rhetorical grouping

Version 46 (3)
Although Elixir contains gestodene Elixir is safe to use since the medicine has been thoroughly tested and it has no significant side effects.

Nucleus precedes satellite
Lost rhetorical grouping
Lost rhetorical grouping

Version 47 (3)
Elixir contains gestodene.

However, the medicine has been thoroughly tested. It has no significant side effects.

Consequently, Elixir is safe to use.

Single-sentence paragraph
Lost rhetorical grouping
Single-sentence paragraph

Version 48 (3)
Elixir is safe to use since

- the medicine has been thoroughly tested
- it has no significant side effects

although Elixir contains gestodene.

Nucleus precedes satellite
Nucleus precedes satellite
Lost rhetorical grouping

Version 49 (3)
Elixir contains gestodene but Elixir is safe to use since the medicine has been thoroughly tested and it has no significant side effects.

Nucleus precedes satellite
Lost rhetorical grouping
Lost rhetorical grouping

Version 50 (3)
Elixir contains gestodene; however, the medicine has been thoroughly tested; it has no significant side effects; consequently, Elixir is safe to use.

Lost rhetorical grouping
Lost rhetorical grouping
Oversimple text-clauses

Version 51 (3)
Elixir contains gestodene.

However, the medicine has been thoroughly tested and it has no significant side effects so Elixir is safe to use.

Single-sentence paragraph
Single-sentence paragraph
Lost rhetorical grouping

Version 52 (3)
Elixir contains gestodene.

However,

- the medicine has been thoroughly tested
- it has no significant side effects.

Consequently, Elixir is safe to use.

Single-sentence paragraph
Lost rhetorical grouping
Single-sentence paragraph

Version 53 (4)
Elixir contains gestodene.

However, the medicine has been thoroughly tested; it has no significant side effects; consequently, Elixir is safe to use.

Single-sentence paragraph
Single-sentence paragraph
Lost rhetorical grouping
Oversimple text-clauses

Version 54 (4)
Elixir is safe to use since the medicine has been thoroughly tested and it has no significant side effects although Elixir contains gestodene.

Nucleus precedes satellite
Nucleus precedes satellite
Lost rhetorical grouping
Lost rhetorical grouping

Version 55 (4)
Elixir contains gestodene.

However, the medicine has been thoroughly tested and it has no significant side effects.

Consequently, Elixir is safe to use.

Single-sentence paragraph
Lost rhetorical grouping
Single-sentence paragraph
Single-sentence paragraph

Version 56 (4)
Elixir contains gestodene.

However, Elixir is safe to use since the medicine has been thoroughly tested and it has no significant side effects.

Single-sentence paragraph
Nucleus precedes satellite
Single-sentence paragraph
Lost rhetorical grouping

Version 57 (5)
Elixir contains gestodene.

However, the medicine has been thoroughly tested; it has no significant side effects.

Consequently, Elixir is safe to use.

Single-sentence paragraph
Lost rhetorical grouping
Single-sentence paragraph
Oversimple text-clauses
Single-sentence paragraph

Version 58 (6)
Elixir contains gestodene.

However, the medicine has been thoroughly tested.

It has no significant side effects.

Consequently, Elixir is safe to use.

Single-sentence paragraph
Lost rhetorical grouping
Lost rhetorical grouping
Single-sentence paragraph
Single-sentence paragraph
Single-sentence paragraph