A Data Model and an XQuery Extension for Concurrent XML Structures

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An XML document is mainly hierarhical, but some applications need to simultaneously associate more than one hierarchy to the same data. In general, concurrent hierarchies cannot be merged in order to get a well-formed XML document. This work stands in this context: it aims at describing and querying hierarchical XML structures defined over the same textual data in a concurrent way. Our proposal called MSXD is composed of a data model (which can be seen as an index over the data and between all the structures) and a dedicated query language defined as an extension of XQuery. The key idea is to propose a method for a compact description of multiple tree-like structures over a single text based on segmentation. Segmentation encoding allows querying overlap/containment relations of markups belonging to different structures. This paper also tackles a solution to define a multistructured schema in order to describe the relationships (as weak constraints) between parts of concurrent structures. Finally, this paper focuses on the architecture of the XML environment implementing our proposals.

Povzetek: Sistem omogoča uveljavljanje več hierarhij v dokumentih XML.

1 Motivation

XML [10] is the *de facto* standard to describe structured data. Several applications in the context of information systems are based on their use: electronic publishing, language engineering, technical documentation, digital libraries, Web, etc.

XML documents are mainly hierarchical. The hierarchy, captured in a tree-like structure [23], corresponds to one level of analysis of the data contained in the document (*e.g* a logical analysis). A large set of tools are now available and widely used in particular for edition, querying (XPath [16], XQuery [7]) or transformation (XSLT [15]). According to us, this success is due to the hierarchical structure which is easier to exploit compared to the graph structure. Moreover, manipulation remains simple in an XML environment.

Recently, the title of an article published in the SIGMOD conference [27] claims that " One hierarchy is not enough " for data-centric application context. Indeed, the CONCUR feature of SGML [24] first pointed out this need in the nineties but in context of document-centric encoding where some applications need to consider more than one hierarchy over the same text in a concurrent way. These last years, several other works about concurrent markups have been published [31, 30, 32, 22, 33, 19, 25, 14, 21]. All these different works propose solutions to describe multiple tree-like structures (with overlapping) into a single document. The main problem with concurrent hierarchies is that they cannot be merged in order to get a well-formed XML document without using a flat representation or hyperlinks that make the structure difficult to query.

Our work stands in this context. It aims at representing and querying concurrent hierarchical XML structures defined over the same textual data. We call such data " multistructured textual documents ". The key idea is to propose a method for a compact description of multiple trees over a single text based on its segmentation. Segmentation encoding allows querying overlap/containment relations of markups belonging to different structures. The solution proposed, called MSXD for MultiStructured XML Documents[1], is entirely XML compatible.

This paper describes on the first hand the MSXD model and its relative query language, and on the other hand, it details the way these proposals are implemented under an XML environment. We also tackle the description of relationships between structures (as weak constraints) in order to propose a solution to define a multistructured schema enabling validation across multiple hierarchies [20].

This paper is an extended version of different preliminary contributions ([11], [12] and [13]).

1.1 A running example

To illustrate the problem, we consider a mediæval manuscript (Princeton, Garrett 80 (PG)) related to medico-pharmaceutical recipes written in Occitan language [8]. This kind of text is studied by philologists of the University

[1] Funded by the french research agency (ANR) – Semweb project (2004-2007)

of Pisa (Italy) in the Department of Language and Romance Literature. Philology is a science that studies ancient or mediæval civilizations by the mean of literary documents.

Researchers are interested in studying the text of the manuscript according to different points of view corresponding to different uses of the document. Each analysis results in a mainly hierarchical markup of the text which could be easily represented in XML.

From the document represented as an image (see Figure 1), for illustrating our intention, we have extracted the following textual content:

```
... Per recobrar maniar Ad home cant a perdut lo maniar
    prin de l erba blanca ...
```

This same text has been segmented and marked up in three ways: its *physical* structure $S1$ (the manuscript is organized into pages, on two columns composed of lines), its *syntactic* structure $S2$ (the manuscript is composed of sentences and words) and its *semantic* structure $S3$ (the manuscript describes medical prescriptions which have signs, ingredients, plants and effects). The result is shown in Figure 2 where three XML documents hierarchically organize the same text according to these three different points of views.

Each structure marks up the text differently from another (see Figure 3). For example the segment of text `'Ad home cant a perdut lo maniar'` is tagged by `Sign` in $S3$, while it is tagged differently in $S1$: `'Ad home cant a perdut'` is marked by `Line` whereas `'lo maniar'` begins another textual segment marked also by `Line`. Moreover notice that a `Sign` can overlap two `lines`. Therefore, these documents are independent with potential overlapping.

Structures (but not the relations between them) could be defined by means of a grammar like a DTD, an XML schema [6] or a RelaxNG schema [17].

These XML documents are currently considered separately even if researchers identify correlations between them. In particular, they would like to be able to express the following queries: What are the sentences that follow the signs? (this query combines syntactic and semantic structures); What is the prescription that contains the larger number of lines? (this query combines physical and semantic structures); What are the words cut by an end of line? (this query combines physical and syntactic structures).

Usual XML manipulation languages do not support concurrent structures, thus our issue is (1) to model multiple hierarchical structures in order to query them in a concurrent way and (2) to provide an XML environment to support multistructured documents.

Finally, notice that the relationship (eventually weak) between parts of these three structures are not defined: for example, one can remark that a page (in the physical structure) always begins with a prescription (in the semantic structure). It could be useful to use this kind of constraint during querying and to check consistency between structures. We tackle this issue by defining a schema to describe the relationships between parts of the concurrent structures.

1.2 Objectives

Our objectives are the following:

A suitable – XML compatible – data model. This model dedicated to multistructured textual documents is called MSXD. It enables (1) to consider several segmentations of the same text, and (2) to define a hierarchical structure for each of these segmentations. Notice that the structures could be weakly coupled and that there is no main structure. The set of segmentations and the set of hierarchical structures are deduced automatically from the given XML structured documents (for example produced by philologists). That is why they could be developed in a distributed way. The replication of the common text (in each XML document) can be seen as a drawback but (i) the data storage according to the volume is not really a problem, and (ii) synchronisation is not an issue because the common text is never updated: the only changing part (the structure) is not replicated. Moreover, each user can then edit its own copy offline. This data model is based on the use of hedges [28], the foundation of grammar language RelaxNG [17] (REgular LAnguage description for XML New Generation);

An extension of XQuery [7]. Our objective is to query the structures and the textual content in a concurrent way and to use an as much as possible unchanged XQuery. One of the original contribution of our proposal is that the MultiStructured document is never instantiated. As we said before, the set of structures can be syntactically described as a distributed set of XML documents: we want to keep each structure safe to use available XML tools and languages for its construction and its manipulation. Given a set of XML documents over the same textual value, a MSXD instance can be seen as an index over the textual value and between all the structures. This index is used to evaluate queries using concurrent structures;

The description of relationships between structures. We propose a solution to define a multistructured schema in order to describe the relationships (as weak constraints) between parts of the concurrent structures. This is done as a set of rules by means of Allen's relations to constrain the relative position of fragments in the structures. This work is a first step towards validation across multiple hierarchies [20].

This paper is organized as follows: Section 2 defines the MSXD data model and shows the XML syntax associated to an MSXD instance. Section 3 presents an extension of XQuery to multistructure. Section 4 proposes a schema enabling to express constraints between concurrent structures. Section 5 specifies the MSXD architecture. Section 6 is dedicated to the related works and section 7 concludes. Currently, we only consider the definition of multiple structures in the single textual modality.

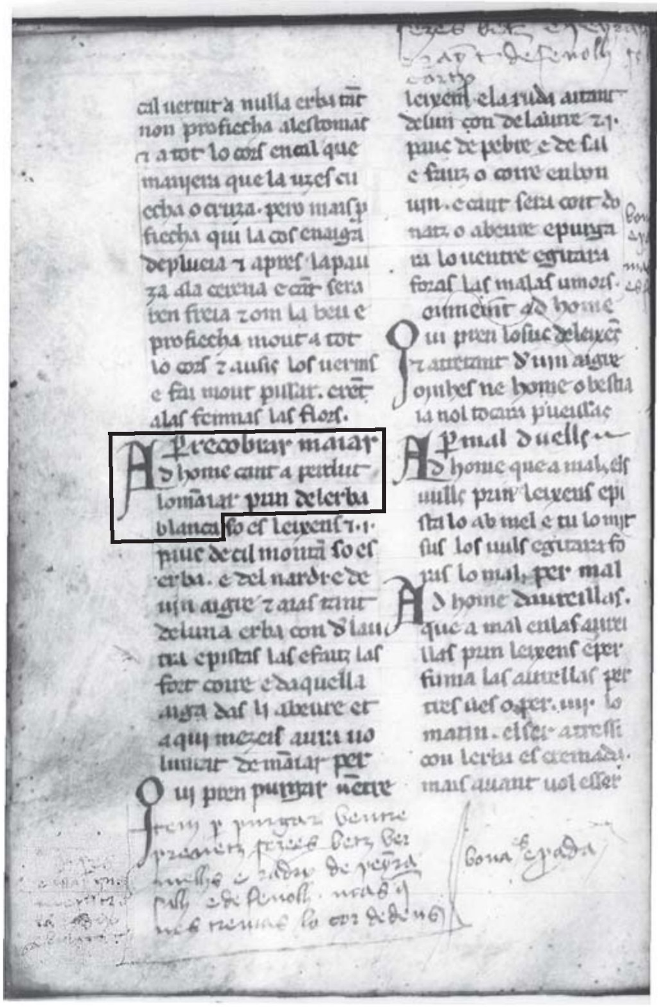


Figure 1: A page from the manuscript

2 The MSXD model

We first choose to define the notion of a multistructured document and then to introduce all the concepts used in this definition. We illustrate the MSXD model with our running example. Our data model is based on the use of hedges (the foundation of RelaxNG). Informally, a hedge is a sequence of trees. In the XML terminology, a hedge is a sequence of elements possibly intervened by character data; in particular, an XML document is a hedge [28].

2.1 Formal model definition

Definition 1. *A Multistructured document is a triplet (V,I,S) where V is a textual value, I a set of segmentations of V and S a set of structures associated to segmentations from I.*

A multistructured document can be seen as a textual value augmented with different hierarchical structures defined over it. These structures share the same text but concern (in general) different strings extracted from that text.

Definition 2. *A segmentation of the textual value V of length l is a list X_V of strings such that $X_V = \{x_i | x_i = V[b_i..e_i]$ and $b_0 = 0$ and $e_i \geq b_i$ and $b_i = e_{i-1} + 1$ and $e_{|X_v|-1} = l - 1\}$, b_i and e_i are respectively the start and the end positions of the fragment in V. We define two functions for each $X_V[i]$, $start(X_V[i]) = b_i$ and $end(X_V[i]) = e_i$. The set X_V makes a total partition of the textual value V.*

For our example, V is the text extracted from the manuscript (`"...Per recobrar maniar Ad home cant a perdut lo maniar prin de l erba blanca..."`) and we consider three segmentations X_V^1, X_V^2 and X_V^3 (corresponding to the set of textual contents of the XML elements from each structure S1, S2 and S3, see Figure 2):

- $X_V^1 = x_1^1 ... \cup ... x_4^1$, with in particular x_1^1 = `"Per recobrar maniar"` and x_4^1 = `"blanca..."`,
- $X_V^2 = x_1^2 ... \cup ... x_{15}^2$, with in particular x_1^2 = `"Per"` and x_{15}^2 = `"blanca"`,
- $X_V^3 = x_1^3 ... \cup ... x_4^3$, with in particular x_1^3 = `"Per recobrar maniar"`, and x_4^3 = `"erba blanca"`.

```
<!-- S1 physical structure -->
<?xml version="1.0" encoding="utf-8"?>
<Manuscript>...
  <Page>
    <Column>...
      <Line>Per recobrar maniar</Line>
      <Line>Ad home cant a perdut</Line>
      <Line>lo maniar prin de l erba</Line>
      <Line>blanca ...</Line>...
    </Column> ...
  </Page>...
</Manuscript>

<!-- S2 syntactic structure -->
<?xml version="1.0" encoding="utf-8"?>
<Manuscript>
 <Syntax>...
  <Sentence><W>Per</W><W>recobrar</W><W>maniar</W></Sentence>
  <Sentence><W>Ad</W> <W>home</W> <W>cant</W><W>a</W>
   <W>perdut</W><W>lo</W> <W>maniar</W> <W>prin</W>
   <W>de</W><W>l</W> <W>erba</W><W>blanca</W> ...</Sentence>...
 </Syntax>
</Manuscript>

<!-- S3 semantic structure -->
<?xml version="1.0" encoding="utf-8"?>
<Manuscript>
 <Prescriptions>...
  <Prescription>Per recobrar maniar <Sign>Ad home cant
  a perdut lo maniar</Sign>prin de l <Ingredient><Plant>erba
  blanca</Plant>...</Ingredient></Prescription>...
 </Prescriptions>
</Manuscript>
```

Figure 2: Physical ($S1$), Syntactic ($S2$) and Semantic ($S3$) structures

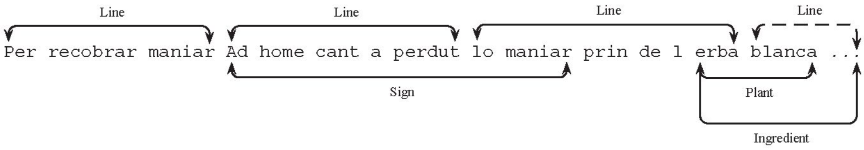

Line
Line
Line
Line
Per recobrar maniar Ad home cant a perdut lo maniar prin de l erba blanca ...
Sign
Plant
Ingredient

Figure 3: Multiple segmentations of the text

We use the concept of *fragment* to define *structures*: fragments mark up a segmentation. Fragment positions in the textual value are useful to compute their relative positions.

Definition 3. *A fragment f is defined over a segmentation X_V of the textual value V and an alphabet Σ_V, a set of labels:*

1. *$f = \varepsilon$ (the empty fragment),*
   $start(f) = end(f) = 0$

2. *$f = v_i$ with $v_i \in X_V$, $start(f) = start(X_V[i])$,*
   $end(f) = end(X_V[i])$

3. *$f = v < x >$ with $v \in \Sigma_V$ and x a fragment,*
   $start(f) = start(x)$,
   $end(f) = end(x)$ (f is called a tree)

4. *$f = xy$ with x and y two fragments and*
   $start(y) = end(x) + 1$,
   $start(f) = start(x)$, $end(f) = end(y)$.

Notice some remarks about definition 3:

- Rule 1 defines the empty fragment. Recall that we want to represent several segmentations of the same text in order to define a hierarchical structure for each of these segmentations (producing several structured documents over the same text). Using empty fragments (as milestones) is not compatible with our model because a fragment has to be related to a segmentation. The only legal empty fragment is the one associated with the empty document.

- Rule 3 uses the alphabet Σ_V, which is a set of labels for fragments having a tree-like structure corresponding to XML element names:
  for the physical analysis,
  $\Sigma_V^1 = \{Manuscript, Page, Column, Line\}$,
  for the syntactic analysis,
  $\Sigma_V^2 = \{Manuscript, Syntax, Sentence, W\}$,
  for the semantic analysis,
  $\Sigma_V^3 = \{Manuscript, Prescription, Ingredient, Sign, Plant\}$.

- Rule 4 produces sequences of fragments. We do not make a distinction between a fragment and a singleton sequence containing that fragment and we do not consider nested sequences.

We now give some examples of fragments respectively constructed over segmentations X_V^1 and X_V^3:

- Over X_V^1 (two fragments):
  (1) $f_1^1 = x_1^1$ with x_1^1 =`"Per recobrar maniar"`, $start(f_1^1) = 1$, $end(f_1^1) = 19$ and
  (2) $f_2^1 = Line < x_1^1 >$, $start(f_2^1) = start(f_1^1)$, $end(f_2^1) = end(f_1^1)$;

  The fragment f_2^1 is represented in XML syntax by `<Line>Per recobrar maniar</Line>`.

- Over X_V^3 (three fragments):
  (1) $f_4^3 = x_4^3$ with x_4^3= `"erba blanca"`, $start(f_4^3) = 60$, $end(f_4^3) = 70$
  (2) $f_5^3 = Plant < f_4^3 >$, $start(f_5^3) = start(f_4^3)$, $end(f_5^3) = end(f_4^3)$ and
  (3) $f_6^3 = Ingredient < f_5^3 >$, $start(f_6^3) = start(f_5^3)$, $end(f_6^3) = 92)$ (we supposed that 92 is the end position of the textual fragment marked by “..." in our example);

  The fragment f_6^3 is represented in XML by

  ```
  <Ingredient>
    <Plant>erba blanca</Plant>...
  </Ingredient>.
  ```

Definition 4. *A structure is a tree f (a labelled fragment) over a segmentation of the textual value V, $end(f) = |X_V| - 1$ and $start(f) = 0$.*

Figure 4 illustrates our model over the two X_V^1 and X_V^3 segmentations (we do not show the third segmentation to make the reading of the figure easier) and the two structures $S1$ and $S3$ defined over them. The figure is composed of two parts: the first indicates the segmentations (start and end positions are associated to each textual segment inside a segmentation; for convenience the numbering of start and end positions only takes into account the segments used in our example), and the second part shows the hierarchical organization of fragments into a structure (physical structure on the left, semantic structure on the right).

In summary, from the XML documents of Figure 2, we can extract the text V, we can deduce three structures ($S1$, $S2$ and $S3$) built on three segmentations (X_V^1, X_V^2 and X_V^3). Fragments are constructed over segmentations.

2.2 Relative position of two fragments

Our model is designed so that Allen's relations [2] can be used on fragments in order to calculate their relative position inside a segmentation or between two segmentations.

Definition 5. *Predicates on two fragments f_1 and f_2 are defined over one or two segmentations on the same textual value:*

$$
\begin{aligned}
before(f_1, f_2) \quad & \equiv finishes(f_2, f_1) \\
& \equiv end(f_1) < start(f_2) \\
before(f_1, f_2, n) \quad & \equiv finishes(f_2, f_1, n) \\
& \equiv start(f_2) - end(f_1) = n \\
meets(f_1, f_2) \quad & \equiv met\text{-}by(f_2, f_1) \\
& \equiv end(f_1) = start(f_2) \\
during(f_1, f_2) \quad & \equiv contains(f_2, f_1) \\
& \equiv start(f_1) > start(f_2) \\
& \quad and\ end(f_1) < end(f_2) \\
overlaps(f_1, f_2) \quad & \equiv is\text{-}overlapped(f_2, f_1) \\
& \equiv start(f_1) < start(f_2) \\
& \quad and\ end(f_1) > start(f_2) \\
& \quad and\ end(f_1) < end(f_2)) \\
starts(f_1, f_2) \quad & \equiv started\text{-}by(f_2, f_1) \\
& \equiv start(f_1) = start(f_2) \\
& \quad and\ end(f_1) < end(f_2) \\
finishes(f_1, f_2) \quad & \equiv finished\text{-}by(f_2, f_1) \\
& \equiv end(f_1) = end(f_2) \\
& \quad and\ start(f_1) > start(f_2) \\
equals(f_1, f_2) \quad & \equiv start(f_1) = start(f_2) \\
& \quad and\ end(f_1) = end(f_2)
\end{aligned}
$$

Notice that if f_1 and f_2 are defined on the same segmentation the predicates *meets* and *overlaps* are always false.

Finally, we need to compute the level of a fragment in a structure. This level captures the parent/child relationship between two fragments in a structure.

Definition 6. *Let $F(s)$ (s is a structure) be the set of fragments f such that $f = s$ or $\exists x \in F(s)$, $\exists a \in \Sigma_V | x = a < f >$. The function $level(s, f)$ returns the level of the fragment f in the structure s, it is calculated with the following algorithm :*

- *$level(s, s) = 0$*
- *$level(s, y) = level(s, x) + 1$ with $x = a < y >$ (x and $y \in F(s)$).*

Figure 4 also shows the relative position of two fragments in two segmentations. In particular, the two following Allen's predicates are true (they indicate that a `Plant` overlaps two `Lines`):
$overlaps(Plant(s'5, e'5), Line(s5, e5)) = true$
$overlaps(Plant(s'5, e'5), Line(s6, e6)) = true$.

Lastly, notice that in Figure 4, we have associated to each fragment its level in the hierarchical structure to which it belongs. For example, in $S1$,
$level(S1, Manuscript <>) = 0$
$level(S1, Page <>) = 1$
$level(S1, Column <>) = 2$
$level(S1, Line <>) = 3$.

2.3 MSXD XML syntax

We see that for a given multistructured document, each structure can be described using an XML syntax, thus its schema can be described using RelaxNG (see Figure 5). We choose RelaxNG because our model relies on hedges

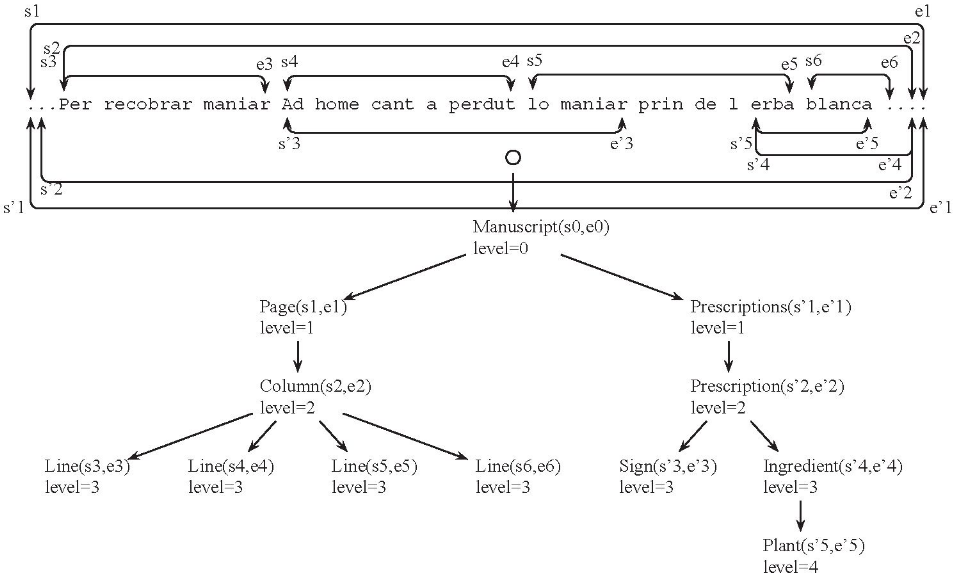


Figure 4: Illustration of our model

to represent XML documents and the design of RelaxNG is based on this theory [28]. Another equivalent solution could have been to use XML Schemas.

We define an XML syntax for an MSXD instance (see Figure 6). In this figure, we refer to the textual value of the manuscript (identified by an uri), each structure (identified by an uri) and its associated schema. Notice that segmentations are implicit.

3 Querying MSXD instances

Our data model is close to XDM (XML Data Model)[23] used in XQuery and XPath. Recall that XDM defines unnested sequences of items (nodes or atomic values). For querying, we propose an extension of XQuery to deal with a multistructured document.

Indeed, we propose to define an XQuery *item* as an atomic value or a fragment (instead of a node) and then we still deal with sequences of items. Thus, the XQuery language can be adapted to query a multistructured document. A XQuery on an MSXD instance with a single structure is equivalent to the same XQuery on the XML document corresponding to this structure. In the case of multiple structures, we extend the semantics of the filters of XQuery. For that, we successively study and extend:

- The accessors defined in the XQuery Data Model (XDM) [23]. Accessors can be seen as a set of primitives to access an instance of the XML data model (*parent*, *child*, . . .).
- The axis defined in XQuery [7]. Axis are an higher level access mode to instances of the XML data model. An axis can be an accessor (for instance *parent* and *child*) or can be based on accessors (for instance the axis *ancestor* is defined by the recursive application of the accessor *parent*).
- The normalization of an extended XQuery into a core XQuery (as defined in the XQuery Formal semantics [18]). To formally define the semantics of XQuery, a subset of XQuery named XQuery core has been defined. Every XQuery can be expressed in the core. For instance, an XPath step is translated in a *For Let Where Return* (FLWR) expression. The dynamic environment existing during the evaluation of an XQuery is explicitly defined by binding a set of standard variables in the XQuery core.

Our objective is to use an as much as possible unchanged XQuery, that is why we choose to rely on the XQuery normative documents.

3.1 Extending XDM accessors and XQuery axis

To navigate in every structure and to adapt Allen's relations, we choose to slighty modify the semantics of some accessors or operators (close to Allen's relations). In other cases, we define new functions.

Accessors. First, to express the containment we adapt the parent/child relationship: The `dm:children` and `dm:parent` accessors have been extended to return every parent and every child of a fragment in every structure it belongs to.

Axis. As a fragment does not belong to every structure and as we want them to be as general as possible, the axis `ancestor` and `descendant` cannot be defined by applying recursively the accessors `dm:parent` and `dm:children` as it is done in XQuery[2]. Thus, we define

[2] `http://www.w3.org/TR/xquery/id-full-axis-feature`

```
<!--  Physical Structure -->
start =
  element Manuscript {

    element Page {
      element Column {
        element line {
          text+
        }+
      }+
    }+
  }
```

```
<!-- Syntactic Structure -->
start =
  element Manuscript {
    element Page {
      element Column {
        element line {
          text+
        }+
      }+
    }+
  }
```

```
<!-- Semantic structure -->
start =
  element Manuscript {
   element Prescriptions {
    element Prescription {
      (text | Dosage | Effect | Ingredient
            | AdministrationMode
       | element Sign { text }
       | element Concoction {
           (text
            | Effect
            | AdministrationMode
            | element Action { (text | Ingredient)+ })+
         })+
    }+
   }
   }
Effect = element Effet { text }
Sign =
  element Ingredient {
    (text | Dosage
     | element Mineral { text }
     | element Plant { text })+
  }
AdministrationMode = element AdministrationMode { text }
Dosage = element Dosage { text }
```

Figure 5: Schemas for the Physical ($S1$), Syntactic ($S2$) and Semantic ($S3$) structures

```
<MsXmlDoc xmlns="http://lsis.univ-tln.fr/msxd/doc/v1/">
 <TextalValue
  uri="http://lsis.univ-tln.fr/msxd/value/manuscript"/>
 <Structure
  type="http://lsis.univ-tln.fr/msxd/structure/manuscript/physical"
  uri="http://lsis.univ-tln.fr/msxd/instance/S1.xml"/>
 <Structure
  type="http://lsis.univ-tln.fr/msxd/structure/manuscript/syntactic"
  uri="http://lsis.univ-tln.fr/msxd/instance/S2.xml"/>
 <Structure
  type="http://lsis.univ-tln.fr/msxd/structure/manuscript/semantic"
  uri="http://lsis.univ-tln.fr/msxd/instance/S3.xml"/>
</MsXmlDoc>
```

Figure 6: XML syntax for the multistructured manuscript

two new accessors:
`dmmsxd:ancestor` and `dmmsxd:descendant` which respectively return the sequence of fragments containing a fragment or contained in a fragment (according to start and end positions).

Order. We need to consider Allen's relations used to compute relative position between two fragments inside a segmentation or between two segmentations. A partial order on fragments in a given multistructured document can be defined on start and end positions. As in XQuery, the boolean operators $n_1 << n_2$, $n_1 >> n_2$ and n_1 *is* n_2 can be defined. They are respectively true for the fragments n_1 and n_2, if n_1 is before n_2, n_1 is after n_2 and if n_1 and n_2 are the same fragment. We use the two first boolean operators ($<<$, $>>$) to express the following (`after`) and preceding (`before`) Allen's relations.

New functions. We introduce each of the remaining relations as functions (evaluated according to the relative positions of two fragments). We only give here the definition of two Allen's relations (`equals` and `overlaps`) and the corresponding operators because they are used in the query examples given below. The remaining relations can be defined in the same way.

- the function `msxd:is-equal(`n_1`,`n_2`)` and the operator `is-equal`, are true if n_1 and n_2 have the same start and end positions in the same multistructured document,

- the function `msxd:is-overlapping(`n_1`,`n_2`)` and the operator `is-overlapping`, are true if $start(n_1) < start(n_2)$ and $end(n_1) > start(n_2)$ and $end(n_1) < end(n_2)$.

3.2 Extending the dynamic evaluation

In the formal semantics of XPath and XQuery, the dynamic context is explicitly defined by binding variables. In particular `$fs:sequence`, `$fs:dot`, `$fs:position` and `$fs:last` variables respectively represent *the sequence of context items*, *the context item*, *the context position*, and *the context size*. The side effect of each operator is also explicit in the core XQuery.

It is necessary to extend the dynamic context to carry information about every structure associated with an MSXD instance. We extend it by binding a new variable `$msxd:selected_structures` to a sequence of strings that represents the set of ids of the structures to be taken into account during the evaluation of the query.

In our example, when the document is loaded by default:

```
$msxd:selected_structures =
{"http://lsis.univ-tln.fr/msxd/instance/S1.xml",
"http://lsis.univ-tln.fr/msxd/instance/S2.xml",
"http://lsis.univ-tln.fr/msxd/instance/S3.xml"};
```

This variable can be used to restrict the set of structures. If it is set to a subset of the structures, only this subset is taken into account by the XQueries.

We need to define two basic functions to return existing structures in a document and to create the instance of a document:

- `msxd:structures($arg as fragment()*) as xs:string*`
  returns a sequence of strings which represents the ids of structures to which every fragment of the sequence `$arg` belongs.

- `msxd:doc($uri as xs:string?) as document-node()?`
  retrieves the XML description of an MSXD instance using `$uri` and returns its document fragment `$root` (equivalent to `fn:doc()` in `http://www.w3.org/TR/xpath-functions/`). This changes the dynamic context by binding `$msxd:selected_structures` to `msxd:structures($root)`, ie by default every structure of a document are consired during a query.

Finally, we slightly modify the normalization of a path expression in XQuery (a step followed by a relative path expression) to return only fragments of the selected structures. The new rule is given in Figure 7.

The standard normalization transforms an XPath step into a *FLWR* expression and it sets the dynamic environment after the evaluation of the first step, and for each item of the result (`$fs:sequence`) the relative path is evaluated (Lines 3,4 and 5). In our extension, we restrict the results to items from the selected structures (Lines 6, 7 and 8). Lines 1 and 2 ensure that each fragment is unique and that every fragment is sorted according to the document global order.

3.3 Query examples

We propose some queries for our running example:
Prolog - Binding the multistructured document to a global variable

```
declare variable
   $msdoc := msxd:doc("manuscript.msxd");
```

Q1 – Children of `Manuscript`

```
$msdoc//Manuscript/*
```

returns every child of the fragment `Manuscript` which is shared by every structure (the results is the sequence `Page` from *S*1, `Syntax` from *S*2 and `Prescriptions` from *S*3, see Figure 2),

Q2 – First `Sentence` *of* `Prescriptions` *described on one* `Column`

```
$msdoc//Column//Prescription//Sentence[1]
```

Q3 – `Words` *cut by an end of* `Line`

```
for $v in $msdoc//Line
return $msdoc//W[. is-overlapping $v]
```

```
[StepExpr / RelativePathExpr]Expr
                ==
fs:apply-ordering-mode (
fs:distinct-doc-order-or-atomic-sequence (
  let $fs:sequence as node()* := [StepExpr]Expr return
  let $fs:last := fn:count($fs:sequence) return
  for $fs:dot at $fs:position in $fs:sequence return
    for $msxd:fragment in [RelativePathExpr]Expr return
     if ([(msxd:structures($msxd:fragment)) = $msxd:selected_structures]Expr)
        return $msxd:fragment
       else return (); ))
```

Figure 7: Extended normalization of a Path expression

Q4 – `Columns` which are `Sentences`
`for $v in $msdoc//Sentence`
`return $msdoc//Column[. is-equal $v]`

Q5 – `Sentences` containing `Plant`
`$msdoc//Sentence[descendant::Plant]`

Q6 – First `Sentence` after a `Sign`
`$msdoc//Sign/following::Sentence[1]`

Q7 – First `Sentence` after a `Sign`
`for $h in $msdoc//Sign`
`return $msdoc//Sentence[. >> $h][1]`
is the same as Q6 but using the order operator instead of the `following` axis.

Q8 – Children of `Manuscript` in S1
`let $msxd:selected_structures :=`
`"http://lsis.univ-tln.fr/msxd/instance/`
`S1.xml"`
`return $msdoc/Manuscript/*`
is the same as Q1 but returns only children from $S1$ because the variable `$msxd:selected_structures` is explicitly set to the identifier of $S1$.

4 A Schema for multistructured documents

We define a schema for multistructured documents as a set of rules (*vs* a content model definition) because our structures are weakly coupled and the multistructured document is not hierarchical. Allen's relations (*starts*, *overlaps*, *equals*, ...) enable to constrain the relative position of fragments belonging to different structures. The constrains are expressed using XPath based predicates, we suppose that an XPath expression applied to a *structure* returns a sequence of fragments.

Definition 7. *A Multistructured document schema is a pair* (G_S, C) *where* G_S *is a set of grammars defining valid structures and* $C = \{c_i | c_i = c(p_1 \text{ in } s_1, p_2 \text{ in } s_2)\}$ *is a set of constrains, where c is the name of an Allen's predicate and* p_1, p_2 *are XPath expressions applied to the structures* s_1 *and* s_2*. The constrain is true if for each fragment* f_1 *in* $val(p1)$*, it exists a fragment* f_2 *in* $val(p_2)$ *such that* $c(f_1, f_2)$ *is true. A document is valid according to the schema if and only if every constrains in C are true.*

Figure 8 (see comments in the figure) shows an XML syntax for multistructured documents schemas and illustrates some constrains between fragments of the three structures of our running example (notice that each constrain is applied to two structures). Every constrain could be read in the same way, for example

- Rule 1: Root fragments of physical and syntactic structures are equal. Each fragment matching `/Manuscript` in every document valid according to the structure (whose alias is) `manuscript_physical` must be *equal* to at least one fragment matching `/Manuscript` in every document valid according to the structure (whose alias is) `manuscript_syntactic`;
- Rule 3: A page starts by a prescription. Each fragment matching `Page` in every document valid according to the structure (whose alias is) `manuscript_physical` *starts by* at least one fragment matching `Prescription` in every document valid according to the structure (whose alias is) `manuscript_semantic`;
- Rule 4: A prescription contains sentences. Each fragment matching `/Prescription` in every document valid according to the structure (whose alias is) `manuscript_semantic` *contains* at least a fragment matching `sentence` in every document valid according to the structure (whose alias is) `manuscript_syntactic`.

This work is a first step towards validation across multiple hierarchies [20]. It enables to check the conformance of concurrent annotations attached to the same textual document related to predefined weak relationships between parts of different structures. Even if the validation is optional, it is useful to use this kind of constraints in case of distributed annotation to check the consistency of structures before querying.

```
<MsXmlSchema xmlns="http://lsis.univ-tln.fr/msxd/v1/">
 <!-- IDENTIFICATION OF THE STRUCTURES  -->
 <MsXmlDoc>
  <Structure type="http://lsis.univ-tln.fr
                   /msxd/structure/manuscript/physical"
             alias="manuscript_physical"
             grammar="manuscript_physical.rnc"/>
  <Structure type="http://lsis.univ-tln.fr
                   /msxd/structure/manuscript/syntactic"
             alias="manuscript_syntactic"
             grammar="manuscript_syntactic.rnc"/>
  <Structure type="http://lsis.univ-tln.fr
                   /msxd/structure/manuscript/semantic"
             alias="manuscript_semantic"
             grammar="manuscript_semantic.rnc"/>
 </MsXmlDoc>
 <Constraints>
 <!-- RELATIVE CONSTRAINTS BETWEEN STRUCTURES -->
 <!-- Rules 1 and 2: Manuscripts in the
      three structures are Equals -->
  <Equals>
     <Fragments name="manuscript_physical
                select="/Manuscript"/>
     <Fragments name="manuscript_syntactic"
                select="/Manuscript"/>
  </Equals>
  <Equals>
     <Fragments name="manuscript_physical"
                select="/Manuscript"/>
     <Fragments name="manuscript_semantic"
                select="/Manuscript"/>
  </Equals>
  <!-- Rule 3: A page starts by a prescription  -->
  <Starts>
     <Fragments name="manuscript_semantic"
                select="Prescription"/>
     <Fragments name="manuscript_physical"
                select="Page"/>
  </Starts>
  <!-- Rule 4: A prescription contains sentences -->
  <Contains>
     <Fragments name="manuscript_semantic"
                select="Prescription"/>
     <Fragments name="manuscript_syntactic"
                select="Sentence"/>
  </Contains>
 </Constraints>
</MsXmlSchema>
```

Figure 8: A grammar for our multistructured document

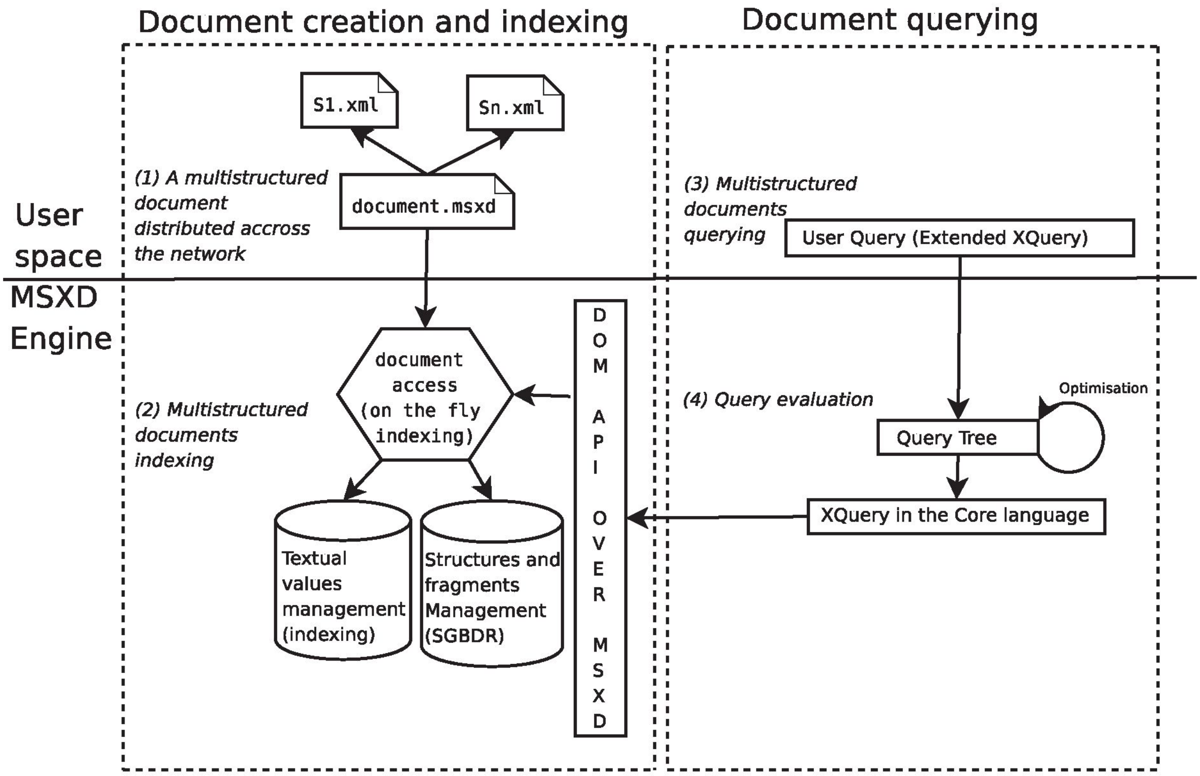

Document creation and indexing
Document querying
S1.xml
Sn.xml
(1) A multistructured document distributed accross the network
document.msxd
User space
MSXD Engine
(3) Multistructured documents querying
User Query (Extended XQuery)
document access (on the fly indexing)
(2) Multistructured documents indexing
D O M A P I O V E R M S X D
(4) Query evaluation
Optimisation
Query Tree
XQuery in the Core language
Textual values management (indexing)
Structures and fragments Management (SGBDR)

Figure 9: MSXD functional architecture

5 Implementation of the MXSD data model and query language

In this section, we describe the architecture of an implementation of the MSXD data model and of a XQuery engine extended to support multistructured documents. Figure 9 presents the functional architecture of our prototype and a typical use case in four steps. The figure is organized in two lines and two columns. The first line presents the user level and the second the MXSD engine level. The first column describes the design and the indexing an MSXD instance from a set of XML documents, the second column illustrates the querying.

5.1 User space: An almost usual XML environment

The user space (parts 1 and 3 in Figure 9) is close to an usual XML environment. First, each user can describe its structures in XML documents which mark up the same text (see Figure 2). Notice that the structures could be distributed over a network. Then the user defines a (virtual) MXSD instance with respect to MSXD XML syntax (see Figure 6). To do this the user only needs an XML editor, he does not have to change its habits.

To query an MXSD instance, a user can express it using the language defined in Section 3. The indexing is automatically done if needed (see next section). Recall that the language extends XQuery: if the user queries a single structure, it is the standard XQuery. Query result is a sequence of fragments represented in XML.

5.2 MSXD Engine: indexing and querying structures and content

As we have shown in Section 2, an MSXD document is a XML meta-document which refers to one XML document for each structure (both of them sharing the same textual value); our implementation of the data model can be seen as a dynamically built index between them (part 2 in Figure 9). We choose to separate the indexing of the structure and the indexing of the content.

The analysis of the first structure enables us to deduce the textual value. The textual value is indexed *only once* in a specific component which is in charge of the textual indexing (to answer full text queries) and in charge of the access to the textual values of fragments (to build XML answers to the queries). When the other structures are analyzed, the consistency of the text is checked, and an alignment by means of spaces, tabulations or end of line is automatically processed if necessary. For the storage of the textual value and its indexing, we use Apache Lucene[3].

The analysis of each structure enables the creation of a relational representation of the structures. We define three main relations for a given document to store: (1) the fragments with their node type (element, attribute, text, ...), their `start` and `end` positions in the normalized textual

[3] `http://lucene.apache.org`

value, their label, (2) the structures and (3) the structure contents (id of the structure, id of the fragment, `level` of the fragment in the structure). Notice that this representation is independent from the textual value, it uses `start` and `end` positions (the textual value manager stores real values) and it computes the `level` of fragments into each structure (a fragment can then be shared between structures). In our prototype, we choose to embed a java RDBMS[4] but an external one can also be used.

We define an API consisting in usual DOM [1] API accessors extended with operators based on Allen's relations (as defined in definition 5). We store segmentations as tuples in a RDBMS, so we implemented it in SQL. This API provides a high level access to multistructured documents. MSXD instances conform to the DOM API and provide new methods such as the access to overlapping fragments. The query langage prototype relies on this API.

To implement the query engine (part 4 in Figure 9) for this academic prototype, we choose to work step by step and to use standards. First, we translate the user query in the XQuery Core language[5]. Even if it is not designed to be the foundation of prototypes, we choose it because we need a clean " simple " language with a well defined semantics. Then, the XQuery Core query is used to build a query tree, which is optimized before its evaluation. Most of our operators are implemented to work in pipe line, the XQuery filters operators (operators which give access to children, ancestors, ... of a given fragment) use the extended DOM API. Notice that, the SQL translation remains visible at query time for future optimization (for example by grouping several SQL queries nested with FLWR operators into a single SQL query).

Figures 10 and 11 show two screenshots of the main window of the application and of the query tree display window. Figure 10 shows a capture from our prototype during the evaluation of query Q2. A user can select (from a set of test cases) or edit an extended XQuery (top/right). The automatic translation in XQuery Core is shown bottom/right and the result (either in XML or in internal format by means of start and end positions) is displayed at bottom/left.

The second figure displays the query tree corresponding to the core query and displays dynamic information during the execution (number of items created or filtered by operators, . . .).

Finally, we developed an implementation of the multistructured schema validation where constraints are checked sequentially. In order to obtain a more efficient validation and to provide a more intuitive way to express contraints, we are investigating the use of ontologies. We currently tackle this proposal with a linguistic application of multilevel analysis of multimodal data (OTIM–`http://lpl-aix.fr/~otim`).

6 Related works

If we look at XML standards, it seems clear that the standard tree-like model [23] and namespaces [9] could be used to represent multistructured documents if each structure is hierarchical and can be merged with others. But, this is not the case in general. In our example, some elements from the physical and syntactic structures can overlap (`Line` and `Sentence`). The problem of overlapping is not recent see [20] for a review. Several works have studied multistructured documents in the context of XML for document-centric encoding. We classify the main proposals into three categories.

The first one concerns the very first works about the representation of several hierarchical structures inside the same text (the CONCUR feature [24] of SGML, TEI[6]); these solutions are often syntactic. TEI's solutions need to choose either a flat representation of the multistructured document or a main (hierarchical) structure and to use references (ID/IDREF) for the description of the other structures.

The second category is based on proprietary graph models. LMNL[7] proposes a new markup language and model such as to overcome the limitations of hierarchical markup in XML and to get an instance of a multistructured document. LMNL graph-based model is not XML compatible even if it is able to import/export. Notice that LMNL considers user annotations but no solution for querying. MultiX [14] is a proprietary graph-based model. It is possible to serialize an instance of it in an unique XML document. The multistructured querying is achieved by means of a set of XQuery [7] functions which in particular, deals with overlapping. Based on [14], [29] proposed a methodology for the construction of multistructured documents. This high level approach aims at defining structures during the construction process. To our knowledge, none other contribution considers *a priori* the problem of that construction which leads to restructuring and automatic differentiation of structures. We did not yet consider the problem of multistructured document edition.

MVDM (Multiview Document Model) [21] is a proprietary graph-based model. The model aims at considering multimedia documents and therefore at representing different kind of relationship between two document entities (and not only hierarchical relation). MVDM focuses on the notion of view which corresponds to a particular organization of a document. Stored in a document repository, multistructured documents can be queried according to criteria linked to one or several views of that document (automatic generation of SQL queries taking into account overlapping); another solution to navigate in the repository is proposed with a multidimensional analysis (OLAP).

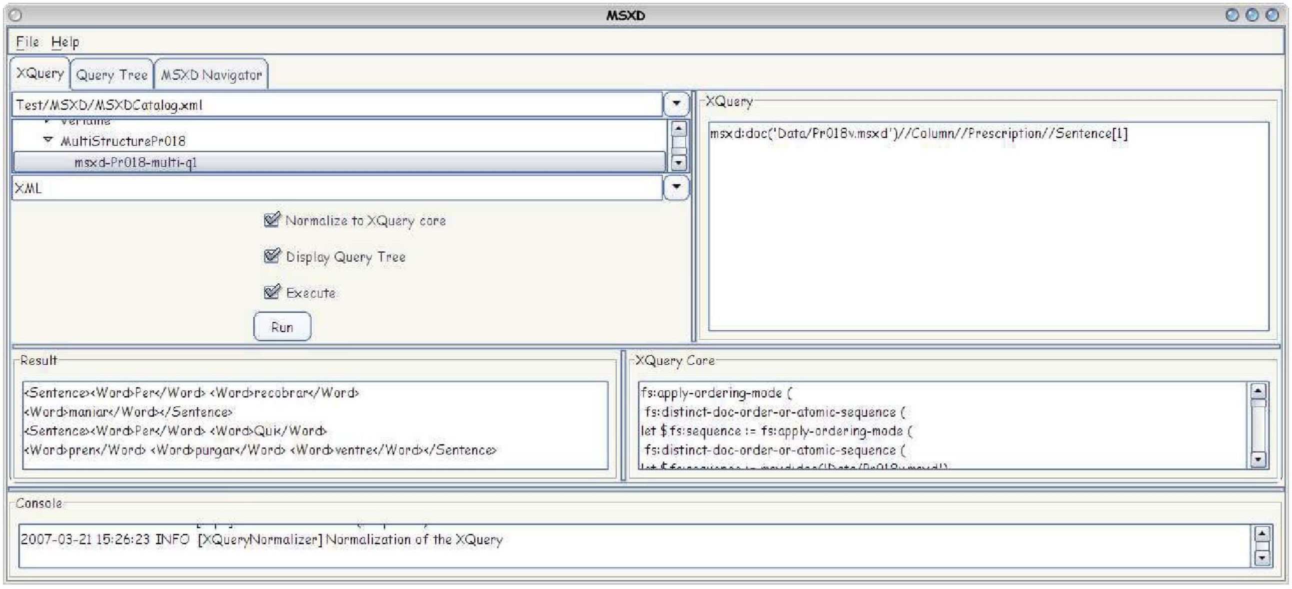
At last, Annotation graphs (AG) [5] are coming from the linguistic domain. Annotation graphs propose a proprietary formal model for the representation over the same flow (au-

[4] `http://www.hsqldb.org/`

[5] `http://www.w3.org/TR/xquery-semantics/`

[6] `http://www.tei-c.org/P4X/NH.html`

[7] `http://www.lmnl.net/`



☑ Normalize to XQuery core

☑ Display Query Tree

☑ Execute

XQuery

```
msxd:doc('Data/Pr018v.msxd')//Column//Prescription//Sentence[1]
```

Result

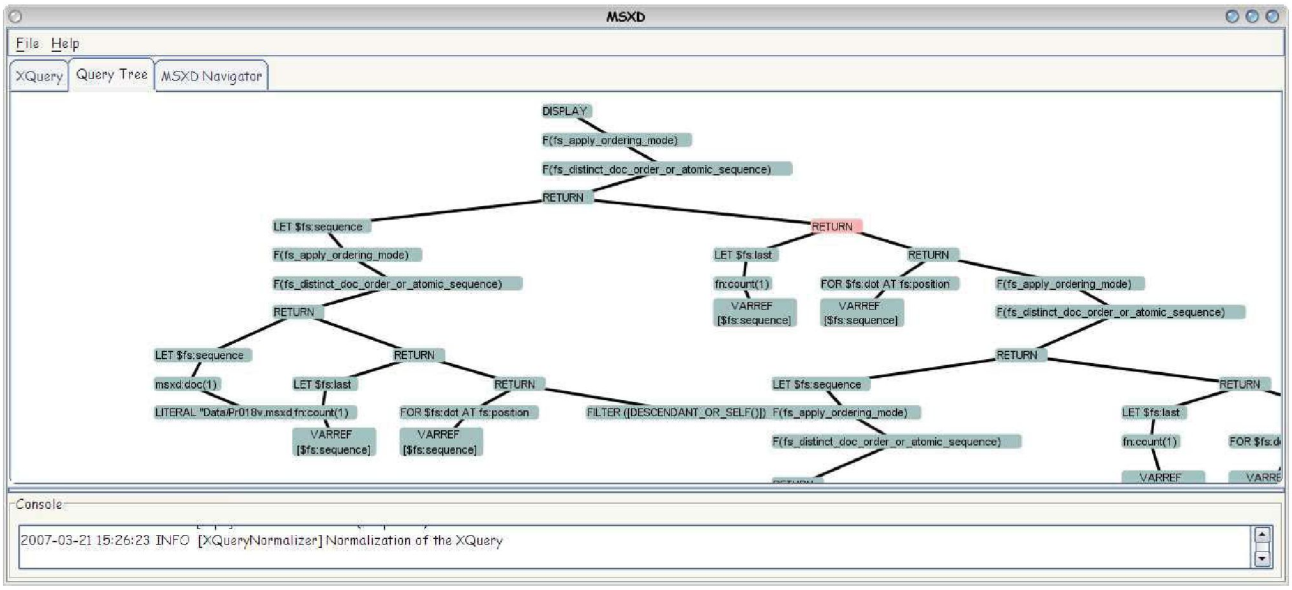
```
<Sentence><Word>Per</Word> <Word>recobrar</Word>
<Word>maniar</Word></Sentence>
<Sentence><Word>Per</Word> <Word>Quik/Word>
<Word>pren</Word> <Word>purgar</Word> <Word>ventre</Word></Sentence>
```

XQuery Core

```
fs:apply-ordering-mode (
 fs:distinct-doc-order-or-atomic-sequence (
let $fs:sequence := fs:apply-ordering-mode (
 fs:distinct-doc-order-or-atomic-sequence (
```

```
2007-03-21 15:26:23 INFO  [XQueryNormalizer] Normalization of the XQuery
```

Figure 10: Evaluation of XQuery Q2 in our prototype


MSXD
File
Help
XQuery
Query Tree
MSXD Navigator
DISPLAY
F(fs_apply_ordering_mode)
F(fs_distinct_doc_order_or_atomic_sequence)
RETURN
LET $fs:sequence
F(fs_apply_ordering_mode)
F(fs_distinct_doc_order_or_atomic_sequence)
RETURN
LET $fs:sequence
msxd:doc(1)
LITERAL "Data/Pr018v.msxd
RETURN
LET $fs:last
fn:count(1)
VARREF [$fs:sequence]
RETURN
FOR $fs:dot AT fs:position
VARREF [$fs:sequence]
FILTER ([DESCENDANT_OR_SELF()])
RETURN
LET $fs:last
fn:count(1)
VARREF [$fs:sequence]
RETURN
FOR $fs:dot AT fs:position
VARREF [$fs:sequence]
F(fs_apply_ordering_mode)
F(fs_distinct_doc_order_or_atomic_sequence)
RETURN
LET $fs:sequence
F(fs_apply_ordering_mode)
F(fs_distinct_doc_order_or_atomic_sequence)
RETURN
LET $fs:last
fn:count(1)
VARREF
FOR $fs:d
VARRE
Console

```
2007-03-21 15:26:23 INFO  [XQueryNormalizer] Normalization of the XQuery
```

Figure 11: Tree of the XQuery Core for Q2 in our prototype

	Data models	XML Compatible	Main structure	Validation	Operators
CONCUR	none	SGML Syntax	no	no	no
TEI (milestones)	None	XML Syntax	yes	no	yes
Annotation graphs (AG)	Proprietary graph	XML Syntax for serialisation	no	no	not for querying Multistructure but only an XPath linguistic extension
LMNL	Proprietary graph	specific markup and XML import / export	no	no	no
MultiX	Proprietary graph	XML import / export	yes	no	specific XQuery functions for querying and structure manipulation
Colored trees	Extension of the XML data model	XML export	no	no	XPath step extension
Based on Goddag	Goddag	DOM Extension and XML import/export	no	no	XPath axis extension
MSXD	Extension of the XML data model	An XML document for each structure	no	weak constraints	XQuery semantics extension and new functions
MVDM	Proprietary graph	XML Syntax by structure	no	no	repository (SQL with overlapping management and multidimensional analysis)

Figure 12: Proposals related to Multistructure

dio, text, …) of several structures (may not be hierarchical). An XML " flat " representation of an AG is proposed but no solution for querying.

The third category presents XML compatible contributions. A very interesting framework is proposed in [19]. It is a new model based on the Goddags data structure [31] which can be seen as a generalization of DOM trees for the representation of multi hierarchical XML documents. This proposal defines also an extension of XPath [26] to navigate between different structures sharing the same textual data (with a specific axis for concurrent querying such as `overlapping`, `xancestor` or `xdescendant`). Another proposal, the colored trees [27], deals with multiple hierarchies in a data-centric context. It aims at sharing atomic data and it does not consider overlapping thus it is out of our scope. The idea is to build several hierarchies (called colors) over the same set of values (text nodes). Thus, nodes are multicolored. In order to navigate between colors/hierarchies, the authors extend the notion of step in XPath. A step begins by a choice of a color (and thus of a structure) before the usual selection of an axis, a test node and some predicates.

Figure 12 summarizes the main features of each proposal related to multistructured documents according to some criteria: *Data model*, *XML compatibility*, *Existence of a main structure* (the user at the logical level or the system at the physical level chooses a main structure so others structures have to be set with regard to this main structure), *Validation of a multistructured document* (is it possible to define a schema for multistructured documents validation across multiple hierarchies [20]) *Operators* (for querying several structures and content in a concurrent way). No query language has been defined for querying annotation graphs, but it exists operators that complete the XML propositions (XPath in particular [3, 4]), they are related to the linguistic context .

Our proposal belongs to the third category, our objective is to remain close to XML standard. Our model is close to Goddags. Indeed, we want to keep the hierarchical aspect of each structure, so that classical XML tools remain available. But, Goddag does not provide mechanisms to add annotations (as LMNL does) and it does not describe relationships between structures for enabling validation across multiple hierarchies [20] (none of these proposals, whatever the approach is, proposes it). We do not detail user annotation but our proposal considers it (see [11] and [12]). Annotations represent textual data added by a user to the text in one structure and so missing in the other structures. It represents specific information que the user needed to integrate to its analysis.

For querying several hierarchies over the same textual content in a concurrent way, we chose to extend the semantics of the filter of XQuery. Our objective is not to add new axis (like Goddag) or to extend XPath step with colors (as with colored trees). Moreover, even if we propose every Allen's relations, we choose to stay simple and to use an as much as possible unchanged XQuery by only adding the necessary function (Unlike MultiX).

7 Conclusion

In this paper, our intention was twofold. First, we defined a XML compatible model for multistructured textual documents which is based on the use of hedges (the foundation of RelaxNG). A multistructured textual document is a text which has several concurrent hierarchical structures defined over it. Each structure corresponds to an analysis of the text according a specific use. Secondly, we proposed an extension of XQuery in order to query structures and content in a concurrent way. We applied our proposals using a medieval manuscript text written in occitan. Finally, we describe the architecture of an implementation of the MSXD data model and of a XQuery engine extended to support multistructured documents. Our solution is entirely XML compatible and conforms to standards.

A multistructured textual document is defined as a set of fragments defined on the same textual value and grouped in concurrent hierarchical structures. The key idea is to propose a method for a compact description of multiple trees over a single text based on segmentation. Segmentation encoding allows querying overlap/containment relations of markups belonging to different structures. We showed how each structure can be described in an XML document. The multistructured textual document is never instantiated.

To query a multistructured textual document, we chose to extend the semantics of the filter of XQuery. We show how to take into account equality, overlapping and other Allen's relations. For that we added functions and operators to XQuery. We are trying to avoid changing the structure of XQuery (as colored trees did without considering overlapping). Moreover, we did not simply add a new axis (as goddag did by adding `xancestor xdescendant`), but one can notice that it makes the query easier to read. However, normalization of `xancestor`, `xdescendant` or even a new axis associated to Allen's relations can be rewritten into our proposal.

Moreover, we defined a multistructured schema in order to express weak constraints between structures; it is defined as a set of rules, Allen's relations are used to constrain the relative position of fragments in the structures. An alternative solution could rely on the use of ontologies. It could offer more flexibility. We currently tackle this proposal with a linguistic application of multilevel analysis of multimodal data (Project OTIM [8]).

Our main perspective is the definition of multiple structures in other modalities than the single textual one. For example, it could be useful to define one or several structures associated to the image of a manuscript as it is done for its textual transcription. Then, the objective would be to manipulate the set of all these structures in a concurrent way. Secondly, we plan to extend our query engine to distribute parts of queries in a P2P network and to enable data sharing.

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