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Processing Link Structures and Linkbases on the Web and its Relevance to the Semantic Web

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Technical Report

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Abstract

Hypertext links are an essential feature of the World Wide Web. Undoubtedly, much of the Web's success is due to HTML's linking capability. XML links, as specified in the XLink recommendation, improve on HTML's links in several ways. In particular, links after XLink can be "out-of-line" (i.e. not defined at a link source) and collected in (possibly several) linkbases. Linkbases considerably ease modeling complex link structures as encountered in context-adaptive systems (e.g. teaching systems), versatile information systems (e.g. eCommerce catalogs), and Web interfaces to systems of all kinds (e.g. eGovernment or banking interfaces).

This article is devoted to two neglected aspects of XML links: the modeling of link structures and the processing of linkbases. It first shows how the modeling of link structures can be considerably improved by adding a notion of "interface" to XLink. Then, it shows that the relevant linkbase(s) might become ambiguous as a link structure is traversed. Three complementary modes for the binding of a linkbase to document(s) are proposed – "transient", "permanent", and "temporary" – as well as an algorithm for processing these bindings under the "open world linking" of the Web. Three usage scenarios are presented to demonstrate that with the approach proposed in this article the relevant linkbases are never ambiguous and the variety of behaviors required by Web applications can nicely be achieved. Finally, the relevance of XLink and the proposed linking modes to the Semantic Web is discussed.

Keywords: Hyperlink, XLink, Link Modeling and Processing, Linkbase

1 Introduction

Hypertext links are an essential, if not the most important feature of the World Wide Web. They make it possible to build structures relating contents and/or pages that might be seen as a Web counterpart to paper books. Link structures are used on almost all Web sites and Web-based applications: company and organization presentations, community sites, catalogs, Web stores, etc. Undoubtedly, much of the Web's success is due to HTML's linking capabilities, in particular the capability to link from some content to any other content on the Web. One might say that the Web supports an "open world linking".

Such an "open world linking" makes the Web significantly different from Open Hypermedia Systems (OHS) such as Sun's Link Service [13], Microcosm [10] and systems built after the Dexter Hypertext Reference Model [12]. In general, an OHS assumes that all resources, i.e. documents or document parts, an application might refer to, are known in advance and

addressable through unique identifiers. One might say that OHS assume a "closed world linking". Thus, OHS are not adapted to the open world linking of the Web.[1]

XML links, as specified in the XLink recommendation, improve on HTML's links in several ways. In particular, a link after XLink can be "out-of-line", i.e. specified in another document than its source. Out-of-line links make linkbases, i.e. specifications of links outside the data (Web pages or content) the links refer to, possible. In turn, linkbases considerably ease modeling complex link structures as encountered in context-adaptive systems (e.g. teaching systems) or in versatile information systems (e.g. catalogs). For this reason, most OHS offer out-of-line links and support linkbases. For a simple processing of linkbases they exploit the fact that all resources the links of an application might refer to are known in advance and have unique identifiers. As a consequence, the processing of out-of-line links and linkbases of OHS is not applicable on the Web.

This article is devoted to processing out-of-line links and linkbases under the open world linking assumption of the Web. This issue has been quite neglected: While advanced linking constructs have been proposed with XLink in a proposal that has reached the status of a recommendation already more than four years ago, the processing of these constructs under the conditions of the Web, i.e. its open world linking, has not received much attention.

This article first shows how the modeling of link structures can be considerably improved by adding a notion of "interface" to XLink. Then, it shows that, as linkbases are currently defined, the relevant linkbases might become ambiguous as a link structure is traversed. Three complementary modes for the binding of a linkbase to a document are proposed – "transient", "permanent" and "temporary" – as well as an algorithm for processing these bindings under the open world linking of the Web. With this approach, the relevant linkbases are never ambiguous and the variety of behaviors required by Web applications can nicely be achieved. These claims are demonstrated on three usage scenarios: "guided tour and their composition", "superimposed guided tours", and "linkbase-aware bookmarks". Finally, this article discusses the relevance of the proposed linking modes to Semantic Web applications.

This article consists of 6 sections. Section 1 is this introduction. Section 2 briefly explains linking on the Web after XLink. It is contrasted with linking in HTML and linking in before-web Hypermedia Systems. Section 3 is concerned with providing interfaces for link structures. Section 4 explains the need for linkbase management and introduces our approach to linkbase management. Section 5 discusses the relevance of linkbase management for the Semantic Web. Research perspectives in Section 6 conclude this article.

2 Linking on the Web

2.1 HTML Links

HTML Hypertext links are specified within their origin using an anchor element. E.g. the following anchor element binds its content (denoted as ...) to the W3C Web page:

```
<a href="http://w3.org/"> ... </a>
```

[1] OHS have been called "open" because they aim at interlinking documents from arbitrary applications, requiring minimal or no hyperlink support from the applications.

Figure 1 Extended link in XLink's XML syntax

```
<xlink xlink:type="extended"
       xmlns:xlink="http://www.w3.org/1999/xlink">
  <res xlink:type="resource" xlink:label="Res1">
     Content of a <em>local</em> resource
  </res>

  <loc xlink:type="locator" xlink:label="Loc1"
       xlink:href="http://example.com" />
  <loc xlink:type="locator" xlink:label="Loc2"
       xlink:href="http://www.w3.org" />

  <arc xlink:type="arc"
       xlink:from="Res1" xlink:to="Loc2" />
  <arc xlink:type="arc"
       xlink:from="Loc2" xlink:to="Loc1" />
</xlink>
```

HTML also has non-Hypertext links that might be called "conceptual links". Such links are specified within the header section of HTML documents using empty link elements such as:

```
<link rel="stylesheet" href="my_rendering.css" />
<link rel="alternate" hreflang="ja"
      href="index_ja.html" />
<link rel="prev" href="page4.html" />
<link rel="next" href="page6.html" />
```

In its current versions (HTML 4.01 and XHTML 1.1), HTML supports 15 types of conceptual links. Current user agents such as browsers usually interpret only conceptual links to style sheets.

HTML links, are they Hypertext or conceptual, are all:

- *inline*, i.e. specified within the HTML documents that are their origins (i.e. contain the link source),
- *uni-directional* and *outbound*, i.e. each link points to only one destination which can be remote from the link's origin,
- *restricted in their types*, as HTML supports only a fixed set of 15 link types (e.g. `stylesheet`, `next`) permitting no associations with meta-data.

2.2 Links After XLink

This section briefly recalls salient features of XLink relevant for this work, for a more detailed explanation of XLink, refer to the W3C recommendation [8]. The following shift in terminology is worth stressing:

HTML-flavor links, i.e. single-source, single-destination hypertext links specified in the source document are called *simple links* in XLink.

An *extended link* is a collection of *arcs*. An XLink arc is a single-source, single-destination hypertext "link", not necessarily specified in the source document. Note that a simple link corresponds to an extended link that contains exactly one arc and is specified at this arc's source.

Simple links are subject to the same limitations as HTML links (cf. 2.1). Extended links overcome these limitations in several ways and can be:

- *out-of-line*, i.e. placed in external documents called linkbases (note that a linkbase usually does not contain the link sources),
- *multi-directional*, allowing not only for *outbound* arcs, i.e. arcs defined at their source (as in HTML), but also *inbound* arcs, i.e. arcs defined at their destination, and *third-party* arcs, i.e. arcs defined separately from their source and destination,
- *typed* and *associated with meta-data* freely. This covers both, machine-readable information in the form of a Uniform Resource Identifier (URI), and human-readable information in the form of XML text. Note that such an association with meta-data is a promising approach for Semantic Web applications.

XLink can be incorporated into arbitrary XML vocabularies. Any normal XML element can become a linking element by carrying the `type`-attribute from the XLink-namespace (`http://www.w3.org/1999/xlink`, assumed to be bound to the prefix `xlink:` in the following). All linking information is provided in attributes; element tag names have no XLink-specific meaning and can be chosen according to an application's needs. One also says that XLink is an "enabling vocabulary".

Extended Links are denoted by having the attribute `xlink:type` set to `extended`. Figure 1 depicts an example in XLink syntax. An extended link associates a number of *participants*, i.e. XML documents, fragments of XML documents, or any other kind of Web resources, using *arcs*.

Arcs pair up two participants in a directed relationship. One participant is designated as starting point of link traversal (source), the other as ending point (destination). In this respect arcs express hyperlink navigation as known from HTML's hyperlinks. Unlike HTML however, a (sub)resource, e.g. a word in an XML text, can be the source of several arcs. Arcs are denoted by `xlink:type="arc"`.

Arcs can carry attributes expressing *when* the hyperlink is followed (on user request or automatically) and *where* the destination is displayed (replacing the source, in a new window, or embedded). These attributes are very important in practice, but are not relevant to this work.

Participants of a link are resources such as XML documents or fragments of XML documents. The resources can either be *local*, that is XML data contained in the extended link itself and surrounded by the *resource* element (`xlink:type="resource"`), or *remote*, that is Web resources identified by URI references given in a *locator* element (`xlink:type="locator"`).

Separation of content and link structure is possible with XLink. By using only *third-party arcs*, i.e. arcs between remote resources, an author can strictly separate content and link structure: content resides is one XML document while a linkbase (which is also XML) provides the links.

All linking elements can be associated with meta-data by assigning them a *role* in the form of a URI. For arcs this is done using the `xlink:arcrole`-attribute. There is only one predefined role for arcs in XLink. It is used to locate linkbases. We will discuss this arcrole in Section 4.1.

Keep in mind that in XLink the important navigation information – the "hyperlinks" – are given by the arcs. The extended link element (`xlink:type="extended"`) is only a mere container holding the participants and arcs. This also means that two resources can participate in the same extended link, though one cannot navigate from one to the other. In the example of Figure 1 this is the case for `Res1` and `Loc1`, as there is no arc specifying a "hyperlink"/"hypertext navigation" between them.

In the remainder of this work, we will explicity speak of "extended link" and "arc" when referring to XLink linking elements. When speaking of hyperlinks in a more general fashion that is not XLink-specific, we will use the term "link" or "hyperlink".

2.3 Hypermedia Systems vs. Web

Separation of content and links, as possible with XLink, has been realized in many before-web Hypermedia Systems such as Sun's Link Service [13] or Microcosm [10]. We will now outline important characteristics of these before-web systems, and contrast them to the Web.

Firstly, before-web Hypermedia Systems usually store links in a central repository. Finding the relevant links for some given content is a simple matter of querying the repository. There have also been approaches to use directory services to provide a distributed link service infrastructure (DLS [7]).

However, the Web is designed as an open, distributed and decentral system. Central repositories or directory services are against this philosophy and have scalability problems. Finding out-of-line links on the Web cannot be a simple matter of querying one (or several) server(s) *known in advance*.

Instead, collections of out-of-line links (linkbases) should be treated as normal Web resources, i.e. be retrievable just like normal documents using HTTP. Consequently, links have to be found and collected as we traverse a number of hypertext documents. This is an important motivation behind our proposal of linkbase management laid out in Section 4. Note that linkbases can be dynamically generated resources in the same way hypertext documents can. Thus treating linkbases as retrievable Web resources is no limitation; directory service-like infrastructures can be built "behind the scenes".

Secondly, in before-web systems, resources (and subresources) are typically identified by means of unique identifiers. This assumption is also inherent to the Dexter Hypertext Reference Model [12].

In contrast, the Web has no unique identifiers. Web resources are identified by Uniform Resource Identifiers (URIs) [2]. A resource does not necessarily have one unique URI, it can be accessible at various URIs, and its URI might change. Our notion of interfaces introduced in Section 3 can ease problems faced when building link structure containing resources with

URIs that are either unknown (e.g. the resource has not been created, yet) or that might change in future (e.g. the resource is moved to a different server).

Finally, many before-web systems allow a user to add annotations or links to documents, or even restructure documents. A user's modifications are managed by the system (i.e. in the resource itself or again in a central repository) and can be shared with other users. This in essence, allows a user to become author.

The Web on the other hand is, from a user's perspective, a read-only system. Only the owner (usually the author) of a resource it allowed to modify it. Any modification a reader might want to apply, such as making an annotation, adding a link, or building his own reader's view of a page [4], cannot be stored in the resource itself. Instead the modifications have to be stored in a new resource to which the reader has write-access. This raises the issue of establishing a connection between the original resource and the resource containing the modifications. Allowing to establish such a connection without write-access to the original resource – i.e. supporting open-world-linking – is another important motivation behind Section 4's linkbase management.

3 Interfaces for Link Structures

In modeling a collection of semantically related documents, a hyperlink rarely comes alone. Instead, a number of links together generally impose some higher structure on the documents they connect. Examples of such link structures include:

- *guided tours*, sequencing a number of independent documents in one or several manners, hinting a reader an order in which they are best read, e.g. for eLearning purposes,
- *link catalogs*, supplying a document, e.g. a table of contents, with many outbound links,
- *glossaries*, linking occurrences of terms in a set of documents to their definitions in a glossary-like document,
- *cross-references*, ranging from simple cross-references to sections within an article or a book to complex cross-references, e.g. in code, API-documentations or meta-data annotations in Semantic Web applications.

Such structures can benefit highly from a separation content (document) and hypertext structure (linkbases) as possible with XLink. By applying different linkbases, a single document can be viewed in different contexts, e.g. stand-alone, as part of a guided tour, with links into a glossary, or enriched with personal annotations, depending on the reader's needs.

Hypertext structures easily suffer from dependence on the URIs of the link endpoints. When building, URIs have to be known in advance by the structure's author, and the structure has to be modified in case a URI changes. Interfaces, as presented here, decouple structure from a document's "physical" location (URI) by providing an indirection.

Also, often the need to combine structures into composite structures arises [11]. Our primary example for this will be the combination of two guided tours into a composed guided tour

being the succession of the smaller ones. By signaling well-defined junctures, our interfaces facilitate composition.

We can imagine hypertext space as a directed graph with documents as nodes and links (i.e. in XLink terminology the arcs) as directed edges. Our interfaces are nodes just like normal resources; they are however transparent to the user and will not be displayed. When a user traverses an arc inbound to an interface, instead of displaying it, an outbound arc will be traversed automatically.

Using the example of a guided tour, we will now first show how a link structure can define its interfaces. Then we will show how these interfaces can be referred to by other structures, in order to reuse an already defined structure in building a composite structure. The example provided will be the combination of two guided tours into a sequence. Finally, using the example of a university's course catalog, we will show how our interfaces decouple structure and physical locations aiding authoring, esp. collaborative authoring, and maintainability.

3.1 Defining Interfaces

A guided tour provides an order over a number of independent documents, e.g. chapters of an online book, by linking them in a chain. It is a common metaphor used in teaching systems or personal adaptive systems. Seen from an outside perspective, it features a start and an end. Instead of just using the first and the last document of the chain, we wish to expose the start and the end more explicitly, as interfaces.

A guided tour can be written in XLink as one big extended link containing locators to the documents as participants and arcs chaining the documents. Interfaces are defined inside the extended link as additional participants. An arc connects from the start interface to the guided tour's first document by an arc. Similarly, the last document is connected to the end interface.

As a conservative extension to XLink, the interface definitions are introduced as new linking elements, signified here by `xlink ext:type="interfacedef"`. We require interface definitions to carry an identifier (in `xml:id`) that is unique within the XML document containing the extended link. This identifier will be used when referring to interfaces (cf. 3.2).

The following gives a flavor of a definition of a guided tour (element tag names are arbitrary for sake of readability):

```
<guidedtour1 xlink:type="extended">
  <start xlink:type="other"
         xlinkext:type="interfacedef"
         xml:id="gt1-start"
         xlink:label="mystart" />

  <arc   xlink:type="arc"
         xlink:from="mystart" xlink:to="doc1" />

  <!-- ... -->
</guidedtour1>
```

Interface definitions are similar to local resources (`xlink:type="resource"`). Unlike local resources however, they are not displayed *as part of a document*, but *stand on their own* and are transparent to the user (i.e. not displayed).

3.2 Referring to Interfaces

Suppose now we have defined two or more guided tours and want to reuse them by sequencing them into one big composed guided tour. Using interfaces this can be done easily. The composed guided tour is another extended link, again having a start and end interface. Arcs provide connections from the end of one component tour to the start of the next component tour in the order.

The starts and ends of the component tours are interfaces as described in the previous section. Inside the composed tour's extended link we need a way to refer to these externally defined interfaces.

Analogous to interface definitions, interface references are introduced as new linking elements and denoted here by `xlinkext:type="interfaceref"`. A URI reference in `xlink:href` provides the interface location and name. The following illustrates the discussed example of a composed guided tour (tag names again arbitrary):

```
<composedguidedtour xlink:type="extended">
  <!-- ... -->
  <gt1e xlink:type="other"
        xlinkext:type="interfaceref"
        xlink:href="http://.../gt1.xml#gt1-end"
        xlink:label="gt1end" />

  <gt2s xlink:type="other"
        xlinkext:type="interfaceref"
        xlink:href="http://.../gt2.xml#gt2-start"
        xlink:label="gt2start" />

  <arc  xlink:type="arc"
        xlink:from="gt1end" xlink:to="gt2start" />
  <!-- ... -->
</composedguidedtour>
```

A composed guided tour modeled this way will automatically reflect changes that are made in any of its component tours, e.g. the insertion of a new document at any place (including the beginning or the end of a component tour). The only requirement for the component tours is to keep their interfaces stable.

3.3 Decoupling Structure and Locations

To show how interfaces can be used to decouple a link structure from the physical locations of the documents it interlinks, we will consider the example of a university's course catalog.

The catalog lists all courses offered in a semester and links to their corresponding course homepages. The individual course homepages are maintained by different authors and hosted by the departments offering the courses. The authors of the catalog and the course homepages need to collaborate to create and maintain the links.

HTML linking requires the author of the course catalog to find out the URIs of all course homepages to link them. If a department changes the structure of its web site (i.e. the URIs change), the catalog author needs to be informed and modify the catalog accordingly to avoid broken links.

Using XLink's external linkbases can help a little: each department can offer a linkbase and the course catalog simply uses the linkbases. Now however, the linkbases must be aware of the catalog's URI and the locations inside the catalog where the links are to be anchored. Especially any restructuring of the catalog, like splitting it into multiple pages or renaming it from `"current.xml"` to `"spring2005.xml"`, will break the linkbases of all departments.

Having well defined interfaces, as we suggest in this work, can distribute the responsibilities and ease collaborative authoring. In this respect, we believe that link interfaces can play a role in authoring hypertext as important as sub-system interfaces do in building software systems.

Instead of linking directly from the catalog to the course homepages, we can use interfaces to insert an indirection. An interface provides a symbolic name for a course homepage, thus making the links less vulnerable to changes in the physical locations of the documents. The authors only have to agree upon the names of the interfaces and the location of the linkbases.

3.4 Interfaces vs. HTTP Redirects

An effect similar to the indirection our interfaces provide, can be achieved by using "HTTP redirects". Redirects are a facility of the Hypertext Transfer Protocol (HTTP) [9] allowing a request for a Web resource to be answered not with the resource but an indication of a different location (URI) where to find the resource. In fact, this way of providing symbolic names has gained widespread use (e.g. [1]).

However, using HTTP redirects has serious drawbacks. Link authors require access to Web server configuration to create them and, more importantly, redirects work only well for destinations of arcs. It would be possible to define the start interface of a guided tour (cf. 3.1) using an HTTP redirect as in the composition the start is the destination of an arc. However, the end interface is the source of an arc in the composition. If a document with some given URI is currently viewed in the browser, we would need to resolve the URIs of the sources of all known arcs to find out if any of them is redirected to the given URI. Resolving a (possibly massive) amount of URIs causes unnecessary network traffic and is practically infeasible.

We are convinced that interfaces should be an essential part of a link structure and defined on the level of the structure in linkbases.

4 Linkbase Management

The separation of content and hypertext structure into document and linkbase(s) allows a document to be viewed in different contexts, e.g. as a stand-alone document, as part of a guided tour, with links into a glossary, or enriched with personal annotations, depending on the reader's needs.

However, this separation poses a new challenge: how can the linkbases relevant for document be found in an open world scenario, and which of the found links should actually be displayed? The procedures defining this are referred to as *linkbase management* here.

4.1 Arcs to Linkbases after XLink

A peculiarity of XLink is that linkbases are found using arcs (called linkbase-arcs henceforth) with the special arcrole `http://www.w3.org/xlink/properties/linkbase`. Sensibly, this introduces no new constructs to XLink. However, it also introduces a circularity, as the linkbase-arcs underly linkbase management themselves.

To see how XLink's linkbase-arcs work, suppose a linkbase B containing a link from document D1 to D2 and another link from D2 to D3. To display the first link when a user is viewing D1, his browser needs to be aware of linkbase B. There has to be some connection between D1 and B.

Such a connection can be established with a linkbase-arc from the document (D1) to the linkbase (B). Given that D1 is the first document a user opens, such a linkbase-arc has to reside inside D1, or else there is no way for the browser to be aware of it.

The interesting question now arising is what happens if the user follows the link from D1 to D2 arriving at D2 not containing a linkbase-arc to B. Will the link from D2 to D3 be displayed, or not? Both behaviors are conceivable, the XLink recommendation is underspecified in this respect.

Allowing a linkbase to be valid only for documents that refer to it directly (by means of a linkbase-arc residing inside the document) or indirectly (by means of chaining linkbases, cf. 4.4), requires a document to know all its linkbases. This renders imposing link structures such as making a document part of a guided tour impossible, if one does not have write access to the document or one of its linkbases. Also, once the document is part of a guided tour, it is not possible to view it as a stand-alone document without the guided tour links or use it in some other guided tour only with the links of that other guided tour.

Collecting links in a "greedy" fashion, i.e. never forgetting link information, on the other hand, allows a document to be presented with different links at different times. However, this can confuse and disorient users. By collecting links greedily, a document could end up containing many irrelevant or unwanted links and be hard to read. Also, storing a vast amount of links and processing them for presentation can mean high demands in memory and computation time.

These two approaches to linkbase management have been called *conservative* (as a document appears always the same) and *inflationary* (as more and more links are collected) in [5]. They are opposite end extremes, and it should be clear that neither of them is satisfying.

The linkbase management mechanism we propose in the following is based on three complementary modes – "transient", "temporary" and "permanent" – for the binding of a linkbase to a document or set of documents. The modes are set individually per linkbase, so a user agent (browser) can have several linkbases loaded, each in a different mode. We adhere closely the original ideas in XLink and use arcs with special arcroles to establish the connection between documents and linkbases. XLink's original linkbase-arcrole is replaced with three new arcroles that signify the mode used to load a linkbase:

```
http://www.pms.ifi.lmu.de/xlinkext/linkbase/transient
http://www.pms.ifi.lmu.de/xlinkext/linkbase/temporary
http://www.pms.ifi.lmu.de/xlinkext/linkbase/permanent
```

The linkbase-arcs with these arcroles will be referred to as `transient`-arc, `temporary`-arc, and `permanent`-arc.

4.2 Transient and Permanent Bindings

A linkbase loaded in the `transient` mode is bound to the current document only. It "lives" for the shortest time possible, i.e. only the current document. When a user leaves the document by traversing a link, the linkbase and all link information contained in it are discarded. Note that this includes any `transient`-arcs residing inside the linkbase. This mode should be used for linkbases known in advance to the document author.

A Linkbases loaded in the `permanent` mode is bound to the current document and *all* future documents. It "lives" the longest time possible: once it is loaded it stays in memory "forever" (more precisely, up to the end of the browsing session). This mode should be used for linkbases containing links we always want to see, such as a user's annotations or links into a glossary.

4.3 Temporary Binding

Our third mode, called `temporary`, is positioned between the extremes of living for the current document only (`transient`) or living forever (`permanent`). A linkbase is bound to a restricted set of documents, called its validity range. It remains valid (i.e. its links are available) while only documents from its validity range are viewed and is discarded when this range is left. The linkbase "lives" for a limited time that ends when the user navigates to a document outside the validity range.

The validity range of a linkbase is expressed with `temporary`-arcs going from all the documents in a linkbase's validity range to the linkbase. When a user traverses a link to a new document, a non-permanently loaded linkbase is discarded, *unless* there is a `temporary`-arc from the new document to the linkbase. In contrast to the `transient`-arc, a `temporary`-arc does not have to reside in the document, but can also reside in the linkbase itself. This means that linkbase information provided by a `temporary`-arc is not immediately discarded when the linkbase it resides in is discarded.

The `temporary` mode is especially useful for building link structures interconnecting a number of documents, e.g. guided tours. The link information for a structure can be placed in a linkbase along with `temporary`-arcs declaring the linkbase's validity range. As long as the

Figure 2 Linkbase-Processing Algorithm

On leaving of the current document:

$lbArcs$:= {all `temporary`-arcs}
DISCARD all non-permanently loaded linkbases
RETRIEVE *newDocument*
$activeLBs := \{newDocument\} \cup permanentLBs$
$lbArcs := lbArcs \cup$ {all lb-arcs in *newDocument*}
$\cup$ {all lb-arcs in $permanentLBs$}

while $\exists a \in lbArcs.\quad a.from \in activeLBs$ DO

CHOOSE $a \in lbArcs$ WITH $a.from \in activeLBs$
if $a.to \in activeLBs$
$lbArcs := lbArcs \backslash \{a\}$
if $a.arcrole =$ `permanent`
$permanentLBs := permanentLBs \cup a.to$
endif
else
RETRIEVE a.to
$lbArcs := (lbArcs \cup$ {all lb-arcs in $a.to$}) $\setminus \{a\}$
$activeLBs := activeLBs \cup \{a.to\}$
if $a.arcrole =$ `permanent`
$permLBs := permLBs \cup a.to$
endif
endif

end

user stays within the documents that are in the validity range, they are displayed as part of the current structure (i.e. with the links from the structure's linkbase). Once the user leaves the structure by navigating to a document outside the validity range, the structure's link information is discarded and the documents function as stand-alone documents in case they are visited again.

4.4 Linkbase Processing

Having presented the functioning of our linkbase management modes as they need to be understood by link authors, we will now discuss the processing of linkbases under these three modes. Special consideration will be given to chaining of linkbases, i.e. a linkbase can be the starting point of a linkbase-arc, and dynamic linkbases, i.e. linkbases that are not static XML documents but are generated dynamically and should be retrieved newly every time a link is traversed.

Figure 2 shows a possible algorithm (in pseudo-code) for linkbase processing. The basic idea is that a browser maintains a set of the active linkbases (*activeLB*). The document currently being displayed is always a member of this set; initially, when there are no permanently loaded linkbases, it is the only member. Whenever a user leaves the current document by following

a link to a new document (*newDocument*), the algorithm is run to update the set of active linkbases.

By retrieving linkbases that are destinations of linkbase-arcs – traversing linkbase-arcs – the algorithm grows the set of active linkbases. For a linkbase-arc (a) to be traversed, its source ($a.from$) must be a member of the set of active linkbases while its destination ($a.to$) is not. When a linkbase-arc is traversed, its destination is retrieved and becomes a member of the set of active linkbases. The retrieval can yield new linkbase arcs that need to be processed. As a linkbase-arc can have its source ($a.from$) in any of the active linkbases (not just the document to be displayed), linkbase chaining is supported.

In principle, computing this set of active linkbases is the same as computing a reflexive, transitive hull in the graph where documents and linkbases are nodes and linkbase-arcs are edges. Note however that this graph is not known in advance but has to be explored: adding a new linkbase to the set of active linkbases can add new linkbase arcs to the graph that start or end in arbitrary (possibly previously unknown) nodes.

Once the set of active linkbases cannot grow anymore, all links have been discovered and the document is ready to be displayed. When the user later leaves the document by traversing a link, the set of active linkbases has to be computed again; its initial members are the new document and any permanently loaded linkbases.

This approach based on growing a set of active linkbases is open to dynamic linkbases. As the user navigates from one document to another, linkbases that stay active are not kept in memory; rather they are "reobtained", i.e. their content is retrieved newly from the web. Of course, caching can be employed to reduce network traffic for static linkbases.

To explain the algorithm in further detail, we will look at how the linkbase-arcs are treated differently according to their type.

Processing `transient`-arcs is straight forward. Linkbases loaded by means of a `transient`-arc are bound to the current document only. When a user leaves the current document by traversing a link to a new document, the linkbase and its links are discarded.

Processing `permanent`-arcs is similarly straight forward. Linkbases loaded by means of a `permanent`-arc apply to the current and all future documents. They are maintained in the set $permanentLBs$ which is joined to the set of active linkbases ($activeLBs$) for every document.

For processing of `temporary`-arcs, recall their functioning: A linkbase that is non-permanently loaded is discarded when the current document is left, *unless* there is a `temporary`-arc from the *new document* (or any linkbase that becomes active for the new document) to the linkbase.

Technically, we give `temporary`-arcs a slightly longer "lifetime" than normal arcs. When a user leaves the current document, all information from non-permanently loaded linkbases is discarded. However, the `temporary`-arcs, are retained and available for traversal when the set of active linkbases grows. This longer lifetime is the only difference between `temporary`-arcs and `transient`-arcs. They can otherwise be treated the same.

Termination and Complexity The algorithm presented here tolerates cycles and terminates, as long as there are no infinite chains of linkbases.[2] Of course, a practical implemen-

[2]Chains of infinite length are impossible with static resources, but a theoretical possibility with dynamic resources: picture e.g. a query `http://example.com/query?param=`*n* with an integer value *n* as parameter

tation might want put further limits on the length of linkbase chains or the number of active linkbases. The algorithm's time complexity is $O(mn^2)$ where m denotes the number of active linkbases after execution and n the number of linkbase-arcs the algorithm is or becomes aware of.

4.5 Scenarios

To demonstrate the potential of our linkbase management mechanism, its usage will now be demonstrated in a three scenarios. The scenarios are chosen with an emphasis on the `temporary` mode, as this is the most interesting and useful.

4.5.1 Guided Tours and their Composition

As discussed above (cf. 3.1), a guided tour can be formulated as one extended link in a linkbase, separate from the documents participating. This linkbase has to stay active as long as the user views documents from the tour. We can achieve this using `temporary`-arcs the following way: the linkbase contains a `temporary`-arc for each document (and interface) participating in the tour. Each arc goes from the document to the linkbase itself.

As the arcs reside inside the linkbase, this only ensures that the linkbase stays active, once it has been loaded. If a user accesses the tour's first document, the linkbase will not be loaded, as this document does not contain an arc to the linkbase. Note that this behavior is actually intended, as we still want to be able to view the document as stand-alone, i.e. as not being part of the guided tour.

This issue is resolved easily: we need an additional document "offering" the guided tour. This document contains an arc to the linkbase (`transient` or `temporary`, both work) and a link to the start of the guided tour (start interface or first document). Note that the document offering the tour can actually be the linkbase itself, as linkbases are arbitrary XML documents and thus can also contain information to be displayed (e.g. XHTML).

It would also be possible to realize the guided tour by loading its linkbase once at the beginning using a `permanent`-arc. This however has two drawbacks: Firstly, when the user decides to leave the guided tour (e.g. by following a link leading outside the tour), the tour's linkbase stays in memory, even though it is not needed anymore. Secondly, there is a problem if we allow composition of guided tours as in Section 3.2.

For this, consider a document being part of two different guided tours that also apply different annotations to this document. In order to compose these tours we need to distinguish whether the document is displayed in the context of the first or the second tour. When we load the linkbases in `permanent` mode, the document will display the links from both tours at the same time, thus not distinguishing the context. In particular, a user has two "next document" links available and can accidentally shortcut the composite guided tour or run in circles by selecting the "wrong" link.

Using `temporary` mode, this is not an issue. The first guided tour's linkbase is discarded before the second guided tour's linkbase is loaded.

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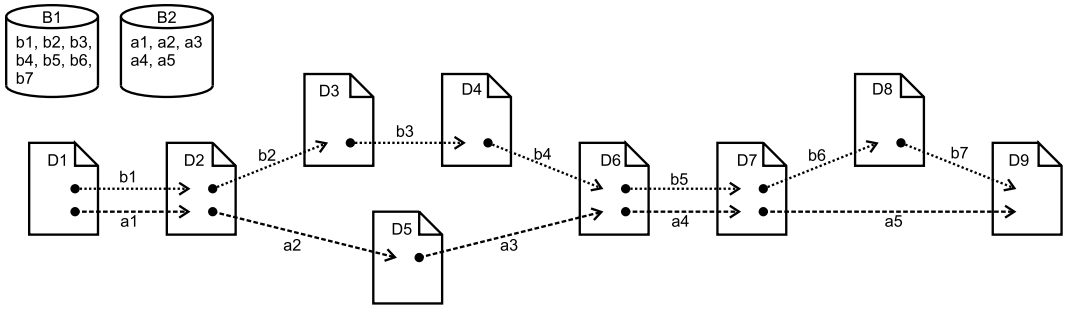
that delivers a linkbase-arc to itself but with the parameter *n+1*. This causes no real problems since a simple restriction of chain length can be assumed in practical implementations.

Figure 3 Superimposed guided tours



4.5.2 Superimposed Guided Tours

Guided tours can even be superimposed on each other: Figure 3 depicts a situation where two guided tours are available: say one covers basic material (arcs bn in linkbase B1, drawn dotted in the figure) while the other covers more advanced material (arcs an in linkbase B2, drawn dashed) of the same subject. The guided tours share some documents. Superimposing the guided tours makes the arcs from both tours available to the user and he can jump freely between the basic and advanced guided tour.

Making use of linkbase chaining, we put `temporary`-arcs from B1 to B2 and from B2 to B1 into a third linkbase B3. This way, both linkbases stay active as long as documents from either of them are viewed. Of course, this linkbase B3 has to take care that itself stays active, so additionally an arc from B1 to B3 or from B2 to B3 is needed. Alternatively, B3 could be loaded permanently.

Superimposing is not limited to guided tours. In fact, any link structures can be superimposed using the linkbase management mechanism proposed in this work. We can thus use many structures in parallel, e.g. enriching a document with annotations from various sources or enriching documents in guided tours with cross-references. This illustrates that the mechanism suggested here is fairly general and powerful.

4.5.3 Linkbase-aware Bookmarks

Applying different linkbases to the same document allows us to view this document in different contexts, e.g. as stand-alone, as part of a guided tour, enriched with annotations, or combinations thereof. When bookmarking such a document we should not only bookmark its URI, but also remember its context, i.e. the linkbases applied.

A bookmark can be an extended link containing a local resource providing a title for the bookmark and a locator to the bookmarked page; an outbound arc connects the two. To make our bookmark linkbase-aware, we need additionally locators to the linkbases and linkbase-arcs.

When the bookmark is created, some linkbases are active non-permanently and some permanently. Permanently loaded linkbases appear in the bookmark extended link as destinations of `permanent`-arcs, non-permanently loaded linkbases as destinations of `transient`-arcs; both types of linkbase arcs originate from the bookmarked page.

This however does not suffice, yet. A `temporary`-arc from the bookmarked page to the document containing the bookmark is needed. This arc is essential; if it does not exist the following happens when the outbound arc of the bookmark is traversed: the link information from the bookmark document is discarded and with it the linkbase-arcs are lost. When the bookmarked page is then displayed, the linkbases are *not* loaded.

This need for the additional arc might seem a little peculiar at first. It illustrates a basic principle behind linkbase management with linkbase-arcs as used in this work: Linkbase-arcs have arbitrary resources (e.g. documents) as sources and linkbases as destinations. A linkbase-arc is followed, i.e. the linkbase it points to becomes active, when the resource it originates from is loaded.

We believe that other, complementary means of linkbase management that is not based on such linkbase-arcs could simplify modeling of some link structures such as the linkbase-aware bookmarks. In particular, we hope to investigate in future mechanisms where the following of a (navigational) hypertext link *directly* triggers changes in the browser's active linkbases. In the current mechanism this is not the case: changes in active linkbases are triggers directly by the loading of resource (which only in turn was triggered by the user following a hypertext link to it).

5 Relevance of XLink and Linkbase Management to the Semantic Web

A central idea of the Semantic Web is to have not only data provided as Web resources, but to augment or annotate such data with meta-data. The same meta-data can be used for annotating different data. For example, an ontology of Japanese food can be applicable to the menus of several Japanese restaurants. Similarly, some data can make use of many different meta-data. For example, some diary data can use a calendar ontology, an ontology ranking the importance of certain tasks, or cross references and access information to supplementary data (e.g. address book, yellow pages, maps).

More often than not, data and meta-data will not reside in the same Web resource. If data and meta-data reside in different resources, we need a way to establish a connection between them. Taking it that data is provided in some XML syntax, one way to establish this connection is an XLink arc. We have already seen a similar situation in Section 4, where we have used arcs (called linkbase-arcs) to establish a connection between hypertext documents and linkbases.

No matter whether we use XLink arcs or some other mechanism to connect data and meta-data, there is an analogy between linkbases and meta-data. We will now show that this analogy is quite interesting and that the modes suggested for binding a linkbase to a document (cf. 4) are transferable to binding meta-data to data.

5.1 Meta-Data-augmented Hypertext

Consider an eLearning application supporting a course on Semantic Web technologies. The course contains many pages, among them pages course authors have no modification rights for (e.g. W3C recommendations). Pages are augmented with different meta-data.

Each single page has some meta-data, e.g. about author, version, or copyright, that is known in advance and should always be available for this page whether its used in the eLearning application or not. This situation corresponds to the `transient` mode for binding a linkbase to a document.

Users are aided by a common ontology for terms used in the course. This ontology should be shared by all pages of the eLearning application. However, it should be valid only in the context of the eLearing application: for example the course instructor wants to use this ontology only when fulfilling her teaching duties, but a different, more detailed ontology, for her research. Binding meta-data to such a restricted set of pages corresponds the `temporary` mode.

Lastly, some users like a automated dictionary at their hands while reading pages that are not written in their native language. A dictionary is not only applicable to our eLearning application, but universally applicable. Therefore the dictionary should be available permanently, which corresponds to the `permanent` mode.

5.2 Querying Data and Meta-Data

Meta-data-augmented eLearning is an application with user interaction and has the same concept of navigation as unaugmented hypertext. We will now go a step further and discuss an example of *automated* travel planning. Navigation of documents now becomes querying of data.

In the example we give, an automated travel planning system arranges a trip to a conference in Japan. The system's customer needs a fight, hotel accommodation, and he also wants to schedule a dinner with his colleagues at a Japanese restaurant during the conference. In arranging the trip, lots of data and meta-data is queried.

Some meta-data is very specific and needed only for querying a particular data source. For example, when the system selects a flight, airlines offer meta data about their frequent flier programs. An airline's meta-data applies only to its own flight data and not to data from other airlines. Making meta-data applicable only to some specific data resembles binding a linkbase to a document in `transient` mode.

Other meta-data is more general and applicable to numerous data sources. When investigating suitable restaurants for the dinner, the system uses an ontology of Japanese food (meta-data) to match the menus of restaurants (data) against the dietary requirements and preferences of the dinner guests (data). The same food ontology meta-data is used for all restaurants but not useful for anything other than restaurants, suggesting a `temporary` mode.

Finally meta-data needed during the whole process, e.g. meta-data on payment methods or a calendar ontology, can be made available permanently using a `permanent` mode.

5.3 Other Semantic Web Languages

Just as links in XLink can be out-of-line, i.e. external from the data, Semantic Web languages such as the Resource Description Framework (RDF) typically define meta-data out-of-line. The same issue of linkbase management formulated in Section 4 applies meta-data: how can the meta data relevant for some given data be found in an open world scenario, and which of the found meta-data should actually be considered (e.g. in evaluating a query)?

XLink and RDF have in common that they are based binary relations. In fact, XLink arcs can be directly mapped into RDF triples [6]. Analogously to the way XLink locates linkbases using an arcs with a special arcrole (cf. 4.1), there is a property `rdfs:seeAlso` in RDF to indicate a resource that might provide additional information [3]. There are no rules governing when a query actually should try to retrieve the resource providing additional information.

The reasons for a need of linkbase management in XLink given in this article also hold for a need of "RDF-sources management" in RDF, or more generally a need of 'meta-data relevance management" in any Semantic Web language.

In the same way linkbase management has been neglected in XLink, we think that "meta-data relevance management" is a neglected topic in current Semantic Web languages.

While we have argued here that navigation and querying are similar and that our binding modes transfer, we won't deny that there are also substantial differences between navigation and querying. These differences surely allow for different methods of establishing a connection of meta-data and data. We plan further research in this direction.

6 Conclusion and Perspectives

Our work is motivated by allowing reuse and composability of structures under an open world linking assumption. A document can be seen in different contexts, i.e. as part of different link structures. It should be possible for this context to be supplied not only by the author but also users that have no write-access to the original document.

Open world linking on the Web differs significantly from closed world linking in before-web systems: The Web is completely decentral; information should be hosted in Web resources, no assumptions should be made about central institutions or even communicating distributed institutions such as directory services. The Web uses URIs as identifiers and these might not be unique or a resource's URI might change. Users of a Web resources have, in general, no write-access to a given resource; any modifications or additions to the resource need to be stored separately in a new resource.

This article has introduced the concept of interfaces for link structures and a linkbase management mechanism based three binding modes. We have shown how XLink can be extended conservatively, i.e. only additions to the language are made, to accommodate both ideas.

Undoubtedly, there are many other methods of aiding reuse and composability. Especially different linkbase management mechanisms are easily imaginable. We hope to investigate these in future.

While our ideas have been presented as extensions to XLink, we suggest that they are also transferable to other Semantic Web languages, e.g. RDF, and that these can benefit highly. Just as linkbase management in XLink, "meta-data relevance management" seems an underexplored issue.

We believe that the interconnection of data and the connection of data and meta-data spread over different Web resources is still an underexplored and maybe neglected issue on the Semantic Web. We plan further and deeper exploration of this issue, the "Web" portion in "Semantic Web".

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