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Strategies for Encoding XML Documents in Relational Databases: Comparisons and Contrasts.

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ABSTRACT

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The rise of XML as a de facto standard for document and data exchange has created a need to store and query XML documents in relational databases, today's de facto standard for data storage. Two common strategies for storing XML documents in relational databases, a process known as document shredding, are Interval Encoding and ORDPATH Encoding. Interval Encoding, which uses a fixed mapping for shredding XML documents, tends to favor selection queries, at a potential cost of O(N) for supporting insertion queries. ORDPATH Encoding, which uses a looser mapping for shredding XML, supports fixed-cost insertions, at a potential cost of longer-running selection queries. Experiments conducted for this research suggest that the breakeven point between the two algorithms occurs when users offer an average 1 insertion to every 5.6 queries, relative to documents of between 1.5 MB and 4 MB in size. However, heterogeneous tests of varying mixes of selects and inserts indicate that Interval always outperforms ORDPATH for mixes ranging from 76% selects to 88% selects. Queries for this experiment and sample documents were drawn from the XMark benchmark suite.

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CHAPTER 1

INTRODUCTION

This work investigates the performance of methods for storing and querying XML documents in relational databases. XML has become the de facto standard for document and data exchange on the Internet. XML's popularity is due in large measure to its expressiveness: XML's expressive data representation and query language support the use of arbitrarily extensible hierarchical structures for capturing taxonomy-based content, a common format for representing information [1].

The rise of XML has generated interest in native XML storage and retrieval systems. These systems, which were first developed in the late 1990's, are designed for storing and retrieving XML documents, and are not simply database systems with XML layers on top. One of the most popular commercial products is Software AG's Tamino, which was first released in 1999 [1]. Well-known open source native XML databases include eXist[1] and Apache's Xindice[2]. Web administrators who have considerable amounts of XML to store and retrieve are the most common users of these systems. Xindice is probably more popular for Web applications, due to its integration with Apache's Tomcat Server.

Even with this interest in native XML storage, the maturity and widespread deployment of relational database technologies suggests a need for storing XML documents in relational databases. Relational database management systems (RDBMSes) have been in use over 20 years and are the de facto standard database implementation. Mature RDBMSes like Oracle, SQLServer, PostgreSQL, and MySQL are more common than native XML databases, and they feature enabling technologies like sophisticated query optimizers that native XML systems still lack. RDBMSes also scale well, perform well, and have proven resilient over time: when object-oriented database management systems (OODBMS) were introduced in the early 1990's, RDBMSes were adapted to emulate OODBMSes, and performed as efficiently as native OODBMSes, due to their 20+ years of query optimization.

[1] Available at http://exist.sourceforge.net/ (retrieved on 15 March 2006)
[2] Available at http://xml.apache.org/xindice/ (retrieved on 15 March 2006)

The literature on RDBMS support for XML describes various strategies for *document shredding*: i.e., the encoding (i.e., storing) of an XML document in an RDBMS. The primary focus of this thesis is a performance comparison between two related strategies for document shredding: *Interval Encoding,* a.k.a. *Nested Sets* [3], and, *ORDPATH Encoding*, which is used in the latest version of Microsoft® SQL Server™ [4]. The two methods share important similarities that make them interesting candidates for performance evaluation. Neither method uses a separate schema to manage stored documents. Both methods, rather, map most XML nodes to a set of rows in RDBMS tables, with one set of columns used to capture information on document structure, and a second to capture content. Minor departures from this use of row-oriented embeddings mainly involve complex elements. These mappings, moreover, are *order-preserving*: they ensure the relative ordering of a document's nodes when that document is retrieved from an RDBMS—in practice, by assigning an ordering identifier to each node.

Where the two kinds of methods differ is in their approach to encoding structure. Interval Encoding essentially assigns a global unique ID to each node in an XML document as it scans from top to bottom. In addition to this ID, another value is assigned to each node that represents the width of the forest rooted at that node. ORDPATH, on the other hand, uses a Dewey-decimal numbering system that assigns to each node the materialized path to that node. The net effect of these differences is that Interval Encoding and ORDPATH should perform differently, relative to operations that query and update a database. Specifically, Interval should be faster at performing selects and ORDPATH should be faster at performing inserts. ORDPATH is a O(C) algorithm for inserts, though lengthening paths can eventually affect performance, and Interval is a O(N) algorithm for inserts.

Data on the relative performance of Interval and ORDPATH encoding has not been published with respect to a standard benchmark. The work described here sought to address this gap in the literature, and to determine when it would be better to use the insert-friendly ORDPATH encoding instead of the select-friendly Interval Encoding algorithm. To achieve this goal, the 20 queries that make up the

XQuery-based XMark[3] benchmark were used to compare the algorithms' performance, relative to a series of sample datasets. These comparisons sought to determine a proportion of insertion to selection operations that put ORDPATH on an equal footing with Interval Encoding. Users whose query mixes featured a greater and lesser proportion of insertions would be advised to use ORDPATH and Interval encodings, respectively,

The work included two implementations of the XMark benchmark suite, relative to two libraries of Python routines that supported query implementation using ORDPATH and Interval Encodings. These supporting libraries used a common interface, which allowed sample queries to be coded once. The library contains a set of path-oriented data access functions including getRootNode and getNodeAtXPath as well as a set of traversal-oriented data access functions including getFirstChild and getNextSibling. Functions were added to this common interface as they were found to be needed.

Python was selected for its rapid development capabilities and platform-independence. In practice, more efficient running times could be achieved by using a compiled language; however, since both methods were handicapped by the same amount, this should not have affected the comparisons.

All benchmarks were run on a Celeron 2.2 GHz processor with 512 MB of RAM and utilized the MySQL[4] 5.0.4-beta-nt database. Test XML files of sizes 1.5 MB, 3.0 MB and 4.5 MB were used.

The data from these experiments shows that queries ran on average 6.38 times slower and inserts ran approximately 31.16 times faster for ORDPATH Encoding than for Interval Encoding. Accordingly, for XML files of sizes in the range tested, it would be beneficial to implement ORDPATH Encoding only if less than 5.6 select queries per insert are expected.

The remainder of this work includes detailed chapters on background information, including detailed descriptions of Interval and ORDPATH Encoding; a discussion of the experiments used to compare Interval- and ORDPATH-encoded documents; the results of these comparisons; an analysis of these results; and a final section that presents conclusions, and suggests further avenues for work.

[3] See http://monetdb.cwi.nl/xml/ (retrieved on 15 Mar 2006)
[4] Available at http://www.mysql.com/ (retrieved on 15 Mar 2006)

CHAPTER 2

BACKGROUND

This chapter includes background information and resources covering XML and XQuery as well as several methods for XML document encoding, which is also known as *shredding*.

2.1 XML and XQuery

2.1.1 XML

The Extensible Markup Language (XML) is a universal format for documents and data shared on the Internet. XML was initially developed by the World Wide Web Consortium (W3C) in 1996 by a group chaired by Jon Bosak of Sun Microsystems. XML, a subset of the Generic Standard Generalized Markup Language (SGML, ISO 8879:1986), was designed for interoperability with HTML. An SGML Working Group, also organized by the W3C, assisted with the development of XML. The initial goal of these groups was to allow for SGML to be "served, transmitted and processed" on the Web as easily as HTML. W3C published the resulting work, the W3C XML Recommendation, in 1998. Two versions of the recommendation have been released since 1998 [8].

SGML was initially conceived in the 1960's and 1970's and became an ISO standard (ISO 8879) in 1986. SGML and XML are markup languages: they support the coding of human-readable data and the metadata that describes it. Valid XML documents are valid SGML documents with additional restrictions that make these documents easier to parse. Some applications of SGML and XML include Hypermedia/Time-based Structuring Language (HyTime), Standard Music Description Language (SMDL), and the News Industry Text Format (NITF) [8]. These languages are best described as applications or instances of SGML or XML. XML and SGML allow users to define grammars for particular applications, including the tags that define a language's vocabulary. Specifying a vocabulary of tags brings an instance of an XML language into existence.

XHTML, a proposed replacement for HTML, is one important example of an XML-based vocabulary. HTML, which was developed before XML, uses harder-to-parse features of SGML like

support for unclosed tags that were not incorporated into XML. XHTML eliminates these features while extending HTML in two key ways: XHTML allows its users to define new tags and to decouple a web page's content from its appearance in a way that allows formatting to be managed by a device-specific rendering agent. This is quite advantageous as more diverse devices are used to browse the Web (such as telephones, PDAs, and televisions). These devices may choose how to display the structured data according to rules applicable to their domain through the use of stylesheets (XSLT or CSS transformations). Another design goal of XHTML was internationalization. In short, XHTML tries to move to a more general expression of web page data.

XML documents can be data- or document-centric. A document-centric XML document consists of free-form text that is "marked-up" with elements that specify italic, bold, and other usual presentation-oriented metadata. A data-centric document, on the other hand, consists mostly of data with elements specifying the dimensions of the data (such as length and height).

An XML document consists of storage units known as entities that may contain either parsed or unparsed content. Parsed content consists of character strings that are classified as either markup, unparsed data, or parsed data. Markup specifies a document's logical structure and storage layout. Unparsed data is left to the application to process. The final type of parsed content, parsed data, is parsed by XML Processors [8]: parsers that read XML documents and provide access to their content and structure. Simple API for XML (SAX) is one of the most common XML Processors. SAX was initially developed for Java but has been ported to several other languages, including Perl and Python.

XML provides a better metaphor for modeling information than preceding data-modeling mechanisms. It does so by supporting the development of heterogeneous, extensible, and flexible data models. Heterogeneity is the ability to express records that may contain different fields. The XML notion of a record allows for varying numbers of fields (or elements in XML terminology). Extensibility is the ability to add new types of data at will without determining them in advance. XML allows for fields with flexible size and configuration from instance to instance. Each data element can be as long or as short as it needs to be [1].

XML is also informationally complete and self-describing: the structure of a program's data can be specified in XML and operated on using preexisting logic. Microsoft and other companies offer frameworks for building applications based on using XML to express information. As Chaudhry notes, "In environments such as these, XML becomes a universal information-structuring tool where system components no longer need to be programmed separately as discreet silos of functionality [1]." Thus, when using an XML-centric system, one can often accommodate changes to a dataset by modifying the underlying XML and letting the application adjust itself accordingly.

There are four basic components used in expressing information in XML: tags, attributes, data elements, and hierarchy. Each component represents a different dimension of information. A code sample will suffice to convey an understanding of these basic components:

Listing 2-1: XML Example [1]

```
<colorimeter_reading>
      <RGB resolution=8>
            <red> 0 </red>
            <green> 1 </green>
            <blue> 255 </blue>
      </RGB>
</colorimeter_reading>
```

In this example, data elements are represented in bold. A data element is the same as the traditional idea of data. XML adds meaning to the data by adding tags (the values specified inside <>'s). Tags describe what the data elements are—i.e., tags are metadata. Attributes, specified in italics in the example, support the interpretation of data elements. Lastly, the hierarchy of elements is specified by containment [1]. When an element is contained by another element, it is a child of that element. An element that contains child elements is a complex element whereas one that does not is a simple element. All XML documents have at least one node or element that is the root of all other nodes.

An XML schema language describes an XML document's structure and content. An XML schema describes the contract between the producer and consumer of an XML document. It essentially defines what constitutes a valid 'XML message' between the two parties. Formats for XML schemas

include DTD, the one inherited from SGML; XDR; and the W3C XML Schema Definition Language (XSD). Currently, XSD is the most popular [9].

XSD was the first XML schema language to expand the role of a schema outside its traditional role of describing the contract between the interchanging parties. It does this through the concept of a Post Schema Validation Infoset (PSVI). An XSD processor accepts as input an XML Infoset and produces as the result a PSVI upon validation. During processing the XSD processor assigns a type to each element and attribute parsed. Then, applications can retrieve type information from the PSVI. According to Obasanjo, "Such strongly-typed XML is very versatile because it can now be mapped to objects using technologies like the .NET Framework's XMLSerializer, mapped to relational tables using technologies like SQLXML and the .NET Framework's Dataset, or it can be processed using XML Query languages that take advantage of strong-typing, such XPath 2.0 and XQuery [9]."

2.1.2 XQuery & Data Adapters

As XML gains in popularity as the standard way to expose data online, the need for a query language for XML data is increasing. Several XML query languages are competing for general acceptance. Currently, XQL has the greatest market penetration. However, most experts expect XML Query, or XQuery, to become the de facto standard due to its rich feature set and endorsement by the W3C (World Wide Web Consortium). One indication of XQuery's importance is the fact that IBM and Oracle have "collectively launched an effort to connect XQuery to Java [10]."

The W3C began work on XQuery in 1998, releasing an initial standard in February 2001. Since that time, XQuery has gone through several revisions. Of the W3C specifications, XQuery is generally regarded as the most carefully designed and therefore has also been the slowest to evolve [10]. The slow evolution of XQuery has been attributed to the lack of prior experience in retrieving XML data. The XQuery specification became a W3C recommendation on 3 November 2005 [11].

The beauty of XML is that it can organize data in a hierarchical, object-oriented, and multi-dimensional way. An XML document represents data in the form of a tree with an arbitrary depth and

width. A traditional relational database table can be thought of as a tree of depth two with unbounded fanout at the first level, and fixed fanout at the second level with the first level representing tuples (or rows) and the second level representing fields (or columns). An XML tree is clearly a more expressive way of representing data as no constraints are placed on either depth or width.

XML's support for expressive data modeling, however, will probably not be enough to motivate companies to replace existing relational databases with XML databases. XML does not yet compare favorably with relational technology in two important regards. First, neither XML nor object-oriented data stores scale as well, in terms of complexity, as relational systems [10]. Second, there is just too much already invested in RDBMS technology; until there is a "quantum leap in technology [10]", there is just no incentive to replace RDBMSes. This point is made by Ivanov in "XQuery Implementation", who notes that even if XML scaled and performed as well as relational databases, it would not be enough to "move the mountain of investment away from the RDBMS legacy [10]." Finally, there are certain classes of data that map well to the relational model and transitioning these to XML would increase overhead with no increase in functionality.

Given the continuing preeminance of RDBMSes, it becomes advantageous to make existing relational databases connect with the emerging XML data stores through use of a data adapter. A data adapter serves at least one and possibly two purposes. First, the necessary purpose is to allow an RDBMS to respond to queries formed against an XML representation of the data. This assumes that the person forming the queries knows the XML view of the data. If this is not the case, then the data adapter must additionally provide an XML view of the layout of the data against which proper queries can be formed.

A simple XML view of a relational database can be achieved by thinking of tables as trees as mentioned above. However, this view does not support transparent access to objects that have been broken into several tables due to normalization. Here, the data adapter must reassemble objects that have been normalized. This will allow queries to be written against the abstract view of the database (i.e., the view the database designer had in mind before it was normalized). In other words, the data adapter will infer joins from the query expression and return the results. A partial implementation of a data adapter

has been provided by this work. A query-supporting API will be provided for two popular methods of encoding XML documents in relational databases. This research stops short of a true data adapter by requiring manual coding of queries in terms of the API instead of allowing queries to be specified in terms of XQuery and automatically processed by a query interpretation layer.

A full appreciation for the power of XQuery depends, in part, on an understanding of XPath. XPath, another W3C specification, is a grammar for referencing parts of an XML document. XML-retrieval expressions supported by the XPath grammar resemble the use of path expressions for referencing the parts of a filesystem. An XPath expression consists of zero to many parent nodes and one leaf node, all separated by a specific delimiter. Additionally, XPath defines a set of standard functions for working with strings, numbers and Boolean expressions. XPath also defines ways for selecting unknown nodes, selecting multiple nodes that match certain criteria, selecting multiple paths and for selecting attributes of nodes among other things.

In its simplest form, an XQuery query can merely be an XPath expression. An XQuery query can also include static XML elements that are returned as is. While this is useful, the real power of XQuery lies in its FLWR (pronounced 'flower') expressions. FLWR stands for For-Let-Where-Return [11]. The FLWR expression allows for SQL-like SELECT functionality and can be fully nested. FLWR expressions also allow for the use of other expressions such as constructors and conditional and logical expressions. A set of XML elements is returned by FLWR expressions.

The main ingredients of a SELECT statement are SELECT, FROM and WHERE clauses. The SELECT portion specifies which columns to return. The set of tables to examine is specified by the FROM clause, and the WHERE clause specifies the search criteria. FLWR expressions are strikingly similar [11]. The For clause of FLWR specifies the XML node list to iterate over [11]. The Let clause allows for defining variables to use in the Where clause. The Where clause, as in SQL, specifies the search condition. Lastly, the Return clause specifies what exactly to return from the statement (allowing for restructuring of the data if needed). XPath expressions may be used in any of the four clauses.

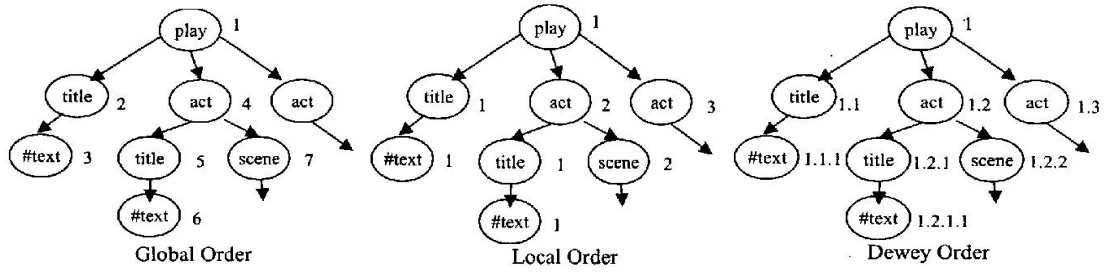
XQuery is a functional programming language that contains standard functional operators, including arithmetic operators, comparison operators, and Boolean operators. It also contains four operators that apply specifically to sequences (item-at, except, union and intersect) and four operators that apply to nodes (node-after (>>), node-before (<<), node-equality (==), and node-inequality (!=)).

2.2 Document Encoding for XML Documents

2.2.1 Order Encoding Methods

The Order Encoding Methods are a set of 3 methods for representing XML node order in the relational database model. The first method, known as Global Order, assigns an increasing global index to each node as the document is scanned from top to bottom. The second, known as Local Order, assigns indices based on a node's position relative to its siblings. The third, Dewey Order, is a hybrid encoding that assigns "a vector that represents the path from the document's root to the node [2]." See Figure 1 for example encodings.

Figure 2-1: Order Encoding Methods [2]



Global Order Encoding. Global Order Encoding resembles the storing of lists in packed arrays. This encoding provides the best support of the three methods for order-related XML queries, including those that use order-axes, such as `following` and `following-sibling`. However, it also provides poor support for node insertion. At some point in a database's lifetime, such as when a new node is inserted early in the document, many nodes will have to be renumbered. Inserts, on average, will force the renumbering of half the nodes in the database.

Sparse numbering (i.e., leaving gaps between nodes on inserts and deletes) reduces the need to renumber on inserts, but is not a magic bullet: eventually the gaps are used up and the problem reemerges. According to Tatarinov, "poor insertion performance is … a potential weakness of Global Order [2]."

Local Order Encoding. Local Order Encoding provides the best support for node insertions. With Local Order, a newly inserted node only requires renumbering the following siblings. Local Order Encoding, however, also provides the worst support for order-related queries. Global document order can be reconstructed from Local Order by combining a node's position with those of its ancestors. However, combing a node's position with those of its ancestors is a very expensive operation in SQL as there is no way to determine a given node's ancestors without walking down to that node from the very top of the document. For this reason, Local Order Encoding has very limited practical use.

Dewey Order Encoding. Dewey Order Encoding strikes a balance between Global and Local Orders. According to Tatarniov, "query processing in Dewey Order is similar to that in Global Order." When a new node is inserted at node X, renumbering is limited to X's successor siblings and their descendants. Dewey Order provides many of the advantages of Global and Local Order, but it also requires extra space to store entire paths from the root to each node [2].

2.2.2 Interval and Dynamic Interval Encoding

Interval Encoding assigns each node an L value and an R value, according to the following rules:

- $L < R$ for each node
- If node s_1 is an ancestor of node s_2 then $L_{s1} < L_{s2}$ and $R_{s2} < R_{s1}$
- If node s_1 is a left sibling of node s_2 then $R_{s1} < R_{s2}$

An example of an XML document and its Interval encoding are shown Listing 2-2 and Figure 2-2. Interval Encoding is essentially Global Order Encoding with an additional R column, which characterizes the width of an XML forest: i.e., a subtree consisting of a node and its descendants. The R-column is particularly useful for narrowing the search domain when looking for specific nodes with given paths.

Also, the R-column makes iterating through siblings much easier and more efficient. The primary disadvantage is the additional storage for the R-column.

Listing 2-2: XML Fragment [3]

```
<site>
  <people>
    <person id="person0">
      <name>Jaak Tempesti</name>
      <emailaddress>mailto:Tempesti@labs.com</emailaddress>
      <phone>+0 (873) 14873867</phone>
      <homepage>http://www.labs.com/~Tempesti</homepage>
    </person>
    ...
  </people>
  ...
</site>
```

Figure 2-2: Interval Encoding of Listing 2-2 [3]

S	L	R
<site>	0	85
<people>	1	46
<person>	2	23
@id	3	6
Person0	4	5
<name>	7	10
Jaak Tempesti	8	9
<emailaddress>	11	14
mailto:Tempesti@labs.com	12	13
<phone>	15	18
+0 (873) 14873867	16	17
<homepage>	19	22
http://www.labs.com/~Tempesti	20	21
.	.	.
.	.	.
.	.	.

Several efficient algorithms for searching a document follow naturally from the addition of the R-column. For instance, to determine the ancestors of a given node, select all nodes with lesser L values and greater R values. Likewise, to determine children of a given node, select all nodes with greater L

values and lesser R values [3]. To determine the root node, select that node with an L value of 1. Lastly, all leaf nodes can be discerned by selecting the nodes with L values equaling their R values minus 1 [5].

Dynamic Interval Encoding is an enhancement to Interval Encoding for supporting XQuery FLWR expressions. In the absence of special indices on XML tuples, strategies for implementing nested FLWR expressions, even in native XML systems, have yielded at best quadratic performance in querying. Dynamic Interval Encoding achieves linear performance for nested FLWR expressions by collapsing FLWR expressions to a single SQL query. Basic SQL templates are defined for each function necessary to fully support FLWR expressions. These templates can be combined and nested as needed by supplying forest (or environment) widths during query execution [3]. The Dynamic Interval enhancements do not require any additional data beyond that which is required by Interval Encoding to be stored. Rather, it generates indices and views dynamically based on input widths.

2.2.3 ORDPATH Encoding

ORDPATH Encoding is essentially an enhanced version of Dewey Order Encoding that uses indefinite path lengths to eliminate the need for renumbering nodes on insertions [4]. To reduce the rate at which paths increase, ORDPATH incorporates three additional changes into the Dewey strategy for assigning control information to object elements:

- New objects are all initially assigned odd-numbered indices when inserted into a database. This leaves even numbers open for later inserts.
- Negative indices are supported as a way of inserting a sibling to the left of the first sibling of a node: in document terms, inserting a child *before* or *above* all other children of an existing node.
- Identifiers (both element names and attribute names) are assigned a unique integer tag stored in the main table with a second tag-to-identifier mapping table for recovering the original identifiers.

An example of an XML document and its ORDPATH encoding are given in Figure 2-3 and Listing 2-3.

The contrast between Figures 2-2 and 2-3 illustrates key differences between ORDPATH and Interval Encoding. First, the ORDPATH encoding in Figure 2-3, unlike Interval encoding, assigns a

unique tag to each identifier in the XML document. The encoding of identifiers as tag numbers saves a significant amount of space when encoding XML documents with many repeated identifiers, which should be the case for data- and document-centric documents. For documents that are neither data- nor document-centric, the benefit of encoding identifiers as integers is less certain. Second, the node type (element, attribute, comment or value) is encoded in a separate column, once again as an integer (a single byte). This node type field provides direct support for XML queries that select node by type; in Interval Encoding, as described by DeHaan, type queries are supported using stored procedures to do string parsing and comparison [4].

Listing 2-3: Another XML Fragment [4]

```
<book isbn="1-55860-438-3">
  <section>
    <title>Bad Bugs</title>
      Nobody loves bad bugs.
    <figure caption="Sample bug"/>
  </section>
  <section>
    <title>Tree Frogs</title>
      All right-thinking people
      <bold>love</bold>tree frogs.
  </section>
</book>
```

Figure 2-3: ORDPATH Encoding of Listing 2-3 [4]

ORDPATH	Tag	Node Type	Value
1.	1 (book)	1 (Element)	NULL
1.1	2 (isbn)	2 (Attribute)	'1-55860-438-3'
1.3	3 (section)	1 (Element)	NULL
1.3.1	4 (title)	1 (Element)	'Bad Bugs'
1.3.3	NULL	4 (Value)	'Nobody loves bad bugs.'
1.3.5	5 (figure)	1 (Element)	NULL
1.3.5.1	6 (caption)	2 (Attribute)	'Sample bug'
1.5	3 (section)	1 (Element)	NULL
1.5.1	4 (title)	1 (Element)	'Tree frogs'
1.5.3	NULL	4 (Value)	'All right-thinking people'
1.5.5	7 (bold)	1 (Element)	'love'
1.5.7	NULL	4 (Value)	'tree frogs'

The ORDPATH itself is a binary encoding of a Dewey-like path that maintains document order and allows cheap and easy node comparisons. This encoding consists of a set of L_i/O_i bitstring pairs: one for each component of the ORDPATH. Each component's L_i portion must satisfy these requirements:

- "Given that one knows where a L_i bitstring starts, he/she can identify where it stops" (i.e., each L_i bitstring must be unique and may not start with (scanning from left to right) the same bit pattern as any other L_i bitstring) [4].
- "Each L_i bitstring specifies the length in bits of the succeeding O_i bitstring [4]."
- The values chosen for L_i bitstrings must maintain document order (when bit-by-bit binary comparisons are done from left to right) [4].

The mapping from L_i bitstrings to O_i bitstring lengths and value ranges is stored in a separate table, as shown in Figure 2-4:

Figure 2-4: ORDPATH Prefix Mapping Table [4]

L_i Bitstring	**L_i**	**O_i value range**
000000001	20	[-1118485, -69910]
00000001	16	[-69909, -4374]
0000001	12	[-4373, -278]
000001	8	[-277, -22]
00001	4	[-21, -6]
0001	2	[-5, -2]
001	1	[-1, 0]
01	0	[1, 1]
10	1	[2, 3]
110	2	[4, 7]
1110	4	[8, 23]
11110	8	[24, 279]
111110	12	[280, 4375]
1111110	16	[4376, 69911]
11111110	20	[69912, 1118487]

This table, for example, would be used to encode the ORDPATH '1.5.3.-9.11' as the bitstring 01110011010000111001110011. This encoding is produced by locating each component value in the O_i value ranges and appending the corresponding L_i bitstring followed by the corresponding number of bits

specifying the offset for the component value from the minimum O_i value for that range. For the example, consider the following translations from component values to L_i bitstrings + O_i offsets:

1 → 01 (offset of 0 from 1 specified in 0 bits)
5 → 110 + 01 (offset of 1 from 4 specified in 2 bits)
3 → 10 + 1 (offset of 1 from 2 specified in 1 bit)
-9 → 00001 + 1100 (offset of 12 from –21 specified in 4 bits)
11 → 1110 + 0011 (offset of 3 from 8 specified in 4 bits)

A set of fairly straightforward algorithms supports the traversal of ORDPATH trees. For instance, to determine the parent of a given node, simply drop the last component of its ORDPATH. To determine siblings, simply increment the last component of the ORDPATH.

The one clear algorithmic advantage of Interval Encoding over ORDPATH is that a node's indices can be used to predict how many descendants that node has. There is no such shortcut with ORDPATH.

2.3 Summary

This chapter included background information on XML and XQuery. It described three basic techniques for shredding XML documents—Global, Local and Dewey Order Encodings—and two alternative encoding strategies for enhancing their performance: Interval Encoding, a variation of Global Order Encoding that essentially adds to a node's label the width of the forest rooted by the node, and ORDPATH, a variation of Dewey Order Encoding that specifies a procedure for expressing a path as a binary bitstring.

CHAPTER 3

EXPERIMENTAL METHODS

3.1 Motivation & High-Level Strategy

As stated previously, this research sought to investigate methods of encoding XML documents in relational databases. This is an important topic because of XML's growing popularity and RDBMS market penetration. Major relational database vendors (Microsoft, Oracle and IBM) now support XML with a layer on top of their RDBMS. Since there were no published studies comparing ORDPATH to Interval Encoding, the decision was made to implement and compare both approaches, determining especially what circumstances the insert-friendly approach of ORDPATH would pay off.

Work on this research began with extensive background research on XML, XQuery, and some related but ultimately irrelevant topics (including Grammars, Compilers, and Finite State Machines). The topic was an extension of a project for a Database Design course on document shredding.

The work described here compared ORDPATH and Interval Encoding by determining the relative performance of insertion and selection operations for the two encodings, relative to the 20 queries that make up the XMark[5] benchmark suite. These actions, which were specifically designed to test performance of XML databases, were each applied to an XML file representing the data for a mock auction (such as would be needed for a site such as Ebay). Listing 3-1 exemplifies the structure of these XML files:

Listing 3-1: Example auction.xml

```
<site>
  <regions>
    <africa>
      <item id="item0">
        <location>United States</location>
        <quantity>1</quantity>
        <name>duteous nine eighteen </name>
        <payment>Creditcard</payment>
        <decription> ... </description>
        ...
      </item>
```

[5] see http://monetdb.cwi.nl/xml/ (retrieved on 15 Mar 2006)

Listing 3-1 (Continued)

```
      ...
    </africa>
    ...
  </regions>
  <categories>
    <category id="category0">
      <name>liquor </name>
      <description>
        <text>
          fondness vines consenting censuring preventions
        </text>
        ...
      </description>
    </category>
    ...
  </categories>
  <people>
    <person id="person0">
      <name>Klemens Pelz</name>
      <emailaddress>mailto:Pelz@duke.edu</emailaddress>
      <creditcard>6491 3985 6149 1938</creditcard>
      <watches>
        <watch open_auction="open_auction23"/>
      </watches>
      ...
    </person>
    ...
  </people>
  </open_auctions>
    <open_auctions>
    <open_auction id="open_auction0">
      <initial>70.44</initial>
      <reserve>391.57</reserve>
      <bidder>
        <date>12/02/2001</date>
        <time>05:07:46</time>
        <personref person="person175"/>
        <increase>9.00</increase>
      </bidder>
      ...
    </open_auction>
    ...
  </open_auctions>
  <closed_auction>
      <seller person="person166"/>
      <buyer person="person148"/>
      <itemref item="item4"/>
      <price>18.00</price>
      <date>03/22/1999</date>
      <quantity>1</quantity>
      <type>Featured</type>
      <annotation>
        <author person="person69"/>
        <description>
          <text>
            entering mock means sore orders allay friendly
          </text>
        </description>
        <happiness>6</happiness>
      </annotation>
    </closed_auction>
    ...
  </closed_auctions>
</site>
```

The following is a brief, intuitive description of each query[6]:

- Query 1 lists the names of all people stored in the data file.
- Query 2 returns the bid increase amount for the second bidder in each open auction.
- Query 3 returns the first and last increase amounts for all open auctions where the last increase is greater than 2 times the first increase.
- Query 4 returns the reserve amount for any open auctions where person18829 bidded before person10487.
- Query 5 returns the number of closed auctions where the price is greater than 40.
- Query 6 returns the number of <item> elements in all regions (regardless of generation or tree depth).
- Query 7 returns the number of <annotation>'s plus the number of <emails>'s plus the number of <description>'s in the site (regardless of generation or tree depth).
- Query 8 returns each person and the number of closed auctions they won.
- Query 9 returns each person and the names of the items that originate from Europe that they bought.
- Query 10 returns each interest category and the people who have that interest transformed as French text.
- Query 11 returns each person and the number of open auctions their income exceeds by a scale factor of 5000.
- Query 12 returns the incomes of the persons and the count of open auctions their income exceeds by a scale factor of 5000, but only if their income is greater than 50000.
- Query 13 returns the names and descriptions of the items originating in Australia.
- Query 14 returns the name of the items in the site whose descriptions contain the word 'Gold' (without regard to tree depth).
- Query 15 returns the keywords that are nested two levels deep in lists contained in the description of a closed auction's annotation.
- Query 16 returns the sellers of items that have non-empty keywords as described in Query 15.
- Query 17 returns the names of persons whose homepage is an empty string.
- Query 18 returns the reserves of all open auctions converted to Euros.
- Query 19 returns the names and locations of all <item>'s in all regions (regardless of tree depth).

[6] See Appendix A.5 for query implementations

- Query 20 returns 4 groupings of customer's based on income: 'preferred', 'standard', 'challenge', and 'na'.

Test XML files of sizes 1.5 MB, 3.0 MB and 4.5 MB, corresponding to XMark scale factors of 0.01, 0.02 and 0.03 respectively, were used. Database operations were executed on a single PC with one processor, which ran the MySQL server and the Python client code as concurrent processes. The PC was rebooted before any benchmarks were run and all non-essential processes were killed. Each benchmark was run once to fill the MySQL query cache and then run 5 subsequent times. There was only a slight difference in running times of the first and second runnings for some of the benchmarks—others were unchanged. MySQL does not have a data cache but, of course, the operating system caches pages. During query execution, a momentary disk read occurred approximately once every 3 seconds for Interval Encoding and once every 6 seconds for ORDPATH Encoding. Additional caching would probably have had little affect on the results—though future investigations of database caching would be of interest. During insert execution, disk activity was constant for Interval and intermittent for ORDPATH. MySQL uses B-Trees for its indices and they are updated on each insert.

Performance comparisons were based on wall-clock time. The Python function 'time.clock()' was used to for all measurements. CPU time, such as returned by the Python benchmarking utility HotShot, was inappropriate for measuring performance: CPU time data excluded time spent in the database and for network transfer which unfairly favored Interval time, whose algorithms require much less local CPU use. This difference in CPU time can be mainly attributed to ORDPATH's encoding of paths to and from bitstrings (which is CPU-intensive). The queries, the encoding methods, and the query-supporting libraries were implemented in the Python programming language. Python was selected for its rapid development capabilities and platform independence.

After intitial results were in, it became clear that running a mix of selects and inserts may produce different results than the uniform running pattern used in benchmarking each query individually and, in an effort to validate the conclusions drawn from the results of the benchmarks, 5 different mixes of 100 operations (selects/inserts) were run for each file size—88/12, 85/15, 82/18, 79/21, and 76/24.

Listing 3-2: AbstractTraverser Interface Specifiation

```
class abstractTraverser( object ):
  ...
  def validateXPath( xpath ):
  def getNodeAtXPath( self, xpath ):
  def getFirstChildByName( self, node, name ):
  def getNthChildByName( self, node, n, name ):
  def getLastChildByName( self, node, name ):
  def getChildrenByName( self, node, name ):
  def getFirstChildWithAttributeValue( self, node, child, attribute, value):
  def getNextSiblingByName( self, node, name ):
  def insertSimpleNode( self, leftSibling, newNode ):
  def getRootNode( self ):
  def getRandomNonrootNode( self ):
  def getNodeType( self, node ):
  def getNodeName( self, node ):
  def getNodeText( self, node ):
  def getNodeAttributeValue( self, node, attribute ):
  def getParent( self, node ):
  def getNextSibling( self, node ):
  def getPreviousSibling( self, node ):
  def getFirstChild( self, node ):
  def getLastChild( self, node ):
  def getDescendants( self, node ):
  def getDescendantsContainingText( self, node, text ):
  def getDescendantsByNameAndNodeType( self, node, name, nodeType ):
  def getNthGenerationDescendantsByNameAndNodeType( self, node, n, name,
                                                    nodeType ):
  def getAncestors( self, node ):
  def compareNodes( self, node1, node2 ):
```

The query-supporting libraries adhered to a common interface, which allowed each query to be coded once. Listing 3-2 gives this interface's specification[7]: i.e., the interface definition for a base class that supports XML document traversal—*abstractTraverser*. The *abstractTraverser* class was subclassed to obtain derived classes that implement the Interval and ORDPATH traversal algorithms. Where possible, *abstractTraverser*'s methods were defined in terms of polymorphic (i.e., ORDPATH or Interval) realizations of other *abstractTraverser* methods. However, in most cases, a more efficient implementation of these methods could be defined in the derived classes proper.

[7] See Appendix A for complete listings of all source codes produced for this project.

3.2 Low-Level Strategy & Implementation Details

This section contains an example query along with its implementation and definitions of key supporting functions for both Interval and ORDPATH encodings. Every query in the XMark suite was encoded by hand, using primitives from *abstractTraverser*. XMark Query 3, shown in the header comment of Listing 3-4, typifies how queries were implemented.

- The final loop in q3, which iterates through all auctions returned by the call to getChildrenByName, corresponds to Query 3's main 'for' loop.
- The first eight lines of processAuction, which retrieve the first bidder, his/her increase, the last bidder, and his/her increase, correspond to the expressions in Query 3's WHERE clause. If any of those accesses fail, the code returns immediately.
- The final 'if eval…' statement in processAuction completes the processing for Query 3's WHERE clause. If the conditions are met, processAuction prints the result to standard output (which corresponds to the RETURN clause of the FLWR statement).

Originally, each query used getNextSibling to iterate through a node's children. The getNextSibling function, however, was replaced by Interval-encoding-specific and ORDPATH-encoding-specific (cf. Listing 3-5 & Listing 3-3) implementations of getChildrenByName after tree-traversal proved inefficient for Interval and ORDPATH.

Listing 3-3: Interval-Specific Implementation of getChildrenByName

```
def getChildrenByName( self, node, name ):
   self.cursor.execute( """SELECT * FROM %s WHERE l > %s AND l < %s AND
      nodeType = %s AND depth = %s AND s = '%s';" "" % \
      ( self.tablename, node[self.L_INDEX], node[self.R_INDEX], \
      self.ELEMENT_NODE_TYPE, node[self.DEPTH_INDEX] + 1, name ))
   return self.cursor.fetchall()
```

Listing 3-4: Interval-Specific Implementation of Query 3

```
#!/usr/bin/env python
#
# ------------------------------------------------------------
# Query 3
# ------------------------------------------------------------
# FOR    $b IN document("auction.xml")/site/open_auctions/open_auction
# WHERE  $b/bidder[0]/increase/text() *2 <=
                                    $b/bidder[last()]/increase/text()
# RETURN <increase first=$b/bidder[0]/increase/text()
#                  last=$b/bidder[last()]/increase/text()/>

import sys, os

sys.path.append( '../shared' )
from util import *

if __name__ == '__main__':
   traverser, conn, cursor = setupForQuery( 'q3' )

   def processAuction( auction ):
      firstBidder = traverser.getFirstChildByName( auction, 'bidder' )
      if not firstBidder: return
      firstIncrease = traverser.getFirstChildByName( firstBidder,
                                                     'increase')
      if not firstIncrease: return
      lastBidder = traverser.getLastChildByName( auction, 'bidder' )
      if not lastBidder: return
      lastIncrease = traverser.getFirstChildByName( lastBidder,
                                                     'increase' )
      if not lastIncrease: return

      firstIncrease = traverser.getNodeText( firstIncrease )[0]
      lastIncrease = traverser.getNodeText( lastIncrease )[0]

      if eval( firstIncrease ) * 2 <= eval( lastIncrease ):
         print '<increase first=%s\nlast=%s />' % ( firstIncrease, \
                                                     lastIncrease )
   def q3():
      rootNode = traverser.getNodeAtXPath( '/site/open_auctions/' )
      if not rootNode: return
      auctions = traverser.getChildrenByName( rootNode, 'open_auction' )
      for auction in auctions:
         processAuction( auction )

   doProfileAndPrintStats( q3, None )
   cursor.close()
   conn.close()
```

For the Interval-encoding-specific code (Listing 3-3), a node's children match the following conditions:

- L is less than the current node's R value and greater than the current node's L value: i.e., `l > node[L_INDEX] AND l < node[R_INDEX]`.
- Nodetype is an element node: i.e., `nodeType = self.ELEMENT_NODE_TYPE`.
- Depth is one greater than current node: i.e., `depth = node[self.DEPTH_INDEX] + 1`.
- S is equal to the search string (name): i.e., `s = '%s' % name`

The key to this SQL statement is the name-matching clause. This clause essentially flattens the part of the database matching the other search criteria and uses the built-in index of node text values to find the proper matches. Additional indices on the nodeType and depth columns also speed the query. A high-quality SQL implementation would use optimizers to process the condition that returns the smallest set first, thereby speeding the remaining conditional matches and overall query execution. One could theoretically implement an entirely separate optimization layer on top of the SQL engine that utilizes 'SELECT COUNT' statements and other metadata to dynamically construct the SQL statements the engine will process. Although implementing this optimization system is beyond the scope of the current thesis, it is the basis, along with other claims made by designers of XML-enabled systems (such as DeHaan's Dynamic Interval Encoding) for the belief that an XML-enabled system could potentially match or outperform native XML systems.

Listing 3-5: ORDPATH-Specific Implementation of getChildrenByName

```
def getChildrenByName( self, node, name ):
   upperBound, node = self.getOrCreateOrdpath( node )
   upperBound.incrementLastComponent( 1 )
   upperBound = upperBound.getHexstringRepr()
   tag = self.getTagFromIdentifier( name )
   if not tag: return None
   self.cursor.execute( """SELECT * FROM %s
                              WHERE ordpath > '%s' AND ordpath < '%s' AND
                                    depth = %s AND tag = %s;""" % \
      ( self.tablename, node[self.HEXSTRING_PATH_INDEX], \
        upperBound, node[self.DEPTH_INDEX] + 1, tag ))
   res = self.cursor.fetchall()
   node[self.ORDPATH_INDEX].incrementLastComponent( -1 )# reset original
                                                        node ordPath object
   return res
```

For the ORDPATH-encoding-specific code (Listing 3-5) the conditions that a node's children match are as follows:

- Ordpath is greater than the current node's and less than the upper bound (which is defined as the current ordpath with the last component incremented): i.e., `ordpath > '%s' AND ordpath < '%s' % ( node[self.HEXSTRING_PATH_INDEX], upperBound )`. Notice that Ordpath uses a string comparison, instead of the integer comparisons for Interval.
- Depth is one greater than current node: i.e., `depth = node[self.DEPTH_INDEX] + 1`.
- Tag is equal to the tag for the search string (name): i.e., `tag = %s % tag`. The tag value is found by the call to getTagFromIdentifer, which locates the value in a separate tag-to-value mapping table.

These conditions resemble those for Interval Encoding: nodeType, the only one that differs, could be omitted because restrictions on tag and depth eliminate all node types but element. Caching of Python Ordpath objects speeds up queries. The function getOrCreateOrdpath takes a node returned from the database and either returns an Ordpath object if it has already been created or creates it (by interpreting the meaning of the hexstring representation of the ORDPATH) and appends it to the node (which is a Python list). Caching allows a node to be used in the calling code with no additional performance penalty after it is first created.

The implementations of the ORDPATH and Interval algorithms were made more efficient by adding a depth column to the relational representation of documents. In the case of Interval Encoding, the depth column allows query-processing logic to discard nodes that appear to satisfy query conditions, but are in fact descendants that are not of interest (e.g., when searching for children of a given node with certain conditions). This depth information could only be computed by examining the label structure of descendant nodes from a node with a certain known depth. For ORDPATH-encoded data, the depth column eliminates the need for an expensive procedure to compute a node's depth from its encoding. In the absence of a depth column, query implementations that used repeated calls to getNextSibling

outperformed implementations that used getChildrenByName. This use of the depth column slowed some queries, but yielded the best overall performance: an observation that suggested the need for an optimization layer that attaches conditions to queries dynamically, based on metadata such as the number of results which would be returned by a certain query conditions. This information could be obtained by executing a less expensive 'SELECT COUNT' statement instead of the actual query and used to order the conditions in much the same way the SQL engine does internally. Other metadata, of course, could be used for this optimization layer as well (such as which columns have indices and which do not and the types of and frequency of data).

CHAPTER 4

DATA

All benchmarks were run five times on a Celeron 2.2 GHz processor running Windows XP Home Edition with 512 MB of RAM utilizing the MySQL[8] 5.0.4-beta-nt database. Each benchmark was run one time to fill the MySQL query cache. Then the subsequent 5 runs were averaged and recorded in Figure 4-1. Figure 4-2 shows the database and index sizes for each encoding method. Figure 4-3 shows the running times for heterogeneous, randomly chosen mixes of selects (first figure) and inserts (second figure).

Figure 4-1: Running Times for Homogeneous Benchmarking (in Wall seconds)

	Interval			Ordpath		
XMark scale	0.01	0.02	0.03	0.01	0.02	0.03
Shredding:	707.8920145	2781.772956	28428.9893	219.377983	418.6594173	1483.219875
Q1:	0.03389062	0.050767695	0.483571795	0.084568569	0.100181797	7.537545135
Q2:	2.92343423	5.84222377	9.34476353	3.897463504	7.349297243	11.94769223
Q3:	11.37351814	41.11639377	495.852481	8.010371709	15.56149214	24.122855
Q4:	0.33954483	0.612422249	1.250773772	2.349757302	3.680001676	5.596107047
Q5:	0.259290217	0.503450508	1.868231856	0.058557603	0.066783348	7.390835986
Q6:	0.103836381	0.190173751	1.508761868	0.310830846	0.239832297	1.473432797
Q7:	0.304454058	0.559815074	4.420741184	0.139898786	0.464513451	2.797863136
Q8:	2.596462679	5.140010811	8.304553512	12.40107528	24.02461676	36.73261322
Q9:	23.19878504	96.81281539	314.5581092	175.6532895	869.9219312	5441.627869
Q10:	11.46765224	20.66158108	39.71360864	72.08478263	130.386211	247.7031264
Q11:	3.310033538	6.738528081	12.59237221	14.59703761	25.49896118	41.33021068
Q12:	2.344210507	4.03921951	6.887741878	13.7594454	23.57714402	36.53974346
Q13:	0.300463327	0.612591125	0.868557317	1.749308641	2.928813411	4.64270459
Q14:	1.086963846	2.023565285	4.651338089	9.101668508	16.39184315	26.0094255
Q15:	1.346100971	1.924933057	4.783023261	13.85388813	18.59962392	36.85256394
Q16:	1.333016906	1.905785582	3.94050445	13.42812313	18.2101162	36.71414412
Q17:	1.176946511	2.042214164	3.401333689	6.864609329	11.67782023	17.82793623
Q18:	0.451598737	0.802419721	1.333466404	2.244224336	3.757220708	5.756101963
Q19:	1.942406088	3.509291265	7.164939678	8.780489699	14.94275742	24.20831726
Q20:	1.104139493	1.876843845	4.009661004	7.071097863	11.91438482	19.16982102
Query average:	3.349837418	9.848252287	46.34692672	18.32202442	59.9646773	301.7990454
Insert 10:	183.697	355.0170937	670.25242	3.8534	5.870919907	26.15054
Insert 40:	685.1365574	1536.883704	2325.114813	14.02225329	23.35731105	113.5574427
Insert 70:	1333.173308	2606.242325	4199.181215	26.69041624	40.26645752	208.9745623
Insert 100:	2223.84736	4549.038209	6416.56104	38.5883	58.56196053	309.4376
Insert average:	1106.463556	2261.795333	3402.777372	20.78859238	32.01416225	164.5300362

[8] See http://www.mysql.com/ (retrieved on 15 Mar 2006)

Figure 4-2: Encoded File Sizes (in bytes)

	Interval			Ordpath		
XMark scale	0.01	0.02	0.03	0.01	0.02	0.03
Datafile size:	2,563,036	5,114,860	7,696,116	1,748,432	3,523,292	5,310,000
Index size:	2,322,432	4,561,920	6,910,976	1,341,440	2,581,504	3,943,424

Figure 4-3: Running Times for Heterogeneous Mixes of Benchmarks

	Interval			Ordpath		
XMark scale	0.01	0.02	0.03	0.01	0.02	0.03
88/12 mix:	633.3603762	8615.328945	12197.74227	2389.689766	13979.85228	35239.04713
85/15 mix:	507.4515172	6627.70985	11734.12373	1874.216816	12924.17084	29376.46781
82/18 mix:	570.547975	11979.90577	17787.11346	2213.795138	17356.16804	72263.38954
79/21 mix:	609.8291414	7825.157828	21126.1911	1793.117581	11415.80042	51248.85994
76/24 mix:	676.678463	5268.479674	17896.35238	1859.414079	11619.01992	32111.42076

Figure 4-4: Interval Query Performance

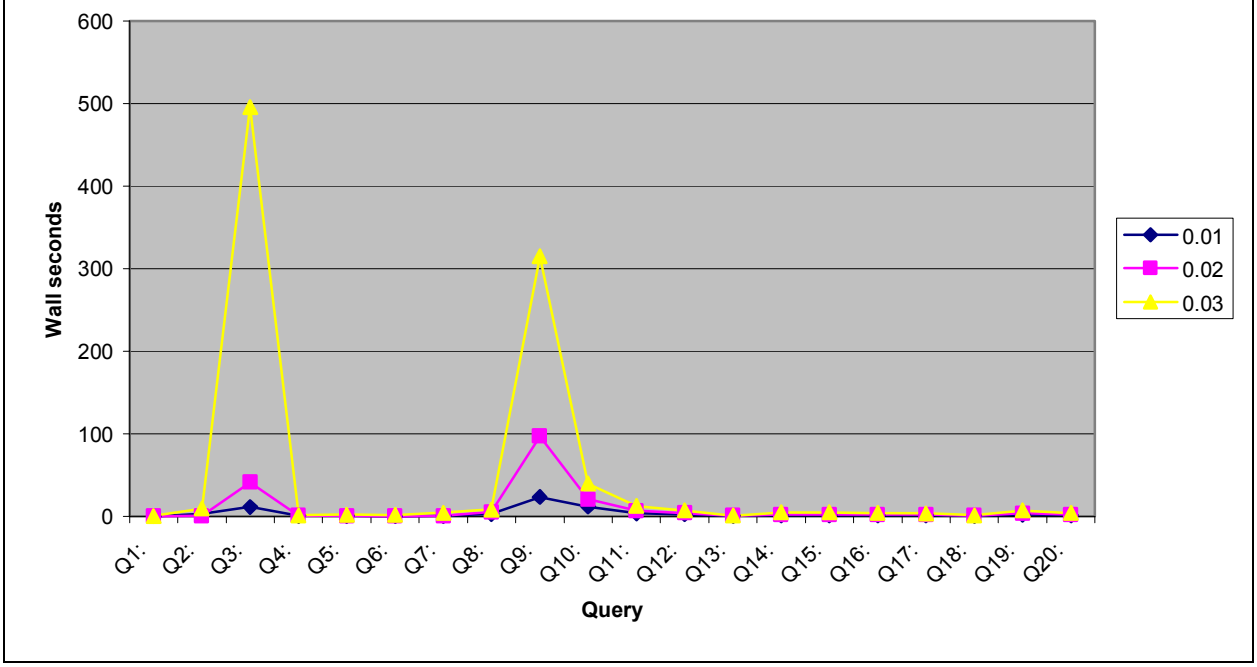


Figure 4-5: ORDPATH Query Performance

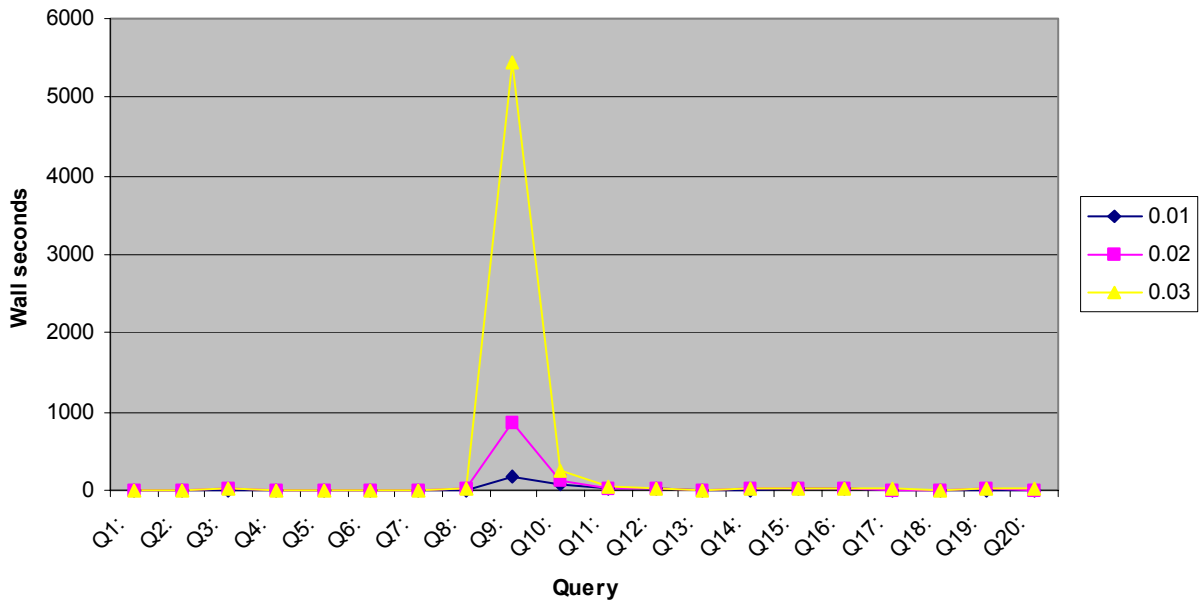


Figure 4-6: Query Comparison – XMark 0.01 Document

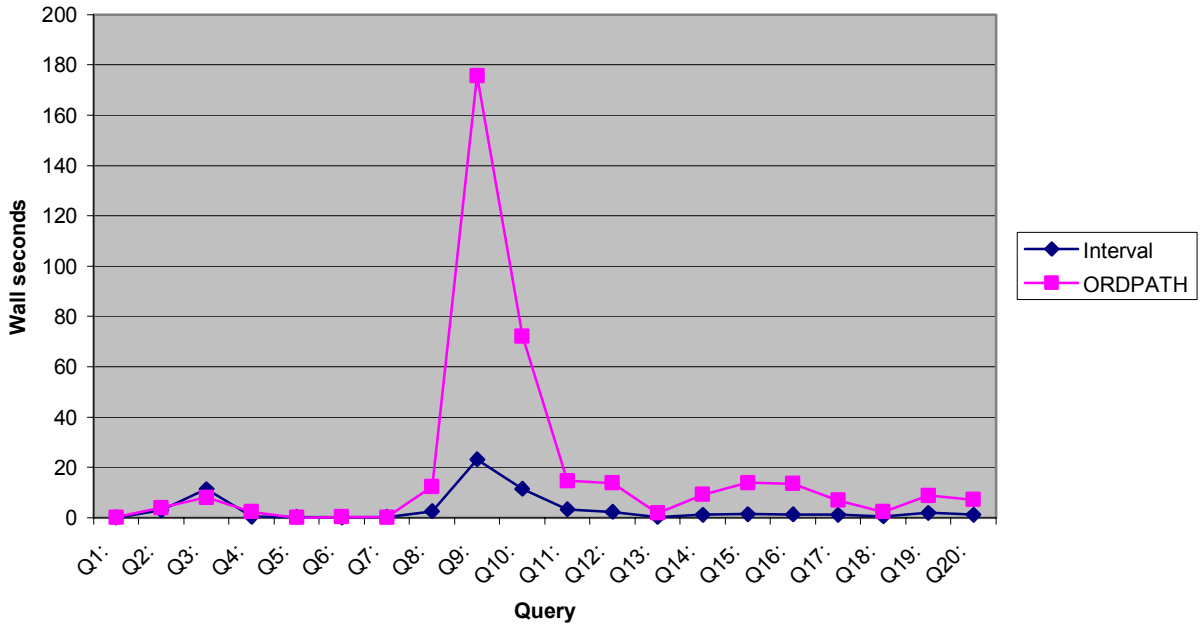


Figure 4-7: Query Comparison – XMark 0.02 Document

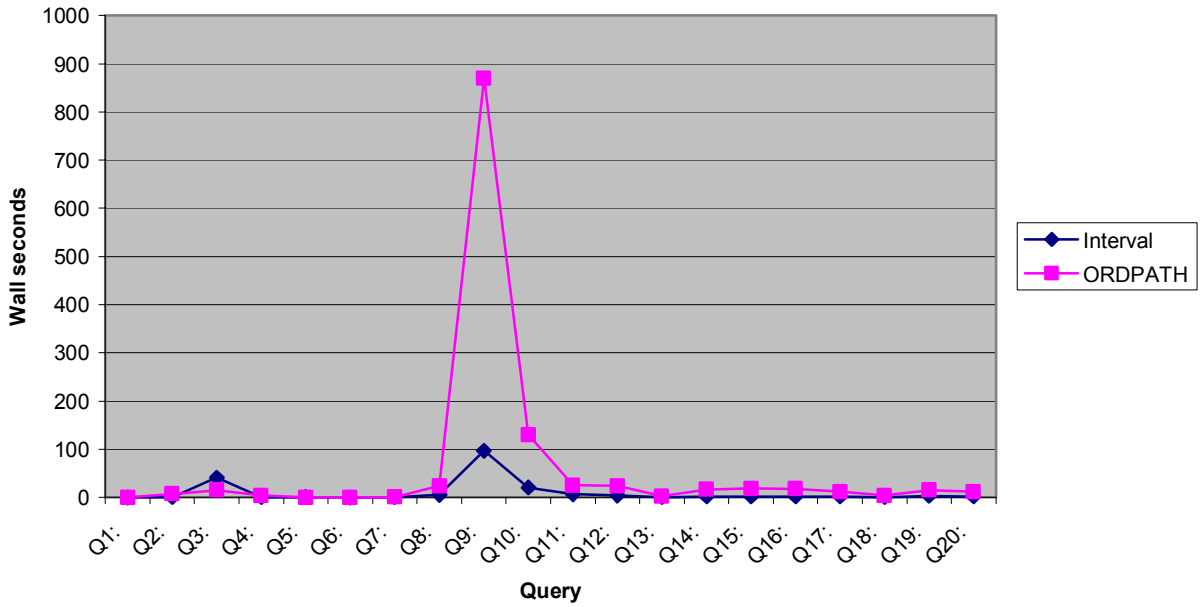


Figure 4-8: Query Comparison – XMark 0.03 Document

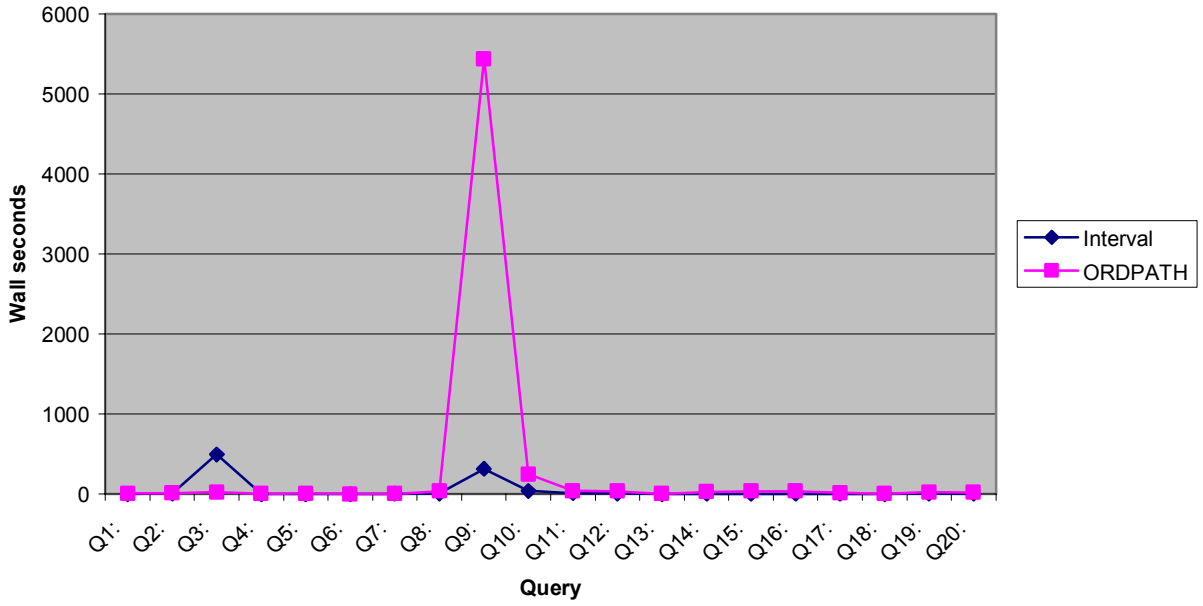


Figure 4-9: Query Comparison – Average

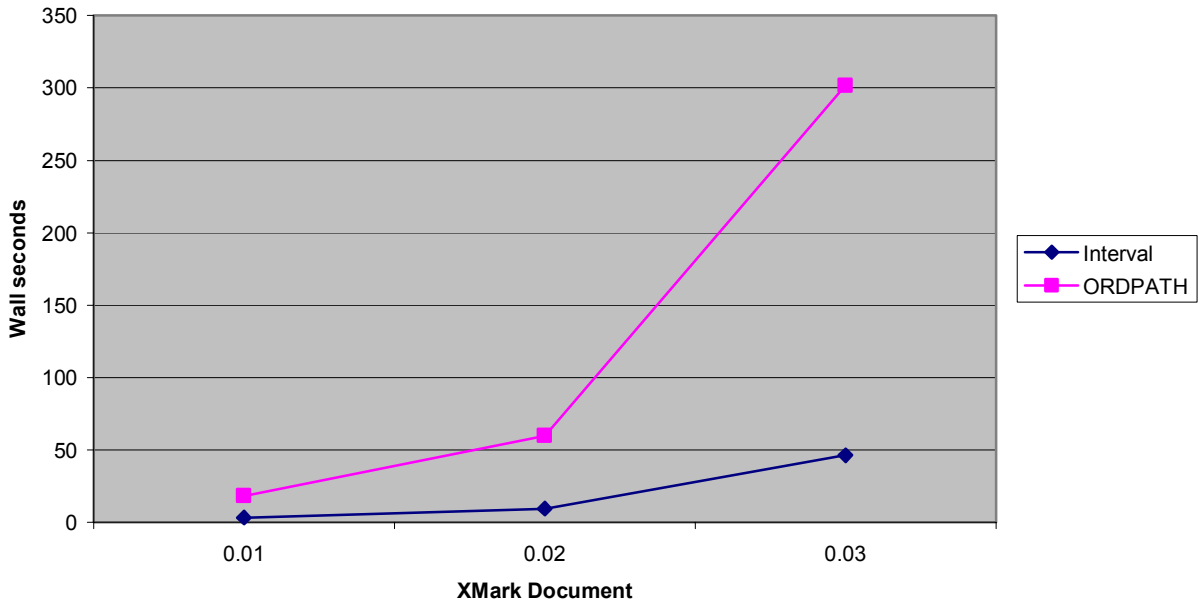


Figure 4-10: Interval Insert Performance

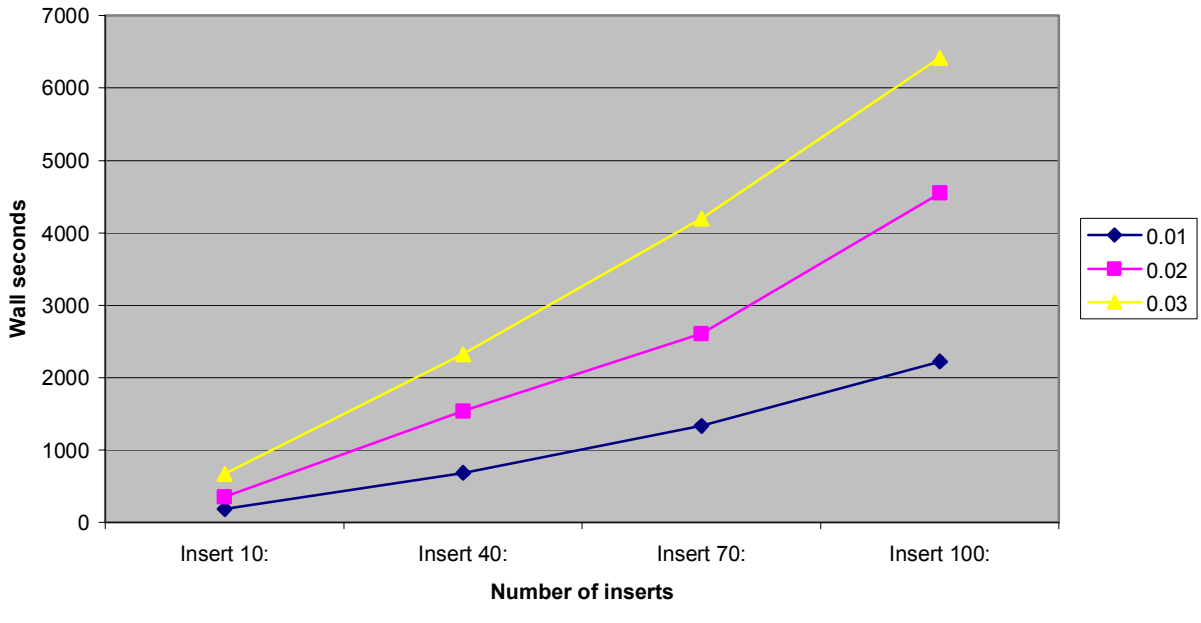


Figure 4-11: ORDPATH Insert Performance

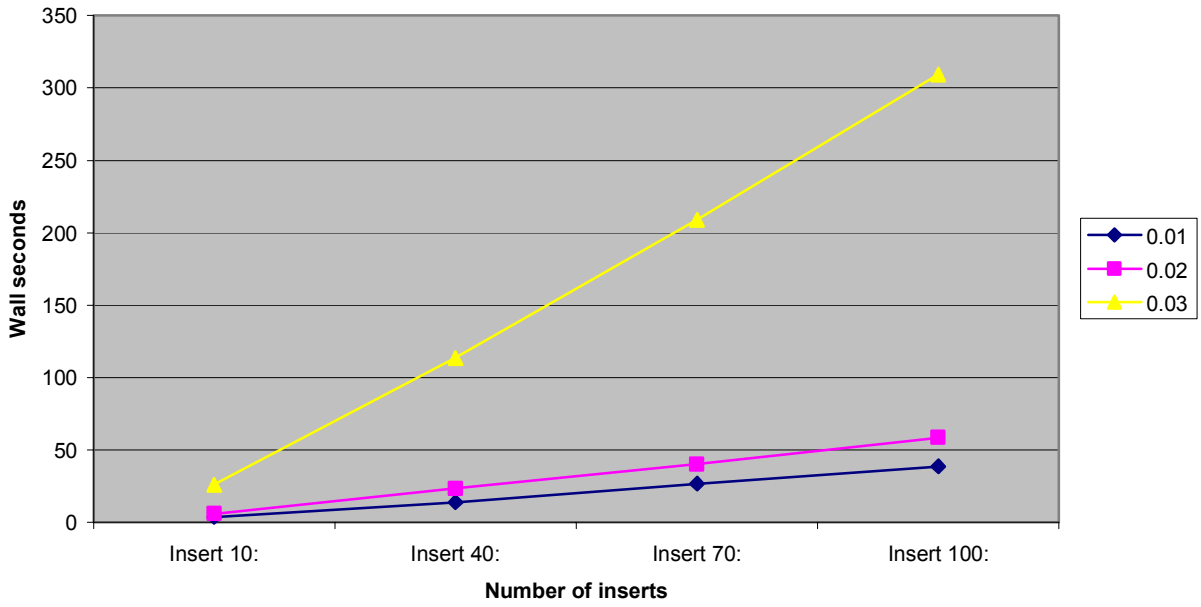


Figure 4-12: Insert Comparison – XMark 0.01 Document

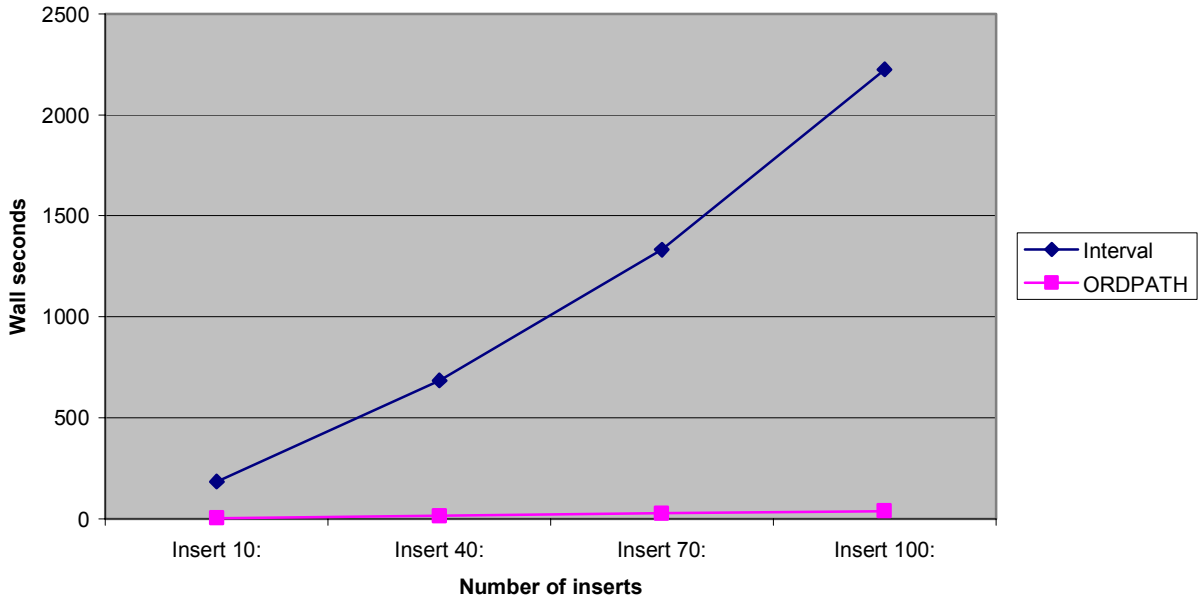


Figure 4-13: Insert Comparison – XMark 0.02 Document

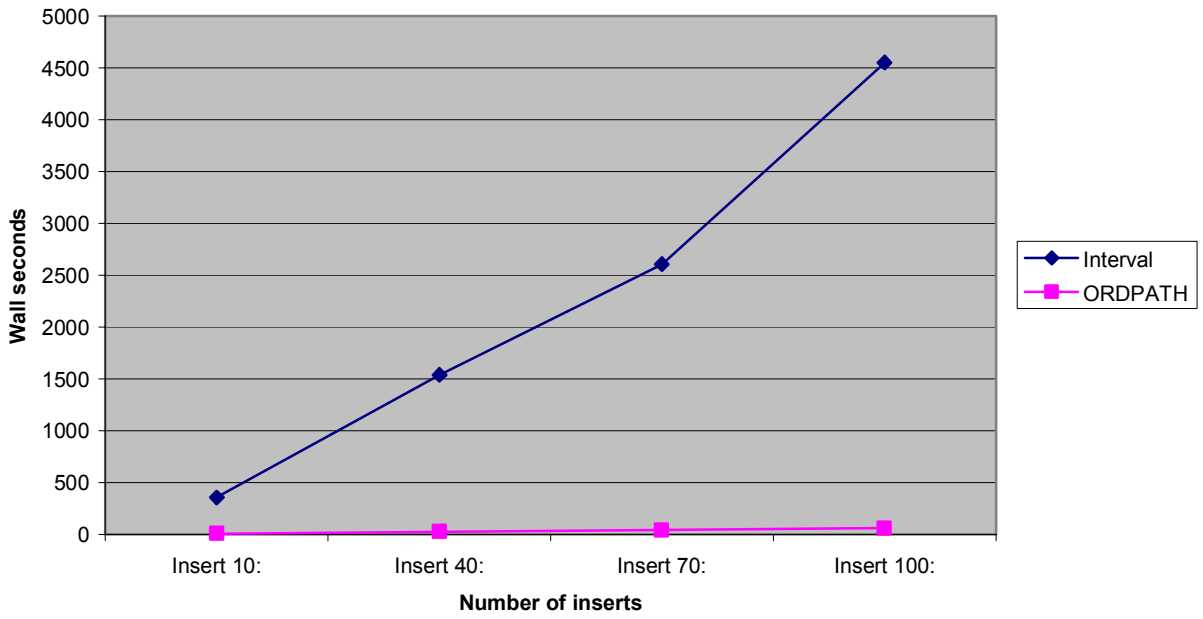


Figure 4-14: Insert Comparison – XMark 0.03 Document

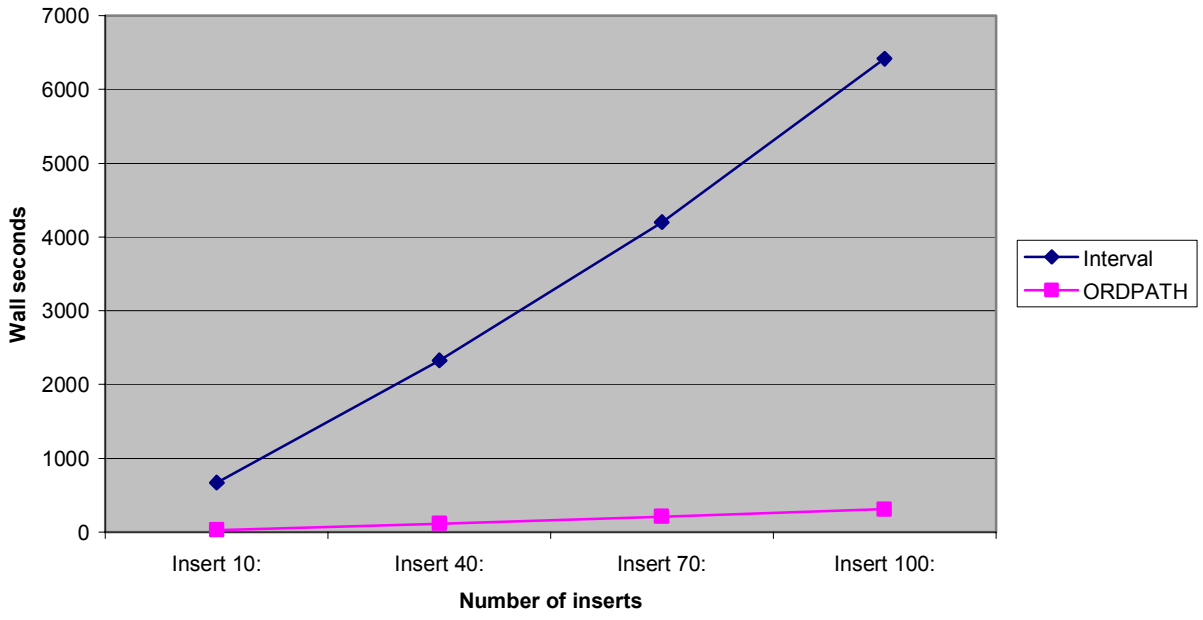


Figure 4-15: Insert Comparison – Average

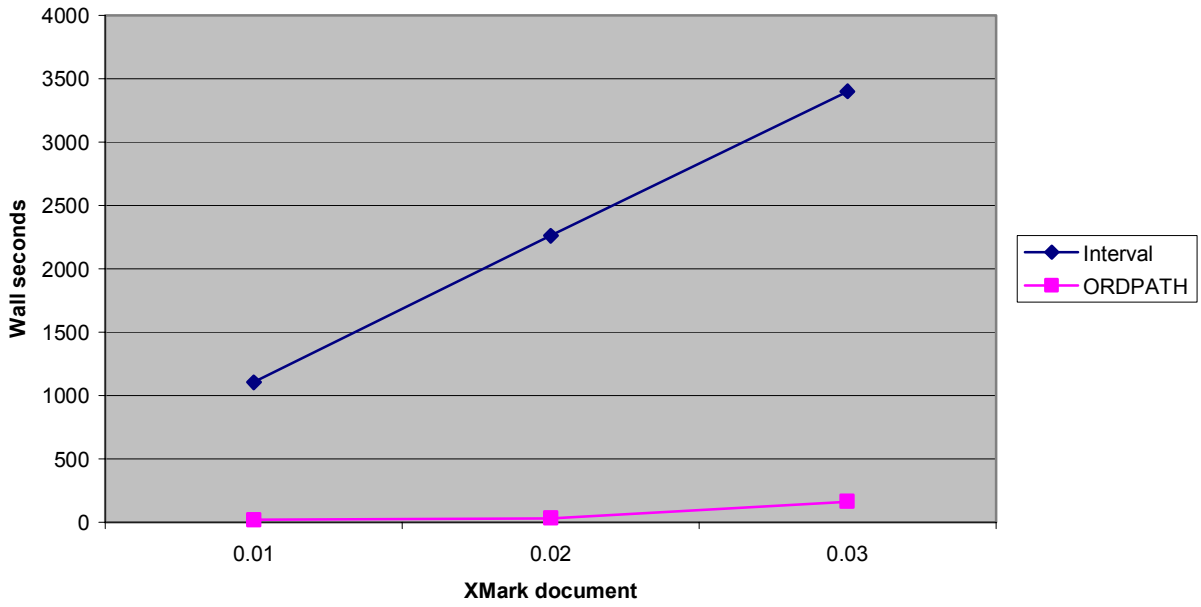


Figure 4-16: Heterogeneous DB Operation Comparison

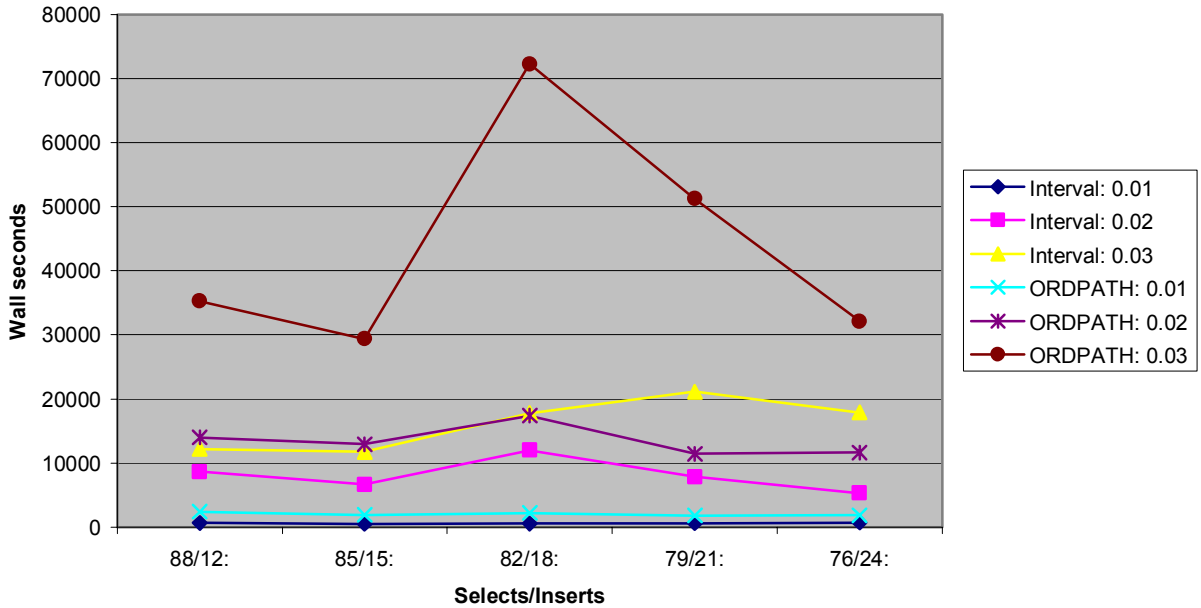


Figure 4-17: Encoding Size Comparison – XMark 0.01 Document

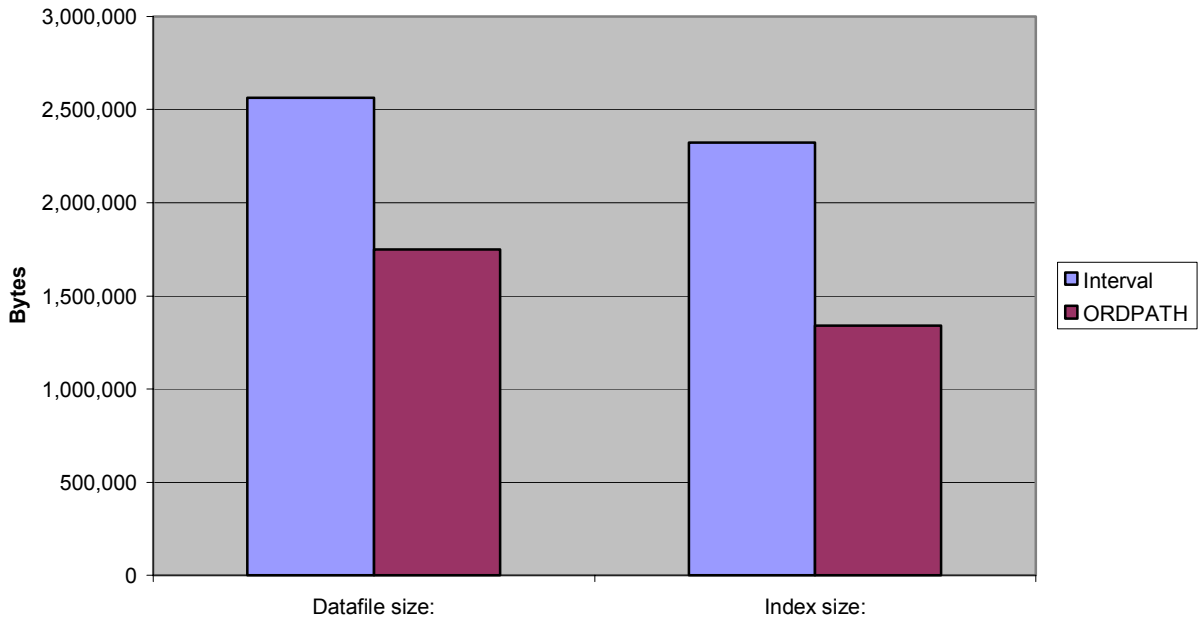


Figure 4-18: Encoding Size Comparison – XMark 0.02 Document

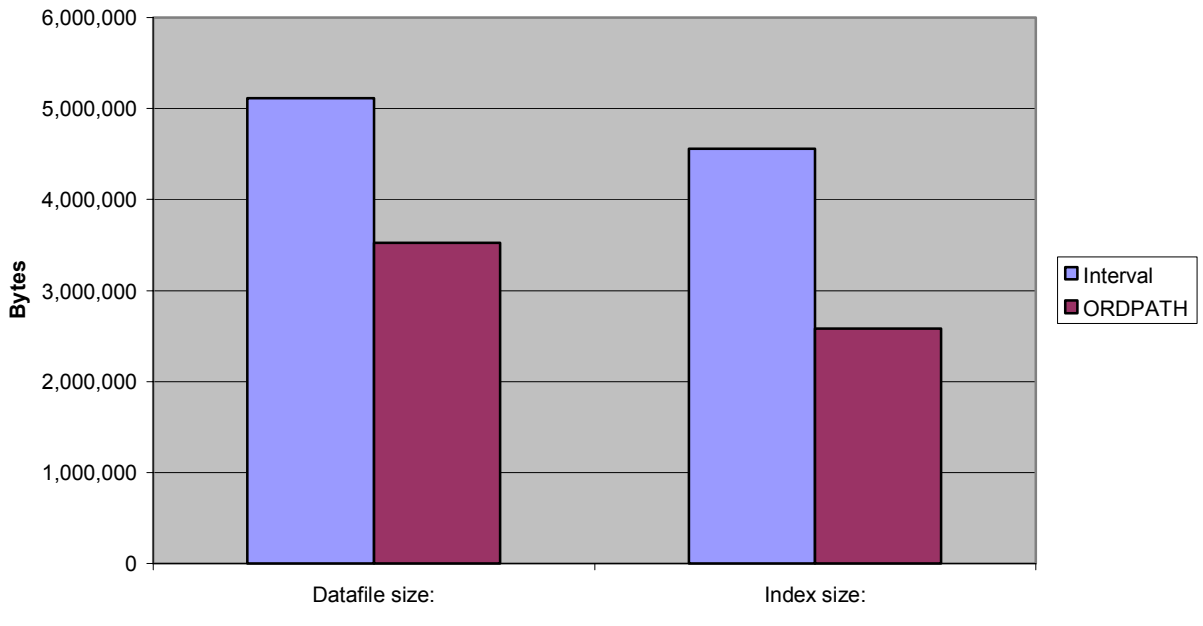
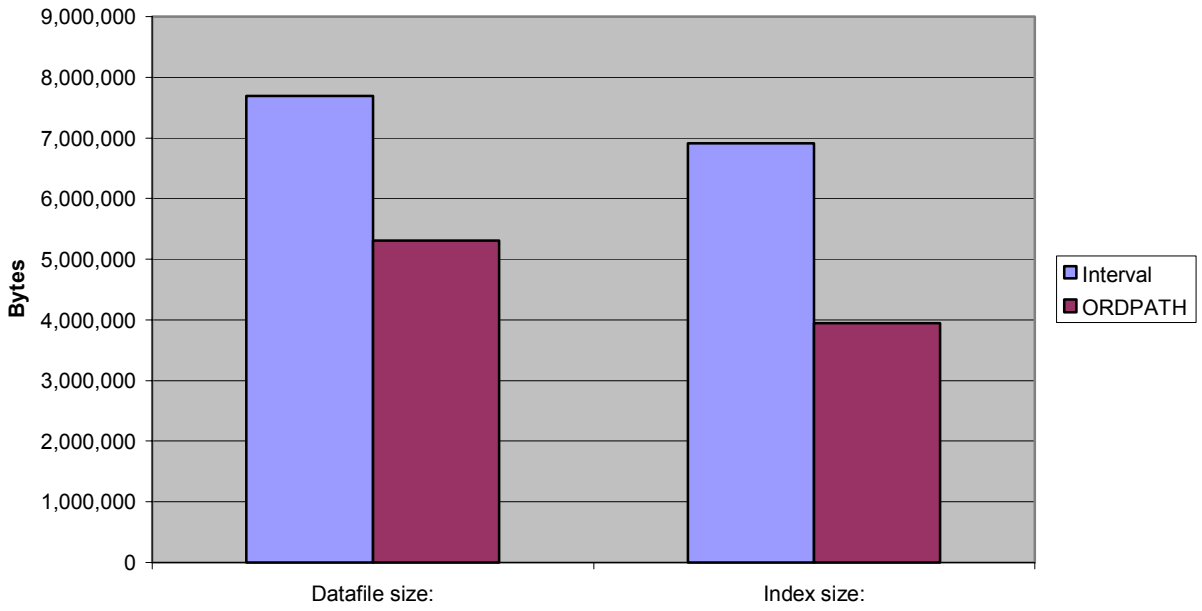


Figure 4-19: Encoding Size Comparison – XMark 0.03 Document



CHAPTER 5

ANALYSIS

5.1 Qualitative Analysis

Of the three Order-Encoding Methods, Local is the least useful, and offers no advantage aside from space-efficiency over ORDPATH. Accordingly, the more interesting comparison is between the Global (or Interval) and Dewey (or ORDPATH) strategies for document encoding. Global is ideal for situations where a query-mostly workload is expected and Dewey is best for a mixture of queries and updates. These same observations apply to Interval and ORDPATH Encodings in their basic form. Interval Encoding, however, can be enhanced to provide better support for insertions. These enhanced encodings, L-Trees and Nested Interval Encoding [6] [7], are beyond the scope of this research, but their support for insertions is apparently comparable to that of ORDPATH (especially Nested Interval Encoding).

It is difficult to assess whether ORDPATH or Interval Encoding would tend to produce smaller databases. The overhead introduced by each method is sensitive to data in use. ORDPATH's use of a 'Tag' column seems to be a win in this respect unless the document being shredded has very few reused tags and/or is mostly NULLs, in the (unlikely but possible) case of documents that consist primarily of content (instead of elements and attributes). ORDPATH's 'Node Type' column requires more space, but it also improves the performance of type-related queries. Finally, the use of NULL to designate the type of complex elements, which would be common for data-centric XML documents, could waste substantial space. Once again, however, this use of space should enhance query efficiency.

5.2 Quantitative Analysis

5.2.1 Shred Comparison

Shredding times were dramatically different for Interval and ORDPATH. This can be attributed to the fact that SAX was used in slightly different ways. ORDPATH used a TreeWalker to do its parsing because a sequential scan as performed by ContentHandler, which Interval used, was insufficient.

5.2.2 Query Performance Comparison

As per the data in Chapter 4, Interval had an average of 3.35 seconds for the XMark 0.01 queries, 9.85 seconds for the 0.02 queries, and 46.35 seconds for the 0.03 queries. As Figure 4-4 shows, queries 3, 9 and 10 were largely responsible for the difference. These queries are scales of magnitude more complex than the others due to their nested-loop structure. The XMark 0.02 file is only twice as large as the XMark 0.01 file; the average query time, however, was almost 3 times slower. The XMark 0.03 file is only 3 times larger than the XMark 0.01 file; however, the average query time was 14 times slower (see Figure 4-9). This can be attributed to the nested traversal-based nature of the queries (esp. queries 3, 9 and 10). Further support for this claim can be obtained by considering any of the queries that do not have a nested-loop structure. Take, for instance, query 2; the times for Interval encoding for XMark 0.01, 0.02 and 0.03 are 2.92s, 5.84s and 9.34s respectively, which is approximately a scaling of 2 and 3.

Figures 4-1 and 4-5 show a similar pattern for ORDPATH encoding. For instance, again take query 2; the times for ORDPATH encoding for XMark 0.01, 0.02 and 0.03 are 3.89s, 7.35s and 11.94s respectively, which is also a scaling of approximately 2 and 3. Also, the times for more complex queries such as query 9 are scaling comparably to Interval. However, Interval outperforms ORDPATH on select queries by an average of 5.47 times for XMark 0.01, 6.09 times for XMark 0.02, and 6.51 times for XMark 0.03. Overall, Interval outperforms ORDPATH by 6.38 times. This figure was calculated by taking the sum of the averages for both approaches and dividing (380.09s / 59.55s). If one extrapolates this out to larger file sizes, it would appear that Interval would continue to outperform ORDPATH by significantly increasing margins (see Figure 4-9). If queries 3, 9, and 10 were thrown out, the data would still favor Interval, but by a moderately smaller margin.

5.2.3 Insert Performance Comparison

The data in Figure 4-1 shows that ORDPATH, as expected, greatly outperforms Interval Encoding for inserts. When using amortized analysis, Interval turns out to have a running time on the order of O(c) for

a given document size although it has to renumber, on average, half the nodes. So, both algorithms are essentially O(C) for inserts (for a given document size) although that C is much greater for Interval.

The data in Figure 4-10 shows a roughly symmetric spread-out for Interval inserts as document sizes and number of inserts increase. However, Figure 4-11 shows an asymmetrical spread-out for ORDPATH—inserts for the largest document size follow a much steeper slope than for the smaller documents. This, the author suspects, is due to the lengthening of the ORDPATH itself as the number of nodes in the document increase. Since the ORDPATH field is the primary key for the ORDPATH encoding, it is slowing both queries and inserts (see Figures 4-9 and 4-11) possibly due to the growing size of the primary key index.

For the XMark 0.01 document, ORDPATH outperforms Interval by a factor of 53.22; for the 0.02 document, by a factor of 70.65; and for the 0.03 document, by a factor of 20.68. Thus, the margin is decreasing as document sizes increase. This is also most likely due to the lengthening of the primary key for the ORDPATH encoding and the resulting increase in index size and the increased use of CPU for translating the longer paths to and from bitstrings.

Overall, ORDPATH outperforms Interval for inserts by a factor of 31.16 times. This figure was calculated by taking the sum of the average insert times for the 0.01, 0.02 and 0.03 documents for both approaches and dividing (6771.04s / 217.33s). This yields the equation:

$$30.16 * numInserts - 5.38 * numSelects = 0$$

which describes the relation between the number of inserts and selects to achieve the perfect balance where both methods would perform equally well. One can use this equation to see if the ORDPATH approach is beneficial (for document sizes in the range tested). For example, consider a situation where a database gets 10 insert queries per hour. Here, one would need to have 56 ((30.16 * 10) / 5.38) select queries per hour to achieve the balance between the methods, and greater than 56 select queries to start seeing any net performance gain. So, the equilibrium ratio of inserts to selects for these two methods is approximately 1:5.6.

5.2.4 Heterogeneous Mix Comparison

According to the data in Figures 4-3 and 4-16, Interval outperformed ORDPATH for every mix of selects and inserts and for each file size. This is a rather surprising result given the analysis contained in sections 5.2.1-5.2.3. This is most likely due to the fact that a standard PC was used to run these tests with a limited amount of memory. Interval encoding involved a much greater amount of disk activity for the homogeneous tests, but during the heterogeneous tests, both Interval and ORDPATH involved near constant disk access. Running these tests on a production server would likely produce different and possibly more relevant results.

5.2.5 Encoding Size Comparison

According to the data presented in Figures 4-2, 4-17, 4-18 and 4-19, there is a considerable difference in the encoding sizes of Interval and ORDPATH encodings. The increase in data and index file sizes from 0.01 to 0.02 and 0.03 is consistent with the scale factors of 2 and 3, which the original document sizes adhere to. Overall, Interval data and index sizes are 1.58 times larger than ORDPATH sizes (29,169,340 bytes/ 18,448,092 bytes). Thus, Interval opts for a space-for-time tradeoff that helps it to outperform on queries.

CHAPTER 6

CONCLUSION

6.1 Final Conclusions

Each of the two methods considered has its particular weaknesses and strengths. According to the homogeneous tests, if less than 18% of an application's database operations (excluding updates which have no bearing on this research) are inserts, then it would not be beneficial to implement ORDPATH. However, the heterogeneous tests indicate that Interval will outperform ORDPATH up to a mix of 24% inserts and likely quite higher. One should have a good understanding of the type and form of the XML data to be shredded and its likely update pattern in order to piece together an implementation that works best for a given situation. Hybrids and combinations of the methods researched are possible and should be considered viable solutions.

6.2 Future Work

Future work in this area could include an XQuery implementation that utilizes the query-supporting libraries produced by this work. Enhancing the Interval Encoding with an insert-friendly approach, such as L-Tree, and doing more comparison between the encodings would also be of interest. It might also be beneficial to translate the Python code presented to a more efficient language such as C++ if the current performance is not satisfactory. Future work could also include running the benchmarks on other RDBMS such as Oracle or MS SQL Server. Additionally, tweaking database caching facilities in order to draw conclusions about caching effects on performance of the encoding approaches studied would also be of interest. It would also be interesting to see these tests run on a production-grade server with enough main memory to store the entire database. Finally, results for additional select/insert mixes between 75/25 and 25/75 would prove valuable.

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APPENDIX A

Complete Source Code Listings

A.1 Database Setup and Utility Functions

```
# ------------------------------------------------------------
# setup.py
# --------
#  Sets up or resets the databases and metatables for
#  xml-rdbms (intrval and ordpath).
# ------------------------------------------------------------

from getpass import *
import MySQLdb
import sys, errno, os

if __name__ == '__main__':
   def printUsage( errMsg = None ):
      if errMsg != None:
         print 'Error: %s' % errMsg
      print "Usage: setup.py mysqlUsername"
      sys.exit(1)

   if len( sys.argv ) != 2:
      printUsage()

   host = "127.0.0.1"
   user = sys.argv[1]
   passwd = getpass( 'Enter password: ' )
   port = 3306

   try:
      conn = MySQLdb.connect( host = host, user = user, passwd = passwd,
                                                          port = port )
   except MySQLdb.Error, e:
      print "Error %d: %s" % (e.args[0], e.args[1])
      sys.exit(1)

   cursor = conn.cursor()
   cursor.execute( 'DROP DATABASE IF EXISTS intrval;' )
   cursor.execute( 'CREATE DATABASE intrval;' )
   cursor.execute( 'DROP DATABASE IF EXISTS ordpath;' )
   cursor.execute( 'CREATE DATABASE ordpath;' )

   fh = open( '../ordpath/createMetatables.sql' )
   lines = fh.readlines()

   for line in lines:
      if line.strip():
         cursor.execute( line )

   cursor.execute( 'COMMIT;' )
   cursor.close()
   conn.close()
```

```
-------------------------------------------------------------------------------
-- createMetatables.sql
-------------------------------------------------------------------------------
-- Creates the prefix mapping table for determining what bitstring prefix is
-- to be used for each ordpath component value.
-------------------------------------------------------------------------------

USE ordpath;
DROP TABLE IF EXISTS prefixMapping;
CREATE TABLE prefixMapping( prefix VARCHAR(10), Li TINYINT, Omin INT, Omax
                            INT, PRIMARY KEY( prefix ));

INSERT INTO prefixMapping VALUES( '000000001', 20, -1118485, -69910 );
INSERT INTO prefixMapping VALUES( '00000001', 16, -69909, -4374 );
INSERT INTO prefixMapping VALUES( '0000001', 12, -4373, -278 );
INSERT INTO prefixMapping VALUES( '000001', 8, -277, -22 );
INSERT INTO prefixMapping VALUES( '00001', 4, -21, -6 );
INSERT INTO prefixMapping VALUES( '0001', 2, -5, -2 );
INSERT INTO prefixMapping VALUES( '001', 1, -1, 0 );
INSERT INTO prefixMapping VALUES( '01', 0, 1, 1 );
INSERT INTO prefixMapping VALUES( '10', 1, 2, 3 );
INSERT INTO prefixMapping VALUES( '110', 2, 4, 7 );
INSERT INTO prefixMapping VALUES( '1110', 4, 8, 23 );
INSERT INTO prefixMapping VALUES( '11110', 8, 24, 279 );
INSERT INTO prefixMapping VALUES( '111110', 12, 280, 4375 );
INSERT INTO prefixMapping VALUES( '1111110', 16, 4376, 69911 );
INSERT INTO prefixMapping VALUES( '11111110', 20, 69912, 1118487 );
```

```
# ------------------------------------------------------------
# util.py
# -------
# Utility file--contains supporting functions.
# ------------------------------------------------------------

import MySQLdb, sys
import hotshot, hotshot.stats
import time, os

DO_DETAILED_PROFILE = False

def getConnection():
   host = "127.0.0.1"
   user = "username"
   passwd = "password"
   port = 3306

   try:
      conn = MySQLdb.connect( host = host, user = user, passwd = passwd,
                                                              port = port )
   except MySQLdb.Error, e:
      print "Error %d: %s" % (e.args[0], e.args[1])
      sys.exit(1)
   return conn

def doProfileAndPrintStats( func, *args ):
   if DO_DETAILED_PROFILE:
      it_profile = hotshot.Profile( 'func profile' )
      if args[0]:
         time.clock()
         it_profile.runcall( func, args[0] )
      else:
         time.clock()
         it_profile.runcall( func )
      print '%s took %s wall seconds.' % ( func, time.clock() )
      it_profile.close()
      stats = hotshot.stats.load( 'func profile' )
      stats.strip_dirs()
      stats.sort_stats( 'file', 'cumulative' )
      stats.print_stats()
      os.remove( 'func profile' )
   else:
      if args[0]:
         time.clock()
         func( args[0] )
      else:
         time.clock()
         func()
      print '%s took %s wall seconds.' % ( func, time.clock() )

def setupForQuery( scriptName, expectedArgCount = 3,
                        variableNamesBeyondFirstThree = '' ):
   def printUsage( errMsg = None ):
      if errMsg != None:
         print 'Error: %s' % errMsg
      print "Usage: %s.py -i|o tablename %s" % ( scriptName,
```

```
                                    variableNamesBeyondFirstThree )
   sys.exit(1)

if len( sys.argv ) != expectedArgCount:
   printUsage()

tablename = sys.argv[2]

conn = getConnection()
cursor = conn.cursor()

if sys.argv[1] == '-i':
   from ilib import intervalTraverser
   cursor.execute( 'USE intrval;' )
   traverser = intervalTraverser( cursor, tablename )
elif sys.argv[1] == '-o':
   from olib import ordpathTraverser
   cursor.execute( 'USE ordpath;' )
   traverser = ordpathTraverser( cursor, tablename )
else:
   printUsage( "'%s' should be -i (for interval) or -o (for ordpath)" %
                                                          sys.argv[1] )

return traverser, conn, cursor
```

```
# ---------------------------------------------------------------
# mix.py
# ---------------------------------------------------------------
# Runs 100 database operations allowing specification of what
# percentage of those are to be selects (the remaining
# percentage will be inserts).  Queries are selected at random
# and run for both encodings.
#
#  Usage: mix.py tablename percentSelects
#
# ---------------------------------------------------------------

import sys, os
import math, random
import popen2

sys.path.append( '../shared' )
from util import *

if __name__ == '__main__':
   def printUsage():
      print 'Usage: mix.py tablename percentSelects'
      sys.exit(0)

   if len(sys.argv) != 3:
      printUsage()

   intervalQueries = []
   ordpathQueries = []

   def addRandomSelect():
      r = random.randint( 1, 20 )
      intervalQueries.append( 'q%s.py -i %s' % ( r, sys.argv[1] ))
      ordpathQueries.append( 'q%s.py -o %s' % ( r, sys.argv[1] ))

   def mix():
      numSelects = eval(sys.argv[2])
      if numSelects < 50:
         print 'Number of selects must be greater than 50'
         printUsage()

      numSelectsPerInsert = math.floor( \
            numSelects / ( 100.0 - numSelects )).__int__()

      for i in range( 100 - numSelects ):
         # run one insert
         intervalQueries.append( 'insert.py -i %s 1' % ( sys.argv[1] ))
         ordpathQueries.append( 'insert.py -o %s 1' % ( sys.argv[1] ))

         # run some selects
         for j in range( numSelectsPerInsert ):
            addRandomSelect()

      for i in range( 100 - len( intervalQueries )):
         addRandomSelect()
```

```
def intervalMix():
   for q in intervalQueries:
      print 'Running: %s' % q
      os.popen( q )

def ordpathMix():
   for q in ordpathQueries:
      print 'Running: %s' % q
      os.popen( q )

mix()
doProfileAndPrintStats( intervalMix, None )
doProfileAndPrintStats( ordpathMix, None )
```

A.2 Shredders

A.2.1 Interval Shredder

```
# ------------------------------------------------------------
# ishred.py
# -------
# The interval method XML document shredder.
# ------------------------------------------------------------

import re
import sys
import threading

# support for SAX-based input parsing
#
from xml.sax import make_parser
from xml.sax.handler import feature_namespaces
from xml.sax import saxutils

sys.path.append( '../shared' )
from util import *

# ------------------------------------------------------------------
# Helper classes
# ------------------------------------------------------------------

class contentHandler( saxutils.DefaultHandler ):
   ELEMENT_NODE_TYPE = 1
   ATTRIBUTE_NODE_TYPE = 2
   COMMENT_NODE_TYPE = 3
   VALUE_NODE_TYPE = 4
   insertedTotal = 0
   def __init__(self, conn, tablename):
      self.conn = conn
      self.cursor = self.conn.cursor()
      self.tablename = tablename
      self.curLVal = 0
      self.curDepth = 1
      self.p = re.compile( "'" ) # for replacing ' with '' in content

   def createTimer(self):
      self.t = threading.Timer( 7.0, self.printStatus )
      self.t.start()

   def printStatus(self):
      print 'total inserted: %s' % self.insertedTotal
      self.createTimer()

   def startDocument(self):
      self.cursor.execute( "USE intrval;" )
      self.cursor.execute( "DROP TABLE IF EXISTS " + self.tablename + ";" )
      self.cursor.execute( "CREATE TABLE " + self.tablename + \
         "( s TEXT, l INT, r INT, nodeType INT, depth INT, PRIMARY KEY( l ),
                              INDEX( nodeType ), INDEX( depth ));" )
```

```
def endDocument(self):
   self.cursor.execute( "COMMIT;" )
   self.cursor.close()
   self.conn.close()

def insertRecord( self, sval, lval, rval, nodeType, depth ):
   self.insertedTotal += 1
   self.cursor.execute("INSERT INTO %s VALUES('%s', %s, %s, %s, %s );" % \
      ( self.tablename, sval, lval, rval, nodeType, depth ))

def startElement(self, name, attrs):
   self.insertRecord( name, self.curLVal, 0, self.ELEMENT_NODE_TYPE,
                                        self.curDepth )
   self.curLVal += 1

   for k,v in zip( attrs.keys(), attrs.values() ):
      # insert k, l, l+3, ATTRIBUTE_NODE_TYPE
      self.insertRecord( k, self.curLVal, self.curLVal + 3,
                          self.ATTRIBUTE_NODE_TYPE, self.curDepth )
      self.curLVal += 1

      # insert v, l, l+1, VALUE_NODE_TYPE
      self.insertRecord( v, self.curLVal, self.curLVal + 1,
                                 self.VALUE_NODE_TYPE, self.curDepth )
      self.curLVal += 3
   self.curDepth += 1

def endElement(self, name):
   self.cursor.execute( "SELECT MAX(l) FROM " + self.tablename + \
      " WHERE r = 0 AND nodeType = %s;" % self.ELEMENT_NODE_TYPE )
   lval = self.cursor.fetchone()[0]

   if lval == None:
      print "Error: couldn't find start element tag"
      sys.exit(1)

   self.cursor.execute( "UPDATE " + self.tablename + " SET r = " + \
      str( self.curLVal ) + " WHERE l = " + str( lval ) + ";" )
   self.curLVal += 1
   self.curDepth -= 1

def characters(self, content):
   if content.strip():
      try:
         self.insertRecord( content, self.curLVal, self.curLVal + 1,
                                 self.VALUE_NODE_TYPE, self.curDepth )
      except MySQLdb.Error, e:
         if e.args[0] == 1064:
            self.insertRecord( self.p.sub( '\'\'', content ),
                                 self.curLVal, self.curLVal + 1,
                                 self.VALUE_NODE_TYPE, self.curDepth )
         else:
            print "Error %d: %s" % (e.args[0], e.args[1])
      self.curLVal += 2
```

```
    def error(self, e):
        print "Error: %r" % e
        sys.exit(1)

    def fatalError(self, e):
        print "Fatal error: %r" % e
        sys.exit(1)

if __name__ == '__main__':
    import sys, errno, os

    if len( sys.argv ) != 3:
        print "Usage: ishred.py filename tablename"
        sys.exit(1)

    try:
        f = file( sys.argv[1] )
    except Exception, err:
        print "Error: cannot open file: " + sys.argv[1]
        sys.exit(1)

    def doShred():
        conn = getConnection()

        parser = make_parser()
        parser.setFeature(feature_namespaces, 0)

        ch = contentHandler( conn, sys.argv[2] )
        parser.setContentHandler( ch )
        parser.parse( f )


    doProfileAndPrintStats( doShred, None )
```

A.2.2 ORDPATH Shredder and Supporting Classes

```
# ------------------------------------------------------------
# ordpath.py
# -------
# Represents an ordpath.  Provides encoding to/from bitstring
# and hexstring representations.  Provides ORDPATH manipulation
# routines.
# ------------------------------------------------------------

from stringConverter import *
import copy

class ordPath(object):
   def __init__(self, cursor):
      self.list = []                # the ordpath as list
      self.string = ''              # the ordpath as bitstring
      self.cursor = cursor
      self.sc = stringConverter()

   def __str__(self):
      retVal = ''
      for i in self.list:
         retVal = retVal + '%d.' % i
      retVal = retVal[:-1]
      return retVal

   def __copy__(self):
      newCopy = ordPath( self.cursor )
      newCopy.list = copy.copy( self.list )
      newCopy.string = copy.copy( self.string )
      newCopy.sc = self.sc
      return newCopy

   def getListRepr(self):
      return self.list

   def getBitstringRepr(self):
      return self.string

   def getHexstringRepr(self):
      return self.sc.bitstring2hexstring( self.string )
   def setFromHexstring( self, hexstring ):
      self.string, self.list = self.decodeOrdpath( hexstring )
   hexstring = property( getHexstringRepr, setFromHexstring )

   def append(self, n):
      """appends new component with value of n"""
      self.list.append(n)
      self.string = self.string + self.encodeOrdpathComponent(n)

   def dropLastComponent(self):
      """drops the last component of the ordpath (regardless of what
         components precede it)"""
      assert( len(self.list) >= 1 )
```

```
      self.string = \
            self.string[ :-len(self.encodeOrdpathComponent( self.list[-1] ))]
      self.list = self.list[:-1]

   def dropLastComponentIncludeEvens(self):
      """drops all components from end of ordpath up
         to next to last odd component"""
      assert( len(self.list) >= 1 )
      assert( self.list[-1] % 2 != 0 ) # last component must be odd
      assert( self.list[0] % 2 != 0 )  # first component must be odd
      i = 2
      l = copy.copy( self.list )
      self.dropLastComponent()
      while( l[-i] % 2 == 0 ):
         self.dropLastComponent()
         i += 1

   def incrementLastComponent(self, n):
      """increments last component of ordpath by n"""
      assert( self.list != [] )
      n = self.list[-1] + n
      self.dropLastComponent()
      self.append(n)

   def encodeOrdpathComponent( self, n ):
      nstr = str(n)
      self.cursor.execute( """SELECT prefix, Li, Omin FROM prefixMapping
                              WHERE Omin <= %s AND Omax >= %s;""" % \
                              (nstr,nstr))

      res = self.cursor.fetchone()
      bitstring = res[0]

      Li = res[1]
      Omin = res[2]

      On = n - Omin
      On = '%x' % On
      On = self.sc.hexstring2bitstring( On ).lstrip( '0' )

      l = len(On)
      if l < Li:
         On = ( "0" * (Li - l)) + On

      bitstring += On
      return bitstring

   def encodeOrdpath( self, ordpath ):
      """returns encoded bitstring representation of ordpath.
         ordpath is a list of numbers [a, b, c, d] representing a.b.c.d"""
      bitstring = ""

      for n in ordpath:
         bitstring += self.encodeOrdpathComponent( n )

      return bitstring
```

```
    def decodeOrdpath( self, hexEncodedOrdpath ):
        if len( hexEncodedOrdpath ) < 1:
            raise ValueError('Error: hexstring must be at least one char long' )
        string = self.sc.hexstring2bitstring( hexEncodedOrdpath ).rstrip( '0' )
        list = []

        i = 0
        l = len( string )
        while( True ):
            j, comp = self.decodeOrdpathComponent( string[i:] )
            list.append( comp )
            i = i + j
            if i >= l:
                break
        return string, list

    def decodeOrdpathComponent( self, bitstring ):
        firstBit = bitstring[0]
        i = 1
        l = len( bitstring )
        while( i < l and bitstring[i] == firstBit ):
            i += 1

        i = i + 1
        self.cursor.execute( """SELECT Li, Omin FROM prefixMapping WHERE prefix
                                        = '%s';""" % bitstring[:i] )
        res = self.cursor.fetchone()
        Li = res[0]
        Omin = res[1]

        if i + Li > l:
            raise ValueError( 'Malformed ordpath.  Expecting another Oi ' + \
                              'component after %s' % Li )

        compVal = self.sc.bitstring2hexstringRtoL( bitstring[ i:Li+i ] )
        if compVal == '':
            compVal = '0'
        return Li + i, int( compVal, 16 ) + Omin

class tagDict(object): # TODO: make singleton ???
    def __init__(self):
        self.tagDict = {}
        self.curTag = 1

    def getTag( self, itemName ):
        if not self.tagDict.has_key( itemName ):
            self.tagDict[ itemName ] = str( self.curTag )
            self.curTag += 1
        return self.tagDict[ itemName ]

    def saveToDatabase( self, cursor, tablename ):
        for i in self.tagDict.items():
            cursor.execute('INSERT INTO '+tablename+" VALUES( '%s', %s );" % i )
```

```
# ------------------------------------------------------------
# stringConverter.py
# ------------------
# Converts hexstrings to bitstrings and vice versa.
# ------------------------------------------------------------

class stringConverter( object ):
   def __init__(self):
      try:
         if stringConverter.bin2hex != None and \
            stringConverter.hex2bin != None: pass
      except:
         # initialize lookup tables
         stringConverter.bin2hex = {
            # Given a 4-char bitstring, return the corresponding 1-char
            # hexstring
            "0000": "0", "0001": "1", "0010": "2", "0011": "3",
            "0100": "4", "0101": "5", "0110": "6", "0111": "7",
            "1000": "8", "1001": "9", "1010": "a", "1011": "b",
            "1100": "c", "1101": "d", "1110": "e", "1111": "f",}

         stringConverter.hex2bin = {}
         for( bin, hex ) in stringConverter.bin2hex.items():
            stringConverter.hex2bin[ hex ] = bin

   def bitstring2hexstring( b ):
      """Take bitstring 'b' and return the corresponding l->r hexstring."""
      result = ""
      l = len(b)
      if l % 4:
         b = b + "0" * (4-(l%4))
      for i in range(0, len(b), 4):
         result = result + stringConverter.bin2hex[b[i:i+4]]
      return result
   bitstring2hexstring = staticmethod( bitstring2hexstring )

   def bitstring2hexstringRtoL( b ):
      """Take bitstring 'b' and return the corresponding r->l hexstring."""
      result = ""
      l = len(b)
      if l % 4:
         b = ("0" * (4-(l%4))) + b
      l = len(b)
      for j in [l - i for i in range(0, l, 4)]:
         result = stringConverter.bin2hex[b[j-4:j]] + result
      return result
   bitstring2hexstringRtoL = staticmethod( bitstring2hexstringRtoL )

   def hexstring2bitstring( h ):
      """Take hexstring 'h' and return the corresponding l->r bitstring."""
      result = ""
      for c in h:
         result = result + stringConverter.hex2bin[c]
      return result
   hexstring2bitstring = staticmethod( hexstring2bitstring )
```

```
# ------------------------------------------------------------
# oshred.py
# -------
# The ORDPATH method XML document shredder.
# ------------------------------------------------------------

import re
import copy
import sys, errno, os
import xml.dom
from xml.dom.ext.reader import Sax2
from xml.dom.NodeFilter import NodeFilter
from ordpath import *

sys.path.append( '../shared' )
from util import *

# ------------------------------------------------------------
# Helper functions
# ------------------------------------------------------------

p = re.compile( "'" ) # for replacing ' with '' in content
curDepth = 0

def insertRecord( ordpath, tag, nodeType, value ):
   def insertRec( val ):
      s = "INSERT INTO %s VALUES( '%s', %s, %s, '%s', %s );" % \
        (tablename, ordpath.getHexstringRepr(), tag, nodeType, val, curDepth)
      cursor.execute( s )

   value = value.strip()
   try:
      insertRec( value )
   except MySQLdb.Error, e:
      if e.args[0] == 1064:
         insertRec( p.sub( '\'\'', value ))
      else:
         print "Error %d: %s" % ( e.args[0], e.args[1] )

def processElement( name, attrs, content, ordpath, tagdict ):
   if content == None:
      content = 'NULL'

   # insert ordpath, tag, 1 (Element), content
   insertRecord( ordpath, tagdict.getTag( name ), 1, content )

   if attrs:
      ordpath.append( -1 )
      for v in attrs.values():
         ordpath.incrementLastComponent( 2 )
         # insert ordpath, tag, 2 (Attribute), value
         insertRecord( ordpath, tagdict.getTag(v.nodeName), 2, v.nodeValue )

def processContent( content, ordpath ):
   insertRecord( ordpath, 'NULL', 4, content ) # 4 represents content
```

```
def processComment( comment, ordpath ):
   insertRecord( ordpath, 'NULL', 3, comment ) # 3 represents comment

def processNode( walker, ordpath, tagdict ):
   global curDepth
   curNode = walker.currentNode
   attrs = curNode._get_attributes()
   childIndices = filter.getAcceptedChildrenIndices( curNode )
   numChildren = len( childIndices )

   curDepth += 1
   if checkComment and curNode.__class__ == xml.dom.Comment.Comment:
      assert( numChildren == 0 )
      assert( not attrs )
      processComment( curNode.nodeValue, ordpath )
   elif curNode.__class__ == xml.dom.Text.Text:
      assert( numChildren == 0 )
      assert( not attrs )
      processContent( curNode.nodeValue, ordpath )
   elif not attrs and numChildren == 1 and \
      curNode.childNodes[ childIndices[ 0 ]].__class__ == xml.dom.Text.Text:
      # simple element node (e.g., <element>text</element>)
      processElement( curNode.nodeName, attrs, walker.nextNode().nodeValue,
                              ordpath, tagdict )
   elif not attrs and numChildren == 0:
      # simple empty element node (e.g., <element></element>
      processElement( curNode.nodeName, attrs, None, ordpath, tagdict )
   else:
      # non-simple element node
      processElement( curNode.nodeName, attrs, None, ordpath, tagdict )
      if numChildren:
         if not attrs:
            ordpath.append( -1 )
         for i in range( numChildren ):
            if walker.nextNode():
               ordpath.incrementLastComponent( 2 )
               processNode( walker, ordpath, tagdict )
            else:
               raise ValueError("""walker.nextNode() returned False when
                                   expecting child nodes.""" )
         ordpath.dropLastComponent()
      elif attrs:
         ordpath.dropLastComponent()
   curDepth -= 1

class filter(object):
   def getAcceptedChildrenIndices( node ):
      indices = []
      for i in range( len( node.childNodes )):
         if filter.acceptNode( node.childNodes[i] ) == \
                                   NodeFilter.FILTER_ACCEPT:
            indices.append( i )
      return indices
   getAcceptedChildrenIndices = staticmethod( getAcceptedChildrenIndices )
   def acceptNode( node ):
      if checkProcessingInstruction: # global variable indicating presence of
                                     # xml.dom.ProcessingInstruction
```

```
            if node.__class__ == \
                    xml.dom.ProcessingInstruction.ProcessingInstruction:
               return NodeFilter.FILTER_REJECT
            if node.__class__ == xml.dom.Text.Text:
               if not node.nodeValue.strip():
                  return NodeFilter.FILTER_REJECT
            return NodeFilter.FILTER_ACCEPT
         acceptNode = staticmethod( acceptNode )

if __name__ == '__main__':
   if len( sys.argv ) != 3:
      print "Usage: oshred.py filename tablename"
      sys.exit(1)

   try:
      f = file( sys.argv[1] )
   except Exception, err:
      print "Error: cannot open file: " + sys.argv[1]
      sys.exit(1)

   def doShred():
      global checkProcessingInstruction, checkComment, cursor, tablename
      conn = getConnection()

      # initialize variables
      reader = Sax2.Reader()
      doc = reader.fromStream( f )
      dirXmlDom = dir( xml.dom )
      checkProcessingInstruction = \
            dirXmlDom.__contains__('ProcessingInstruction')
      checkComment = dirXmlDom.__contains__( 'Comment' )
      cursor = conn.cursor()
      tablename = sys.argv[2]
      tagdict = tagDict()
      ordpath = ordPath( cursor )
      walker = doc.createTreeWalker( doc.documentElement,
                                 NodeFilter.SHOW_ALL, filter, 0 )

      cursor.execute( "USE ordpath;" )
      cursor.execute( "DROP TABLE IF EXISTS " + tablename + ";" )
      cursor.execute( "DROP TABLE IF EXISTS " + tablename + "_tags" + ";" )
      cursor.execute( """CREATE TABLE %s( ordpath TEXT, tag INT,
                         nodeType INT, value TEXT, depth INT,
                         PRIMARY KEY( ordpath(255)),
                         INDEX( depth ),
                         INDEX( nodeType ));""" % tablename )
      cursor.execute( """CREATE TABLE %s_tags( tagName TEXT, tagNum INT,
                         PRIMARY KEY( tagNum ),
                         UNIQUE( tagName(255)));""" % tablename )

      ordpath.append( 1 )
      processNode( walker, ordpath, tagdict )
      tagdict.saveToDatabase( cursor, tablename + "_tags" )
      cursor.execute( "COMMIT;" )
      cursor.close()
      conn.close()
   doProfileAndPrintStats( doShred, None )
```

A.3 Abstract Base Traverser Class

```
# ------------------------------------------------------------
# abstractTraverser.py
# --------------------
# The application programming interface to support queries
# against underlying shredded XML documents.  Classes to
# support querying specific shredding methods should
# implement this interface.
# ------------------------------------------------------------

class abstractTraverser( object ):

   ELEMENT_NODE_TYPE = 1
   ATTRIBUTE_NODE_TYPE = 2
   COMMENT_NODE_TYPE = 3
   VALUE_NODE_TYPE = 4
   ATTR_VALUE_NODE_TYPE = 5 # used only to distinguish between content and
                            # attribute values types for
                            # getDescendantsByNameAndNodeType and
                            # getNthGenerationDescendantsByNameAndNodeType

   def validateXPath( xpath ):
      if len(xpath) < 2:
         return False, 'Must be at least 2 characters long.'
      if xpath[0] != '/':
         return False, "Must begin with '/'"
      return True, ''
   validateXPath = staticmethod( validateXPath )

   def getNodeAtXPath( self, xpath ):
      res, msg = self.validateXPath( xpath )
      if not res:
         raise ValueError( 'Error: Invalid XPath: %s: %s.' % ( xpath, msg ))

      levels = xpath.split( '/' )[2:]
      curNode = self.getRootNode()

      for l in [ k for k in levels if k != '']:
         if curNode == None:
            break
         curNode = self.getFirstChildByName( curNode, l )
      return curNode

   # derived classes can supply a better version of this
   def getFirstChildByName( self, node, name ):
      child = self.getFirstChild( node )
      while( child and self.getNodeName( child ) != name ):
         child = self.getNextSiblingByName( child, name )
      return child

   # derived classes can supply a better version of this
   ## 1-based ##
   def getNthChildByName( self, node, n, name ):
      count = 0
      child = self.getFirstChildByName( node, name )
```

```
      while( child != None ):
         count += 1
         if count == n:
            break
         child = self.getNextSiblingByName( child, name )
      return child

   # derived classes can supply a better version of this
   def getLastChildByName( self, node, name ):
      child = self.getLastChild( node )
      while( child != None ):
         if self.getNodeName( child ) == name:
            break
         child = self.getPreviousSibling( child )
      return child

   # derived classes can supply a better version of this
   def getChildrenByName( self, node, name ):
      retVal = []
      child = self.getFirstChildByName( node, name )
      while( child != None ):
         retVal.append( child )
         child = self.getNextSiblingByName( child, name )
      return retVal

   # derived classes may have ability to define a better version of this.
   def getFirstChildWithAttributeValue(self, node, child, attribute, value):
      curChild = self.getFirstChildByName( node, child )
      while( curChild and
            self.getNodeAttributeValue( curChild, attribute ) != value ):
         curChild = self.getNextSiblingByName( curChild, child )
      return curChild

   # derived classes can define a better version of this.
   def getNextSiblingByName( self, node, name ):
      curSibling = self.getNextSibling( node )
      while( curSibling and self.getNodeName( curSibling ) != name ):
         curSibling = self.getNextSibling( curSibling )
      return curSibling

   def insertSimpleNode( self, leftSibling, newNode ): abstract
   def getRootNode( self ): abstract
   def getRandomNonrootNode( self ): abstract
   def getNodeType( self, node ): abstract
   def getNodeName( self, node ): abstract
   def getNodeText( self, node ): abstract
   def getNodeAttributeValue( self, node, attribute ): abstract
   def getParent( self, node ): abstract
   def getNextSibling( self, node ): abstract
   def getPreviousSibling( self, node ): abstract
   def getFirstChild( self, node ): abstract
   def getLastChild( self, node ): abstract
   def getDescendants( self, node ): abstract
   def getDescendantsContainingText( self, node, text ): abstract
   def getDescendantsByNameAndNodeType( self, node, name, nodeType ):
      abstract
   def getNthGenerationDescendantsByNameAndNodeType( self, node, n, name,
```

```
                                                        nodeType ):
    abstract
def getAncestors( self, node ): abstract
            def compareNodes( self, node1, node2 ): abstract
```

A.4 Method-Specific Derivations of AbstractTraverser

A.4.1 Interval Implementation

```
# ------------------------------------------------------------
# ilib.py
# -------
# Interval-specific implementation of abstractTraverser.
# ------------------------------------------------------------

import MySQLdb
from abstractTraverser import *

# ------------------------------------------------------------------
# Helper functions
# ------------------------------------------------------------------

def createRootOperator( cursor, tablename ):
   cursor.execute( 'DROP VIEW IF EXISTS %s_root;' % tablename )
   s = """CREATE VIEW %s_root AS
            SELECT u.s as s, u.l as l, u.r as r
            FROM %s u
            WHERE NOT EXISTS(
              SELECT *
              FROM %s v
              WHERE v.l < u.l AND u.r < v.r );""" % \
                        (tablename, tablename, tablename)
   cursor.execute( s )

def createChildrenOperator( cursor, tablename ):
   cursor.execute( 'DROP VIEW IF EXISTS %s_children;' % tablename )
   s = """CREATE VIEW %s_children AS
            SELECT u.s as s, u.l as l, u.r as r
            FROM %s u
            WHERE EXISTS(
              SELECT *
              FROM %s v
              WHERE v.l < u.l AND u.r < v.r );""" % \
                                  (tablename, tablename, tablename)
   cursor.execute( s )

# ----------------------
# Tree-traversal
# ----------------------
class intervalTraverser( abstractTraverser ):
   S_INDEX = 0
   L_INDEX = 1
   R_INDEX = 2
   NODE_TYPE_INDEX = 3
   DEPTH_INDEX = 4

   def __init__( self, cursor, tablename ):
      self.cursor = cursor
      self.tablename = tablename

   def compareNodes( self, node1, node2 ):
```

```
   return node1[self.L_INDEX].__cmp__( node2[self.L_INDEX] )

def insertSimpleNode( self, leftSibling, node ):
   self.cursor.execute( """UPDATE %s SET l = l + 2, r = r + 2 WHERE l > %s
                           ORDER BY l DESC;""" % \
       ( self.tablename, leftSibling[self.R_INDEX] ))
   self.cursor.execute("INSERT INTO %s VALUES( '%s', %s, %s, %s, %s);" % \
       ( self.tablename, node, leftSibling[self.R_INDEX] + 1,
          leftSibling[self.R_INDEX] + 2,
          self.ELEMENT_NODE_TYPE, leftSibling[self.DEPTH_INDEX] ))
   parent = self.getParent( leftSibling )
   while( parent ):
      self.cursor.execute( "UPDATE %s SET r = r + 2 WHERE l = %s;" % \
          ( self.tablename, parent[self.L_INDEX] ))
      parent = self.getParent( parent )
   self.cursor.execute( "COMMIT;" )

def getRootNode( self ):
   self.cursor.execute( "SELECT * FROM %s WHERE l = 0;" % self.tablename )
   return self.cursor.fetchone()

def getRandomNonrootNode( self ):
   self.cursor.execute( """SELECT * FROM %s WHERE nodeType = %s AND l > 0
                           ORDER BY RAND() LIMIT 1;""" % \
                           ( self.tablename, self.ELEMENT_NODE_TYPE ))
   return self.cursor.fetchone()

def getNodeName( self, node ):
   return node[self.S_INDEX]

def getNodeText( self, node ):
   if node == None: return [""]
   self.cursor.execute( """SELECT * FROM %s WHERE l > %s AND l < %s AND
                           depth = %s AND nodeType = %s;""" % \
       ( self.tablename, node[self.L_INDEX], node[self.R_INDEX],
         node[self.DEPTH_INDEX] + 1, self.VALUE_NODE_TYPE ))
   res = self.cursor.fetchall()
   return [x[self.S_INDEX] for x in res]

def getNodeAttributeValue( self, node, attribute ):
   attrIndex = node[self.L_INDEX] + 1
   while 1:
      self.cursor.execute("SELECT * FROM %s WHERE l=%s AND nodeType=%s;" %
          ( self.tablename, attrIndex, self.ATTRIBUTE_NODE_TYPE ))
      res = self.cursor.fetchone()
      if not res: return None
      if res[self.S_INDEX] == attribute:
         self.cursor.execute( "SELECT * FROM %s WHERE l = %s;" % \
                           ( self.tablename, res[self.L_INDEX] + 1 ))
         res = self.cursor.fetchone()
         return res[self.S_INDEX]
      attrIndex += 4

def getNextSibling( self, node ):
   self.cursor.execute( "SELECT * FROM %s WHERE l=%s AND nodeType=%s;" % \
       ( self.tablename, node[self.R_INDEX] + 1, self.ELEMENT_NODE_TYPE ))
   res = self.cursor.fetchone()
```

```
    if res == None:
       # try skipping a VALUE node (text content for parent element) to
       # find next sibling
       self.cursor.execute( """SELECT t.* FROM(
                                  SELECT * FROM %s WHERE l = %s AND
                                  nodeType = %s ) t """ % \
                             ( self.tablename, node[self.R_INDEX] + 3,
                                  self.ELEMENT_NODE_TYPE ) + \
           """WHERE EXISTS(
                SELECT * FROM %s
                      WHERE l = t.l - 2 AND nodeType = %s );""" % \
           ( self.tablename, self.VALUE_NODE_TYPE ))
       res = self.cursor.fetchone()
    return res

 def getNextSiblingByNameAlt( self, node, name ):
    self.cursor.execute( """SELECT * FROM %s
                            WHERE l > %s AND nodeType = %s AND depth = %s
                            AND s = '%s' ORDER BY l LIMIT 1;""" % \
        ( self.tablename, node[self.L_INDEX], self.ELEMENT_NODE_TYPE,
                                       node[self.DEPTH_INDEX], name ))
    return self.cursor.fetchone()

 def getPreviousSibling( self, node ):
    self.cursor.execute( """SELECT * FROM %s
                            WHERE r = %s AND nodeType = %s;" % \
       ( self.tablename, node[self.L_INDEX] - 1 , self.ELEMENT_NODE_TYPE ))
    res = self.cursor.fetchone()
    if res == None:
       # try skipping a VALUE node (text content for the parent element) to
       # find prev sibling
       self.cursor.execute( """SELECT t.* FROM(
                                  SELECT * FROM %s
                                    WHERE r=%s AND nodeType = %s ) t""" % \
                             ( self.tablename, node[self.L_INDEX] - 3,
                                       self.ELEMENT_NODE_TYPE ) + \
           """ WHERE EXISTS(
                SELECT * FROM %s WHERE l=t.l+2 AND nodeType = %s );""" % \
                      ( self.tablename, self.VALUE_NODE_TYPE ))
    return res

 def getFirstChild( self, node ):
    sql = """SELECT * FROM %s
                WHERE l > %s AND l < %s AND nodeType = %s
                ORDER BY l LIMIT 1;""" % \
                      ( self.tablename, node[self.L_INDEX],
                            node[self.R_INDEX], self.ELEMENT_NODE_TYPE )
    self.cursor.execute( sql )
    return self.cursor.fetchone()

 def getFirstChildByName( self, node, name ):
    self.cursor.execute( "SELECT * FROM %s " % self.tablename + \
       """ WHERE l > %s AND l < %s AND nodeType = %s AND s = '%s'
                AND depth = %s ORDER BY l LIMIT 1;""" % \
                ( node[self.L_INDEX], node[self.R_INDEX],
          self.ELEMENT_NODE_TYPE, name, node[self.DEPTH_INDEX] + 1 ))
    return self.cursor.fetchone()
```

```
def getNthChildByName( self, node, n, name ):
   self.cursor.execute( "SELECT * FROM %s " % self.tablename + \
      """ WHERE l > %s AND l < %s AND nodeType = %s AND s = '%s'
               AND depth = %s ORDER BY l LIMIT 1 OFFSET %s;""" % \
      ( node[self.L_INDEX], node[self.R_INDEX], self.ELEMENT_NODE_TYPE,
                    name, n - 1, node[self.DEPTH_INDEX] + 1 ))
   return self.cursor.fetchone()

def getParent( self, node ):
   self.cursor.execute( "SELECT * FROM %s WHERE l = " % self.tablename + \
       """( SELECT MAX(l) FROM %s WHERE l <= %s AND depth = %s
                    AND nodeType = %s );" % \
       ( self.tablename, node[self.L_INDEX], node[self.DEPTH_INDEX] - 1,
                                  self.ELEMENT_NODE_TYPE))
   return self.cursor.fetchone()

def getDescendants( self, node ):
   self.cursor.execute( "SELECT * FROM %s WHERE l >= %s AND l <= %s;" % \
       ( self.tablename, node[self.L_INDEX], node[self.R_INDEX] ))
   return self.cursor.fetchall()

def getDescendantsContainingText( self, node, text ):
   self.cursor.execute( """SELECT * FROM %s WHERE l >= %s AND l <= %s
                                  AND s LIKE '%%%s%%';""" % \
       ( self.tablename, node[self.L_INDEX], node[self.R_INDEX], text ))
   return self.cursor.fetchall()

def getDescendantsByNameAndNodeType( self, node, name, nodeType ):
   if nodeType == self.ATTR_VALUE_NODE_TYPE:
      nodeType = self.VALUE_NODE_TYPE
   self.cursor.execute( """SELECT * FROM %s WHERE l > %s AND l < %s
                                  AND s = '%s' AND " % \
       ( self.tablename, node[self.L_INDEX], node[self.R_INDEX], name) + \
         "nodeType = %s;" % nodeType )
   return self.cursor.fetchall()

def getNthGenerationDescendantsByNameAndNodeType( self, node, n, name,
                                                              nodeType ):
   if nodeType == self.ATTR_VALUE_NODE_TYPE:
      nodeType = self.VALUE_NODE_TYPE
   self.cursor.execute( "SELECT * FROM %s " % self.tablename + \
       """ WHERE l > %s AND l < %s AND nodeType = %s AND s = '%s'
               AND depth = %s;" % \
       ( node[self.L_INDEX], node[self.R_INDEX], nodeType, name,
                                     node[self.DEPTH_INDEX] + n ))
   return self.cursor.fetchall()

def getLastChild( self, node ):
   self.cursor.execute("SELECT * FROM %s WHERE r=%s AND nodeType=%s;" % \
       ( self.tablename, node[self.R_INDEX] - 1, self.ELEMENT_NODE_TYPE ))
   return self.cursor.fetchone()

def getLastChildByName( self, node, name ):
   self.cursor.execute("SELECT * FROM %s WHERE l=" % (self.tablename) + \
                       """( SELECT MAX(l) FROM %s WHERE r < %s
                           AND nodeType = %s AND s = '%s' );" % \
```

```
        (self.tablename,node[self.R_INDEX], self.ELEMENT_NODE_TYPE, name ))
    return self.cursor.fetchone()

def getChildrenByName( self, node, name ):
    self.cursor.execute( """SELECT * FROM %s WHERE l > %s AND l < %s
                        AND nodeType = %s AND depth = %s AND s = '%s';" % \
        ( self.tablename, node[self.L_INDEX], node[self.R_INDEX],
                self.ELEMENT_NODE_TYPE, node[self.DEPTH_INDEX] + 1, name ))
    return self.cursor.fetchall()

def getAncestors( self, node ):
    self.cursor.execute( "SELECT * FROM %s WHERE l < %s AND r > %s;" % \
          ( self.tablename, node[self.L_INDEX], node[self.R_INDEX] ))
    return cursor.fetchall()
```

A.4.2 ORDPATH Implementation

```
# ------------------------------------------------------------
# olib.py
# -------
# ORDPATH-specific implementation of abstractTraverser.
# ------------------------------------------------------------

import MySQLdb
import sys
import copy
from abstractTraverser import *

sys.path.append( '../ordpath' )
from ordpath import *

# ----------------------
# Tree-traversal
# ----------------------
class ordpathTraverser( abstractTraverser ):
   rootHexstring = None
   HEXSTRING_PATH_INDEX = 0
   TAG_INDEX = 1
   NODE_TYPE_INDEX = 2
   VALUE_INDEX = 3
   DEPTH_INDEX = 4
   ORDPATH_INDEX = 5

   def __init__( self, cursor, tablename ):
      self.cursor = cursor
      self.tablename = tablename

      if self.rootHexstring == None:
         o = ordPath( self.cursor )
         o.append( 1 )
         self.rootHexstring = o.getHexstringRepr()

   def getOrCreateOrdpath( self, node ):
      if len(node) == 6:
         return node[self.ORDPATH_INDEX]
      else:
         o = ordPath( self.cursor )
         o.setFromHexstring( node[self.HEXSTRING_PATH_INDEX] )
         node = ( node[0], node[1], node[2], node[3], node[4], o )
         return o, node

   def compareNodes( self, node1, node2 ):
      if node1[self.HEXSTRING_PATH_INDEX] == \
                              node2[self.HEXSTRING_PATH_INDEX]:
         return 0
      elif node1[self.HEXSTRING_PATH_INDEX] < \
                              node2[self.HEXSTRING_PATH_INDEX]:
         return -1
      else:
         return 1
```

```
def insertSimpleNode( self, leftSibling, node ):
   nextSib = self.getNextSibling( leftSibling )
   leftSibOrdpath, leftSibling = self.getOrCreateOrdpath( leftSibling )
   if nextSib:
      nextSibOrdpath, nextSib = self.getOrCreateOrdpath( nextSib )
      if len( leftSibOrdpath.getListRepr() ) == \
               len( nextSibOrdpath.getListRepr() ):
         newNodeOrdpath = copy.copy( leftSibOrdpath )
         newNodeOrdpath.incrementLastComponent( 1 )
         newNodeOrdpath.append( 1 )
      else:
         newNodeOrdpath = copy.copy( nextSibOrdpath )
         newNodeOrdpath.incrementLastComponent( -2 )
   else:
      newNodeOrdpath = copy.copy( leftSibOrdpath )
      newNodeOrdpath.incrementLastComponent( 2 )
   tag = self.getTagFromIdentifier( node )
   if not tag:
      self.cursor.execute( "SELECT MAX(tagNum) + 1 FROM %s_tags;" % \
          ( self.tablename ))
      tag = self.cursor.fetchone()[0]
      self.cursor.execute( "INSERT INTO %s_tags VALUES( '%s', %s );" % \
          ( self.tablename, node, tag ))
   self.cursor.execute("INSERT INTO %s VALUES('%s',%s, %s, NULL, %s);" % \
       ( self.tablename, newNodeOrdpath.getHexstringRepr(), tag,
              self.ELEMENT_NODE_TYPE, leftSibling[self.DEPTH_INDEX] ))
   self.cursor.execute( "COMMIT;" )

def getRootNode( self ):
   self.cursor.execute( "SELECT * FROM %s WHERE ordpath = '%s'" % \
                            ( self.tablename, self.rootHexstring ))
   return self.cursor.fetchone()

def getRandomNonrootNode( self ):
   self.cursor.execute( """SELECT * FROM %s WHERE nodeType = %s
                    AND ordpath != '%s' ORDER BY RAND() LIMIT 1;" % \
       ( self.tablename, self.ELEMENT_NODE_TYPE, self.rootHexstring ))
   return self.cursor.fetchone()

def getNodeText( self, node ):
   if node == None: return [""]
   if node[self.VALUE_INDEX] != 'NULL':
      return [node[self.VALUE_INDEX]]
   else:
      upperBound, node = self.getOrCreateOrdpath( node )
      upperBound.incrementLastComponent( 1 )
      upperBound = upperBound.getHexstringRepr()

      self.cursor.execute( "SELECT * FROM %s WHERE nodeType = %s AND " % \
         ( self.tablename, self.VALUE_NODE_TYPE ) + \
         " ordpath > '%s' AND ordpath < '%s' AND depth = %s;" % \
         ( node[self.HEXSTRING_PATH_INDEX], upperBound,
                                    node[self.DEPTH_INDEX] + 1 ))
      res = self.cursor.fetchall()
      # reset original node ordPath object
      node[self.ORDPATH_INDEX].incrementLastComponent( -1 )
      return [x[self.VALUE_INDEX] for x in res]
```

```
def getNextSibling( self, node ):
   o, node = self.getOrCreateOrdpath( node )
   upperBound = copy.copy( o )
   upperBound.dropLastComponentIncludeEvens()
   upperBound.incrementLastComponent( 1 )
   upperBound = upperBound.getHexstringRepr()
   self.cursor.execute( """SELECT *
                            FROM %s
                            WHERE ordpath > '%s' AND ordpath < '%s'
                                AND depth = %s
                                ORDER BY ordpath LIMIT 1;""" % \
                ( self.tablename, node[self.HEXSTRING_PATH_INDEX], \
                                 upperBound, node[self.DEPTH_INDEX] ))
   res = self.cursor.fetchone()
   return res

def getNextSiblingByName( self, node, name ):
   o, node = self.getOrCreateOrdpath( node )
   upperBound = copy.copy( o )
   upperBound.dropLastComponentIncludeEvens()
   upperBound.incrementLastComponent( 1 )
   upperBound = upperBound.getHexstringRepr()
   tag = self.getTagFromIdentifier( name )
   if not tag: return None
   self.cursor.execute( """SELECT *
                           FROM %s
                           WHERE ordpath > '%s' AND ordpath < '%s'
                             AND depth = %s
                             AND tag = %s ORDER BY ordpath LIMIT 1;""" % \
              ( self.tablename, node[self.HEXSTRING_PATH_INDEX], \
                               upperBound, node[self.DEPTH_INDEX], tag ))
   res = self.cursor.fetchone()
   return res

def getPreviousSibling( self, node ):
   o, node = self.getOrCreateOrdpath( node )
   lowerBound = copy.copy( o )
   lowerBound.dropLastComponentIncludeEvens()
   lowerBound = lowerBound.getHexstringRepr()
   self.cursor.execute( """SELECT *
                           FROM %s
                           WHERE ordpath = (
                             SELECT MAX( ordpath )
                             FROM %s
                             WHERE ordpath > '%s' AND ordpath < '%s'
                                 AND depth = %s );""" % \
               ( self.tablename, self.tablename, lowerBound, \
                node[self.HEXSTRING_PATH_INDEX], node[self.DEPTH_INDEX] ))
   res = self.cursor.fetchone()
   return res

def getFirstChild( self, node ):
   upperBound, node = self.getOrCreateOrdpath( node )
   upperBound.incrementLastComponent( 1 )
   upperBound = upperBound.getHexstringRepr()
   self.cursor.execute( """SELECT *
```

```
                                FROM %s
                                WHERE ordpath > '%s' AND ordpath < '%s'
                                AND depth = %s
                                ORDER BY ordpath LIMIT 1;""" % \
                        ( self.tablename, node[self.HEXSTRING_PATH_INDEX], \
                          upperBound, node[self.DEPTH_INDEX] + 1 ))
        res = self.cursor.fetchone()
        # reset original node ordPath object
        node[self.ORDPATH_INDEX].incrementLastComponent( -1 )
        return res

    def getFirstChildByName( self, node, name ):
        upperBound, node = self.getOrCreateOrdpath( node )
        upperBound.incrementLastComponent( 1 )
        upperBound = upperBound.getHexstringRepr()
        tag = self.getTagFromIdentifier( name )
        if not tag: return None
        self.cursor.execute( """SELECT *
                                FROM %s
                                WHERE ordpath > '%s' AND ordpath < '%s'
                                  AND depth = %s
                                  AND tag = %s
                                  ORDER BY ordpath LIMIT 1;""" % \
                    ( self.tablename, node[self.HEXSTRING_PATH_INDEX], \
                         upperBound, node[self.DEPTH_INDEX] + 1, tag ))
        res = self.cursor.fetchone()
        # reset original node ordPath object
        node[self.ORDPATH_INDEX].incrementLastComponent( -1 )
        return res

    def getNthChildByName( self, node, n, name ):
        upperBound, node = self.getOrCreateOrdpath( node )
        upperBound.incrementLastComponent( 1 )
        upperBound = upperBound.getHexstringRepr()
        tag = self.getTagFromIdentifier( name )
        if not tag: return None
        self.cursor.execute( """SELECT *
                                FROM %s
                                WHERE ordpath > '%s' AND ordpath < '%s'
                                AND depth = %s
                                AND tag = %s
                                ORDER BY ordpath LIMIT 1 OFFSET %s;""" % \
               ( self.tablename, node[self.HEXSTRING_PATH_INDEX], \
                 upperBound, node[self.DEPTH_INDEX] + 1, tag, n - 1 ))
        res = self.cursor.fetchone()
        # reset original node ordPath object
        node[self.ORDPATH_INDEX].incrementLastComponent( -1 )
        return res

    def getChildrenByName( self, node, name ):
        upperBound, node = self.getOrCreateOrdpath( node )
        upperBound.incrementLastComponent( 1 )
        upperBound = upperBound.getHexstringRepr()
        tag = self.getTagFromIdentifier( name )
        if not tag: return None
        self.cursor.execute( """SELECT *
                                FROM %s
```

```
                                WHERE ordpath > '%s' AND ordpath < '%s'
                                AND depth = %s
                                AND tag = %s;""" % \
                    ( self.tablename, node[self.HEXSTRING_PATH_INDEX], \
                      upperBound, node[self.DEPTH_INDEX] + 1, tag ))
      res = self.cursor.fetchall()
      # reset original node ordPath object
      node[self.ORDPATH_INDEX].incrementLastComponent( -1 )
      return res

   def getLastChild( self, node ):
      upperBound, node = self.getOrCreateOrdpath( node )
      upperBound.incrementLastComponent( 1 )
      upperBound = upperBound.getHexstringRepr()
      self.cursor.execute( """SELECT *
                              FROM %s
                              WHERE ordpath = (
                                SELECT MAX( ordpath )
                                FROM %s
                                WHERE ordpath > '%s' AND ordpath < '%s'
                                AND depth = %s );""" % \
        ( self.tablename, self.tablename, node[self.HEXSTRING_PATH_INDEX], \
                          upperBound, node[self.DEPTH_INDEX] + 1 ))
      res = self.cursor.fetchone()
      # reset original node ordpath object
      node[-1].incrementLastComponent( -1 )
      return res

   def getLastChildByName( self, node, name ):
      upperBound, node = self.getOrCreateOrdpath( node )
      upperBound.incrementLastComponent( 1 )
      upperBound = upperBound.getHexstringRepr()
      tag = self.getTagFromIdentifier( name )
      if not tag: return None
      self.cursor.execute( """SELECT *
                              FROM %s
                              WHERE ordpath = (
                                SELECT MAX( ordpath )
                                FROM %s
                                WHERE ordpath > '%s' AND ordpath < '%s'
                                AND depth = %s AND tag = %s );""" % \
        ( self.tablename, self.tablename, node[self.HEXSTRING_PATH_INDEX], \
                        upperBound, node[self.DEPTH_INDEX] + 1, tag ))
      res = self.cursor.fetchone()
      # reset original node ordpath object
      node[self.ORDPATH_INDEX].incrementLastComponent( -1 )
      return res

   def getIdentifierFromTag( self, tag ):
      self.cursor.execute ( "SELECT * FROM %s_tags WHERE tagNum = %s;" %
         ( self.tablename, tag ))
      res = self.cursor.fetchone()
      if res:
         res = res[0]
      return res
```

```
def getTagFromIdentifier( self, id ):
   self.cursor.execute ( "SELECT * FROM %s_tags WHERE tagName = '%s';" % \
      ( self.tablename, id ))
   res = self.cursor.fetchone()
   if res:
      res = res[1]
   return res

def getNodeName( self, node ):
   return self.getIdentifierFromTag( node[self.TAG_INDEX] )

def getParent( self, node ):
   self.cursor.execute( "SELECT * FROM %s WHERE ordpath = ( " % \
     ( self.tablename ) + \
     "SELECT MAX(ordpath) FROM %s WHERE ordpath<'%s' AND depth=%s );" % \
       ( self.tablename, node[self.HEXSTRING_PATH_INDEX],
                                 node[self.DEPTH_INDEX] - 1 ))
   return self.cursor.fetchone()

def getNodeAttributeValue( self, node, attribute ):
   upperBound, node = self.getOrCreateOrdpath( node )
   upperBound.incrementLastComponent( 1 )
   upperBound = upperBound.getHexstringRepr()
   attributeTag = self.getTagFromIdentifier( attribute )

   self.cursor.execute( """SELECT * FROM %s WHERE tag = %s
                           AND nodeType = %s AND """ % \
       ( self.tablename, attributeTag, self.ATTRIBUTE_NODE_TYPE ) + \
       " ordpath > '%s' AND ordpath < '%s' AND depth = %s;" % \
       ( node[self.HEXSTRING_PATH_INDEX], upperBound, \
                                      node[self.DEPTH_INDEX]))
   res = self.cursor.fetchone()
   if res:
      res = res[self.VALUE_INDEX]
   # reset original node ordpath object
   node[self.ORDPATH_INDEX].incrementLastComponent( -1 )
   return res

def getDescendants( self, node ):
   upperBound, node = self.getOrCreateOrdpath( node )
   upperBound.incrementLastComponent( 1 )
   upperBound = upperBound.getHexstringRepr()

   self.cursor.execute( """SELECT * FROM %s WHERE ordpath > '%s'
                                 AND ordpath < '%s';""" % \
       ( self.tablename, node[self.HEXSTRING_PATH_INDEX], upperBound ))
   res = self.cursor.fetchall()
   # reset original node ordPath object
   node[self.ORDPATH_INDEX].incrementLastComponent( -1 )
   return res

def getDescendantsContainingText( self, node, text ):
   upperBound, node = self.getOrCreateOrdpath( node )
   upperBound.incrementLastComponent( 1 )
   upperBound = upperBound.getHexstringRepr()
   tag = self.getTagFromIdentifier( text )
```

```
      if not tag:
         tag = "value LIKE '%%%s%%'" % text
      else:
         tag="tag in (SELECT * from %s_tags WHERE tagName LIKE '%%%s%%')" % \
                  ( self.tablename, tag )

      sql = """SELECT * FROM %s WHERE ordpath > '%s' AND ordpath < '%s'
                  AND %s;""" % \
          (self.tablename, node[self.HEXSTRING_PATH_INDEX], upperBound, tag )
      self.cursor.execute( sql )
      res = self.cursor.fetchall()
      # reset original node ordPath object
      node[self.ORDPATH_INDEX].incrementLastComponent( -1 )
      return res

   def getDescendantsByNameAndNodeType( self, node, name, nodeType ):
      upperBound, node = self.getOrCreateOrdpath( node )
      upperBound.incrementLastComponent( 1 )
      upperBound = upperBound.getHexstringRepr()
      tag = self.getTagFromIdentifier( name )
      if not tag:
         if nodeType != self.VALUE_NODE_TYPE:
            return []
         else:
            tag = "value = '%s'" % name
      else:
         tag = 'tag = %s' % tag

      self.cursor.execute( """SELECT * FROM %s WHERE ordpath > '%s'
                                    AND ordpath < '%s'""" % \
          ( self.tablename, node[self.HEXSTRING_PATH_INDEX], upperBound ) + \
          " AND nodeType = %s AND %s;" % \
          ( nodeType, tag ))

      res = self.cursor.fetchall()
      # reset original node ordPath object
      node[self.ORDPATH_INDEX].incrementLastComponent( -1 )
      return res

   def getNthGenerationDescendantsByNameAndNodeType( self, node, n, name, \
                                                                  nodeType ):
      upperBound, node = self.getOrCreateOrdpath( node )
      upperBound.incrementLastComponent( 1 )
      upperBound = upperBound.getHexstringRepr()

      if nodeType == self.ATTR_VALUE_NODE_TYPE:
         nodeType = self.ATTRIBUTE_NODE_TYPE
         tag = "value = '%s' AND" % name
      else:
         tag = self.getTagFromIdentifier( name )
         if not tag:
            if nodeType != self.VALUE_NODE_TYPE:
               return None
            tag = "value = '%s' AND" % name
         else:
            tag = 'tag = %s AND' % tag
```

```
self.cursor.execute( """SELECT * FROM %s WHERE ordpath > '%s'
                        AND ordpath < '%s'""" % \
    ( self.tablename, node[self.HEXSTRING_PATH_INDEX], upperBound ) + \
    " AND nodeType = %s AND %s depth = %s;" % \
    ( nodeType, tag, node[self.DEPTH_INDEX] + n ))

res = self.cursor.fetchall()
# reset original node ordPath object
node[self.ORDPATH_INDEX].incrementLastComponent( -1 )
                            return res
```

```
# ------------------------------------------------------------
# Query 1
# ------------------------------------------------------------
# FOR    $b IN document("auction.xml")/site/people/person[@id="person0"]
# RETURN $b/name/text()

import sys, os

sys.path.append( '../shared' )
from util import *

if __name__ == '__main__':
   traverser, conn, cursor = setupForQuery( 'q1' )
   def q1():
      parentNode = traverser.getNodeAtXPath( '/site/people/' )
      if parentNode:
         node = traverser.getFirstChildWithAttributeValue( parentNode, \
                                                'person', 'id', 'person0' )
         if node:
            name = traverser.getFirstChildByName( node, 'name' )
            print traverser.getNodeText( name )[0]

   doProfileAndPrintStats( q1, None )
   cursor.close()
   conn.close()
```

```
# ------------------------------------------------------------------
# Query 2
# ------------------------------------------------------------------
# FOR $b IN document("auction.xml")/site/open_auctions/open_auction
# RETURN <increase> $b/bidder[1]/increase/text() </increase>

import sys, os

sys.path.append( '../shared' )
from util import *

if __name__ == '__main__':
   traverser, conn, cursor = setupForQuery( 'q2' )

   def processAuction( auction ):
      secBidder = traverser.getNthChildByName( auction, 2, 'bidder' )
      if not secBidder: return
      increase = traverser.getFirstChildByName( secBidder, 'increase' )
      if not increase: return
      print '<increase> %s </increase>' % \
                        traverser.getNodeText( increase )[0]

   def q2():
      parentNode = traverser.getNodeAtXPath( '/site/open_auctions/' )
      if not parentNode: return
      auctions = traverser.getChildrenByName( parentNode, 'open_auction' )
      for auction in auctions:
         processAuction( auction )

   doProfileAndPrintStats( q2, None )
   cursor.close()
   conn.close()
```

```
# ------------------------------------------------------------
# Query 3
# ------------------------------------------------------------
# FOR    $b IN document("auction.xml")/site/open_auctions/open_auction
# WHERE  $b/bidder[0]/increase/text() *2 <= $b/bidder[last()]/increase/text()
# RETURN <increase first=$b/bidder[0]/increase/text()
#                  last=$b/bidder[last()]/increase/text()/>

import sys, os

sys.path.append( '../shared' )
from util import *

if __name__ == '__main__':
   traverser, conn, cursor = setupForQuery( 'q3' )

   def processAuction( auction ):
      firstBidder = traverser.getFirstChildByName( auction, 'bidder' )
      if not firstBidder: return
      firstIncrease = traverser.getFirstChildByName( firstBidder, 'increase')
      if not firstIncrease: return
      lastBidder = traverser.getLastChildByName( auction, 'bidder' )
      if not lastBidder: return
      lastIncrease = traverser.getFirstChildByName( lastBidder, 'increase' )
      if not lastIncrease: return

      firstIncrease = traverser.getNodeText( firstIncrease )[0]
      lastIncrease = traverser.getNodeText( lastIncrease )[0]

      if eval( firstIncrease ) * 2 <= eval( lastIncrease ):
         print '<increase first=%s\nlast=%s />' % \
                        ( firstIncrease, lastIncrease )

   def q3():
      rootNode = traverser.getNodeAtXPath( '/site/open_auctions/' )
      if not rootNode: return
      auctions = traverser.getChildrenByName( rootNode, 'open_auction' )
      for auction in auctions:
         processAuction( auction )

   doProfileAndPrintStats( q3, None )
   cursor.close()
   conn.close()
```

```
# ------------------------------------------------------------
# Query 4
# ------------------------------------------------------------
# FOR    $b IN document("auction.xml")/site/open_auctions/open_auction
# WHERE  $b/bidder/personref[@person="person18829"] BEFORE
#        $b/bidder/personref[@person="person10487"]
# RETURN <history> $b/reserve/text() </history>

import sys, os

sys.path.append( '../shared' )
from util import *

if __name__ == '__main__':
   traverser, conn, cursor = setupForQuery( 'q4' )

   def q4():
      rootNode = traverser.getNodeAtXPath( '/site/open_auctions/' )
      auctions = traverser.getChildrenByName( rootNode, 'open_auction' )

      for auction in auctions:
         firstPersonRefs = \
            traverser.getNthGenerationDescendantsByNameAndNodeType( \
                  auction, 2, 'person120', traverser.ATTR_VALUE_NODE_TYPE )
         if firstPersonRefs:
            secondPersonRefs = \
                  traverser.getNthGenerationDescendantsByNameAndNodeType( \
                     auction, 2, 'person230', traverser.ATTR_VALUE_NODE_TYPE)
            if secondPersonRefs:
               fprcob = None
               for fpr in firstPersonRefs:
                  parent = traverser.getParent( fpr )
                  if traverser.getNodeName( parent ) == 'bidder':
                     fprcob = fpr
                     break
               if fprcob:
                  for spr in secondPersonRefs:
                     parent = traverser.getParent( spr )
                     if traverser.getNodeName( parent ) == 'bidder':
                        if traverser.compareNodes( fprcob, spr ) < 0:
                           reserve = traverser.getFirstChildByName(auction, \
                                                                   'reserve' )
                           print '<history> %s </history>' % \
                                    traverser.getNodeText( reserve )[0]
                        break

   doProfileAndPrintStats( q4, None )
   cursor.close()
   conn.close()
```

```
# ------------------------------------------------------------------
# Query 5
# ------------------------------------------------------------------
# COUNT(FOR $i IN document("auction.xml")/site/closed_auctions/closed_auction
#         WHERE  $i/price/text() >= 40
#         RETURN $i/price)

import sys, os

sys.path.append( '../shared' )
from util import *

if __name__ == '__main__':
   traverser, conn, cursor = setupForQuery( 'q5' )

   def q5():
      rootNode = traverser.getNodeAtXPath( '/site/closed_auctions/' )
      prices = traverser.getNthGenerationDescendantsByNameAndNodeType( \
                        rootNode, 2, 'price', traverser.ELEMENT_NODE_TYPE )

      for price in prices:
         priceText = traverser.getNodeText( price )[0]
         if eval( priceText ) > 40:
            print priceText

   doProfileAndPrintStats( q5, None )
   cursor.close()
   conn.close()
```

```
# ------------------------------------------------------------------
# Query 6
# ------------------------------------------------------------------
# FOR    $b IN document("auction.xml")/site/regions
# RETURN COUNT ($b//item)

import sys, os

sys.path.append( '../shared' )
from util import *

if __name__ == '__main__':
   traverser, conn, cursor = setupForQuery( 'q6' )

   def q6():
      rootNode = traverser.getNodeAtXPath( '/site/regions/' )
      items = traverser.getDescendantsByNameAndNodeType( rootNode, 'item', \
                                                         traverser.ELEMENT_NODE_TYPE )
      print len(items)

   doProfileAndPrintStats( q6, None )
   cursor.close()
   conn.close()
```

```
# ------------------------------------------------------------------
# Query 7
# ------------------------------------------------------------------
# FOR $p IN document("auction.xml")/site
# RETURN count($p//description) + count($p//annotation) + count($p//email);

import sys, os

sys.path.append( '../shared' )
from util import *

if __name__ == '__main__':
   traverser, conn, cursor = setupForQuery( 'q7' )

   def q7():
      rootNode = traverser.getNodeAtXPath( '/site/' )
      descriptions = traverser.getDescendantsByNameAndNodeType( rootNode, \
                                 'description', traverser.ELEMENT_NODE_TYPE )
      annotations = traverser.getDescendantsByNameAndNodeType( rootNode, \
                                 'annotation', traverser.ELEMENT_NODE_TYPE )
      emails = traverser.getDescendantsByNameAndNodeType(rootNode, 'email', \
                                                   traverser.ELEMENT_NODE_TYPE )
      print len( descriptions ) + len( annotations ) + len( emails )

   doProfileAndPrintStats( q7, None )
   cursor.close()
   conn.close()
```

```
# ------------------------------------------------------------------
# Query 8
# ------------------------------------------------------------------
# FOR $p IN document("auction.xml")/site/people/person
# LET $a := FOR $t IN
#     document("auction.xml")/site/closed_auctions/closed_auction
#               WHERE $t/buyer/@person = $p/@id
#               RETURN $t
# RETURN <item person=$p/name/text()> COUNT ($a) </item>

import sys, os

sys.path.append( '../shared' )
from util import *

if __name__ == '__main__':
   traverser, conn, cursor = setupForQuery( 'q8' )

   def q8():
      buyerIDs = []
      rootNode = traverser.getNodeAtXPath( '/site/people/' )
      people = traverser.getChildrenByName( rootNode, 'person' )
      rootNode = traverser.getNodeAtXPath( '/site/closed_auctions/' )
      auctions = traverser.getChildrenByName( rootNode, 'closed_auction' )
      for auction in auctions:
         buyer = traverser.getFirstChildByName( auction, 'buyer' )
         buyerIDs.append( traverser.getNodeAttributeValue( buyer, 'person' ))

      for person in people:
         matchedAuctions = []
         personName = traverser.getFirstChildByName( person, 'name' )
         personID = traverser.getNodeAttributeValue( person, 'id' )
         print '<item person=%s> %s </item>' % \
            ( traverser.getNodeText( personName )[0], \
                                    buyerIDs.count( personID ))

   doProfileAndPrintStats( q8, None )
   cursor.close()
   conn.close()
```

```
# ------------------------------------------------------------------
# Query 9
# ------------------------------------------------------------------
# FOR $p IN document("auction.xml")/site/people/person
# LET $a := FOR $t IN
#      document("auction.xml")/site/closed_auctions/closed_auction
#           LET $n := FOR $t2 IN
#                 document("auction.xml")/site/regions/europe/item
#                        WHERE  $t/itemref/@item = $t2/@id
#                        RETURN $t2
#             WHERE $p/@id = $t/buyer/@person
#             RETURN <item> $n/name/text() </item>
# RETURN <person name=$p/name/text()> $a </person>

import sys, os

sys.path.append( '../shared' )
from util import *

if __name__ == '__main__':
   traverser, conn, cursor = setupForQuery( 'q9' )

   def q9():
      peopleRoot = traverser.getNodeAtXPath( '/site/people/' )
      people = traverser.getChildrenByName( peopleRoot, 'person' )
      peopleIDs = []
      for person in people:
         peopleIDs.append( traverser.getNodeAttributeValue( person, 'id' ))

      europeRoot = traverser.getNodeAtXPath( '/site/regions/europe/' )
      europianItems = traverser.getChildrenByName( europeRoot, 'item' )
      europianItemIDs = []
      for item in europianItems:
         europianItemIDs.append(traverser.getNodeAttributeValue(item, 'id' ))

      rootNode = traverser.getNodeAtXPath( '/site/closed_auctions/' )
      itemrefs = traverser.getNthGenerationDescendantsByNameAndNodeType( \
                        rootNode, 2, 'itemref', traverser.ELEMENT_NODE_TYPE )

      rootNode = traverser.getNodeAtXPath( '/site/closed_auctions/' )
      buyers = traverser.getNthGenerationDescendantsByNameAndNodeType( \
                        rootNode, 2, 'buyer', traverser.ELEMENT_NODE_TYPE )
      buyerIDs = []
      for buyer in buyers:
         buyerIDs.append( traverser.getNodeAttributeValue( buyer, 'person' ))
      for i in range( len( peopleIDs ) - 1, -1, -1 ):
         if not buyerIDs.count( peopleIDs[i] ) > 0:
            peopleIDs.__delitem__( i )

      matches = {}
      itemIDsToNames = {}
      for itemref in itemrefs:
         itemID = traverser.getNodeAttributeValue( itemref, 'item' )
         if europianItemIDs.count( itemID ) > 0:
            auction = traverser.getParent( itemref )
            buyer = traverser.getFirstChildByName( auction, 'buyer' )
            buyerID = traverser.getNodeAttributeValue( buyer, 'person' )
```

```
            if itemIDsToNames.keys().count( itemID ) > 0:
               itemName = itemIDsToNames( itemID )
            else:
               item = traverser.getFirstChildWithAttributeValue(europeRoot, \
                                                    'item', 'id', itemID )
               itemName = traverser.getFirstChildByName( item, 'name' )
               itemName = traverser.getNodeText( itemName )[0]
               itemIDsToNames[ itemID ] = itemName
            if matches.keys().count( buyerID ) > 0:
               matches[ buyerID ].append( itemName )
            else:
               matches[ buyerID ] = [ itemName ]

      for id in peopleIDs:
         if matches.keys().count( id ) > 0:
            person = traverser.getFirstChildWithAttributeValue( peopleRoot, \
                                                    'person', 'id', id )
            personName = traverser.getFirstChildByName( person, 'name' )
            personName = traverser.getNodeText( personName )[0]
            print '<person name=%s> ' % personName
            for item in matches[ id ]:
               print '<item> %s </item>' % item
            print '</person>'

doProfileAndPrintStats( q9, None )
cursor.close()
conn.close()
```

```
# ------------------------------------------------------------
# Query 10
# ------------------------------------------------------------
# FOR $i IN DISTINCT
#  document("auction.xml")/site/people/person/profile/interest/@category
# LET $p := FOR    $t IN document("auction.xml")/site/people/person
#           WHERE  $t/profile/interest/@category = $i
#             RETURN <personne>
#                 <statistiques>
#                         <sexe> $t/gender/text() </sexe>,
#                         <age> $t/age/text() </age>,
#                         <education> $t/education/text()</education>,
#                         <revenu> $t/income/text() </revenu>
#                 </statistiques>,
#                 <coordonnees>
#                         <nom> $t/name/text() </nom>,
#                         <rue> $t/street/text() </rue>,
#                         <ville> $t/city/text() </ville>,
#                         <pays> $t/country/text() </pays>,
#                         <reseau>
#                                 <courrier> $t/email/text() </courrier>,
#                                 <pagePerso> $t/homepage/text()</pagePerso>
#                         </reseau>,
#                 </coordonnees>
#                 <cartePaiement> $t/creditcard/text()</cartePaiement>
#               </personne>
# RETURN <categorie>
#         <id> $i </id>,
#         $p
#       </categorie>

import sys

sys.path.append( '../shared' )
from util import *

if __name__ == '__main__':
   traverser, conn, cursor = setupForQuery( 'q10' )

   def q10():
      def getPersonsInterestCategories( person ):
         categories = []
         profile = traverser.getFirstChildByName( person, 'profile' )
         if profile != None:
            interests = traverser.getChildrenByName( profile, 'interest' )
            for interest in interests:
               category =traverser.getNodeAttributeValue(interest,'category')
               if not categories.__contains__( category ):
                  categories.append( category )
         return categories

      interestToPeopleMap = {}

      rootNode = traverser.getNodeAtXPath( '/site/people/' )
      people = traverser.getChildrenByName( rootNode, 'person' )

      for person in people:
```

```
      personsCategories = getPersonsInterestCategories( person )
      for category in personsCategories:
         if not interestToPeopleMap.keys().__contains__( category ):
            interestToPeopleMap[ category ] = [ person ]
         else:
            interestToPeopleMap[ category ].append( person )

   for category in interestToPeopleMap.keys():
      print "<categorie>\n<id> %s </id>,\n" % category
      for person in interestToPeopleMap[ category ]:
         stringArgs = (
            traverser.getNodeText(
               traverser.getFirstChildByName( person, 'gender' ))[0],\
            traverser.getNodeText(
               traverser.getFirstChildByName( person, 'age' ))[0],\
            traverser.getNodeText(
               traverser.getFirstChildByName( person, 'education' ))[0],\
            traverser.getNodeText(
               traverser.getFirstChildByName( person, 'income' ))[0],\
            traverser.getNodeText(
               traverser.getFirstChildByName( person, 'name' ))[0],\
            traverser.getNodeText(
               traverser.getFirstChildByName( person, 'street' ))[0],\
            traverser.getNodeText(
               traverser.getFirstChildByName( person, 'city' ))[0],\
            traverser.getNodeText(
               traverser.getFirstChildByName( person, 'country' ))[0],\
            traverser.getNodeText(
               traverser.getFirstChildByName( person, 'email' ))[0],\
            traverser.getNodeText(
               traverser.getFirstChildByName( person, 'homepage' ))[0],\
            traverser.getNodeText(
               traverser.getFirstChildByName( person, 'creditcard' ))[0])
         print """
            <personne>
            <statistiques>
                  <sexe> %s </sexe>,
                  <age> %s </age>,
                  <education> %s </education>,
                  <revenu> %s </revenu>
            </statistiques>,
            <coordonnees>
                  <nom> %s </nom>,
                  <rue> %s </rue>,
                  <ville> %s </ville>,
                  <pays> %s </pays>,
                  <reseau>
                        <courrier> %s </courrier>,
                        <pagePerso> %s </pagePerso>
                  </reseau>,
            </coordonnees>
            <cartePaiement> %s </cartePaiement>
            </personne>""" % stringArgs
      print "</categorie>"
doProfileAndPrintStats( q10, None )
cursor.close()
conn.close()
```

```
# ------------------------------------------------------------
# Query 11
# ------------------------------------------------------------
# FOR $p IN document("auction.xml")/site/people/person
# LET $l := FOR $i IN
#        document("auction.xml")/site/open_auctions/open_auction/initial
#           WHERE $p/profile/@income > (5000 * $i/text())
#           RETURN $i
# RETURN <items name=$p/name/text()> COUNT ($l) </items>

import sys, os

sys.path.append( '../shared' )
from util import *

if __name__ == '__main__':
   traverser, conn, cursor = setupForQuery( 'q11' )

   def q11():
      rootNode = traverser.getNodeAtXPath( '/site/people/' )
      people = traverser.getChildrenByName( rootNode, 'person' )
      rootNode = traverser.getNodeAtXPath( '/site/open_auctions/' )
      auctions = traverser.getChildrenByName( rootNode, 'open_auction' )
      initials = []
      for auction in auctions:
         initial = traverser.getFirstChildByName( auction, 'initial' )
         if initial != None:
            initial = eval( traverser.getNodeText( initial )[0] ) * 5000
            initials.append( initial )

      for person in people:
         matchedInitials = []
         name = traverser.getFirstChildByName( person, 'name' )
         profile = traverser.getFirstChildByName( person, 'profile' )
         if profile:
            income = traverser.getNodeAttributeValue( profile, 'income' )
            if income:
               for initial in initials:
                  if eval( income ) > initial:
                     matchedInitials.append( initial )
         print '<items name=%s> %s </items>' % ( traverser.getNodeText( \
                                          name )[0], len( matchedInitials ))

   doProfileAndPrintStats( q11, None )
   cursor.close()
   conn.close()
```

```
# ------------------------------------------------------------------
# Query 12
# ------------------------------------------------------------------
# FOR $p IN document("auction.xml")/site/people/person
# LET $l := FOR $i IN
#       document("auction.xml")/site/open_auctions/open_auction/initial
#           WHERE $p/profile/@income > (5000 * $i/text())
#           RETURN $i
# WHERE  $p/profile/@income > 50000
# RETURN <items person=$p/name/income/text()> COUNT ($l) </person>

import sys, os

sys.path.append( '../shared' )
from util import *

if __name__ == '__main__':
   traverser, conn, cursor = setupForQuery( 'q12' )

   def q12():
      rootNode = traverser.getNodeAtXPath( '/site/people/' )
      people = traverser.getChildrenByName( rootNode, 'person' )
      rootNode = traverser.getNodeAtXPath( '/site/open_auctions/' )
      auctions = traverser.getChildrenByName( rootNode, 'open_auction' )
      initials = []
      for auction in auctions:
         initial = traverser.getFirstChildByName( auction, 'initial' )
         if initial != None:
            initial = eval( traverser.getNodeText( initial )[0] ) * 5000
            initials.append( initial )

      for person in people:
         matchedInitials = []
         name = traverser.getFirstChildByName( person, 'name' )
         profile = traverser.getFirstChildByName( person, 'profile' )
         if profile:
            income = eval( traverser.getNodeAttributeValue( \
                                                profile, 'income' ))
            if income > 50000:
               for initial in initials:
                     if income > initial:
                        matchedInitials.append( initial )
               print '<items name=%s> %s </items>' % \
                   ( traverser.getNodeText( name )[0], \
                                    len( matchedInitials ))

   doProfileAndPrintStats( q12, None )
   cursor.close()
   conn.close()
```

```
# ------------------------------------------------------------------
# Query 13
# ------------------------------------------------------------------
# FOR $i IN document("auction.xml")/site/regions/australia/item
# RETURN <item name=$i/name/text()> $i/description </item>

import sys, os

sys.path.append( '../shared' )
from util import *

if __name__ == '__main__':
   traverser, conn, cursor = setupForQuery( 'q13' )

   def q13():
      rootNode = traverser.getNodeAtXPath( '/site/regions/australia/' )
      items = traverser.getChildrenByName( rootNode, 'item' )
      for item in items:
         name = traverser.getFirstChildByName( item, 'name' )
         desc = traverser.getFirstChildByName( item, 'description' )
         text = traverser.getFirstChild( desc )
         text = traverser.getNodeText( text )
         print '<item name=%s> %s </item>' % \
            ( traverser.getNodeText( name )[0], str.join( '\n', text ))

   doProfileAndPrintStats( q13, None )
   cursor.close()
   conn.close()
```

```
# ------------------------------------------------------------------
# Query 14
# ------------------------------------------------------------------
# FOR $i IN document("auction.xml")/site//item
# WHERE CONTAINS ($i/description,"gold")
# RETURN $i/name/text()

import sys, os

sys.path.append( '../shared' )
from util import *

if __name__ == '__main__':
   traverser, conn, cursor = setupForQuery( 'q14' )

   def q14():
      count = 0
      rootNode = traverser.getNodeAtXPath( '/site/' )
      items = traverser.getDescendantsByNameAndNodeType( \
                  rootNode, 'item', traverser.ELEMENT_NODE_TYPE )
      for item in items:
         desc = traverser.getFirstChildByName( item, 'description' )
         descDescendants = traverser.getDescendantsContainingText( \
                                                      desc, 'gold' )
         if descDescendants:
            count += 1
            name = traverser.getFirstChildByName( item, 'name' )
            print traverser.getNodeText( name )[0]

   doProfileAndPrintStats( q14, None )
   cursor.close()
   conn.close()
```

```
# ------------------------------------------------------------
# Query 15
# ------------------------------------------------------------
# FOR $a IN
#   document("auction.xml")/site/closed_auctions/closed_auction/annotation/\
#     description/parlist/listitem/parlist/listitem/text/emph/keyword/text()
# RETURN <text> $a <text>

import sys, os

sys.path.append( '../shared' )
from util import *

if __name__ == '__main__':
   traverser, conn, cursor = setupForQuery( 'q15' )

   def q15():
      rootNode = traverser.getNodeAtXPath( '/site/closed_auctions/' )
      auctions = traverser.getChildrenByName( rootNode, 'closed_auction' )
      for auction in auctions:
         annot = traverser.getFirstChildByName( auction, 'annotation' )
         if annot:
            desc = traverser.getFirstChildByName( annot, 'description' )
            if desc:
               parlist = traverser.getFirstChildByName( desc, 'parlist' )
               if parlist:
                  listitems = traverser.getChildrenByName( parlist, \
                                                           'listitem' )
                  for listitem in listitems:
                     parlist = traverser.getFirstChildByName( listitem, \
                                                              'parlist' )
                     if parlist:
                        innerListItems = traverser.getChildrenByName( \
                                                    parlist, 'listitem' )
                        for innerListItem in innerListItems:
                           text = traverser.getFirstChildByName( \
                                                    innerListItem, 'text' )
                           if text:
                              emphs = traverser.getChildrenByName( text, \
                                                              'emph' )
                              for emph in emphs:
                                 keywords = traverser.getChildrenByName( \
                                                          emph, 'keyword' )
                                 for keyword in keywords:
                                    print '<text> %s </text>' % str.join( \
                                      '\n', traverser.getNodeText( keyword ))

   doProfileAndPrintStats( q15, None )
   cursor.close()
   conn.close()
```

```
# ------------------------------------------------------------
# Query 16
# ------------------------------------------------------------
# FOR $a IN document("auction.xml")/site/closed_auctions/closed_auction
# WHERE NOT EMPTY ($a/annotation/description/parlist/listitem/parlist/\
#                      listitem/text/emph/keyword/text())
# RETURN <person id=$a/seller/@person />

import sys, os

sys.path.append( '../shared' )
from util import *

if __name__ == '__main__':
   traverser, conn, cursor = setupForQuery( 'q16' )

   def processAuction( auction ):
      annot = traverser.getFirstChildByName( auction, 'annotation' )
      if annot:
         desc = traverser.getFirstChildByName( annot, 'description' )
         if desc:
            parlist = traverser.getFirstChildByName( desc, 'parlist' )
            if parlist:
               listitems = traverser.getChildrenByName( parlist, 'listitem' )
               for listitem in listitems:
                  parlist = traverser.getFirstChildByName( listitem, \
                                                           'parlist' )
                  if parlist:
                     innerListItems = traverser.getChildrenByName( parlist, \
                                                          'listitem' )
                     for innerListItem in innerListItems:
                        text = traverser.getFirstChildByName(innerListItem, \
                                                             'text' )
                        if text:
                           emphs = traverser.getChildrenByName(text, 'emph' )
                           for emph in emphs:
                              keywords = traverser.getChildrenByName( emph, \
                                                             'keyword' )
                              for keyword in keywords:
                                 keywordTxt = traverser.getNodeText(keyword )
                                 if keywordTxt:
                                    seller = traverser.getFirstChildByName( \
                                                       auction, 'seller' )
                                    if seller:
                                       print '<person id=%s />' % \
                                          traverser.getNodeAttributeValue( \
                                                       seller, 'person' )
                                       return

   def q16():
      rootNode = traverser.getNodeAtXPath( '/site/closed_auctions/' )
      auctions = traverser.getChildrenByName( rootNode, 'closed_auction' )
      for auction in auctions:
         processAuction( auction )
   doProfileAndPrintStats( q16, None )
   cursor.close()
   conn.close()
```

```
# ------------------------------------------------------------------
# Query 17
# ------------------------------------------------------------------
# FOR    $p IN document("auction.xml")/site/people/person
# WHERE  EMPTY($p/homepage/text())
# RETURN <person name=$p/name/text()/>

import sys, os

sys.path.append( '../shared' )
from util import *

if __name__ == '__main__':
   traverser, conn, cursor = setupForQuery( 'q17' )

   def q17():
      rootNode = traverser.getNodeAtXPath( '/site/people/' )
      persons = traverser.getChildrenByName( rootNode, 'person' )
      for person in persons:
         homepage = traverser.getFirstChildByName( person, 'homepage' )
         if not homepage:
            name = traverser.getFirstChildByName( person, 'name' )
            print '<person name=%s/>' % traverser.getNodeText( name )[0]

   doProfileAndPrintStats( q17, None )
   cursor.close()
   conn.close()
```

```
# ------------------------------------------------------------------
# Query 18
# ------------------------------------------------------------------
# FUNCTION CONVERT ($v)
# {
#   RETURN 2.20371 * $v -- convert Dfl to Euro
# }
#
# FOR    $i IN document("auction.xml")/site/open_auctions/open_auction/
# RETURN CONVERT($i/reserve/text())

import sys, os

sys.path.append( '../shared' )
from util import *

if __name__ == '__main__':
   traverser, conn, cursor = setupForQuery( 'q18' )

   def q18():
      rootNode = traverser.getNodeAtXPath( '/site/open_auctions/' )
      auctions = traverser.getChildrenByName( rootNode, 'open_auction' )

      for auction in auctions:
         reserve = traverser.getFirstChildByName( auction, 'reserve' )
         if reserve:
            print eval( traverser.getNodeText( reserve )[0]) * 2.20371

   doProfileAndPrintStats( q18, None )
   cursor.close()
   conn.close()
```

```
# ------------------------------------------------------------------
# Query 19
# ------------------------------------------------------------------
# FOR    $b IN document("auction.xml")/site/regions//item
# LET    $k := $b/name/text()
# RETURN <item name=$k> $b/location/text() </item>
# SORTBY (.)

import sys, os

sys.path.append( '../shared' )
from util import *

if __name__ == '__main__':
   traverser, conn, cursor = setupForQuery( 'q19' )

   def q19():
      rootNode = traverser.getNodeAtXPath( '/site/regions/' )
      items = traverser.getDescendantsByNameAndNodeType( rootNode, \
                                    'item', traverser.ELEMENT_NODE_TYPE )

      results = {}

      for item in items:
         name = traverser.getFirstChildByName( item, 'name' )
         name = traverser.getNodeText( name )[0]
         location = traverser.getFirstChildByName( item, 'location' )
         location = traverser.getNodeText( location )[0]
         results[ name ] = location

      keys = results.keys()
      keys.sort()

      for k in keys:
         print '<item name=%s> %s </item>' % ( k, results[k] )

   doProfileAndPrintStats( q19, None )
   cursor.close()
   conn.close()
```

```
# -----------------------------------------------------------------
# Query 20
# -----------------------------------------------------------------
# <result>
#  <preferred>
#   COUNT(
#    document("auction.xml")/site/people/person/profile[@income >= 100000])
#  </preferred>,
#  <standard>
#   COUNT(
#    document("auction.xml")/site/people/person/profile[@income < 100000
#                                                   and @income >= 30000])
#  </standard>,
#  <challenge>
#   COUNT(
#    document("auction.xml")/site/people/person/profile[@income < 30000])
#  </challenge>,
#  <na>
#   COUNT (FOR    $p in document("auction.xml")/site/people/person
#          WHERE  EMPTY($p/@income)
#          RETURN $p)
#  </na>
# </result>

import sys, os

sys.path.append( '../shared' )
from util import *

if __name__ == '__main__':
   traverser, conn, cursor = setupForQuery( 'q20' )

   def q20():
      rootNode = traverser.getNodeAtXPath( '/site/people/' )
      people = traverser.getChildrenByName( rootNode, 'person' )

      preferredCount = 0
      standardCount = 0
      challengeCount = 0
      naCount = 0

      for person in people:
         profile = traverser.getFirstChildByName( person, 'profile' )
         if profile:
            income = traverser.getNodeAttributeValue( profile, 'income' )
            if income:
               income = eval( income )
               if income >= 100000:
                  preferredCount += 1
               elif income >= 30000:
                  standardCount += 1
               elif income:
                  challengeCount += 1
               else:
                  print 'Something went wrong.'
            else:
               naCount += 1
```

```
      else:
         naCount += 1

   print """
<result>
  <preferred>
    %s
  </preferred>,
  <standard>
    %s
  </standard>,
  <challenge>
    %s
  </challenge>,
  <na>
    %s
  </na>
</result>""" % ( preferredCount, standardCount, challengeCount, naCount )

doProfileAndPrintStats( q20, None )
cursor.close()
conn.close()
```

A.6 Top-Level Insert Implementation

```
# ---------------------------------------------------------------
# insert.py
# ---------------------------------------------------------------
#  Top-level insert.
# ---------------------------------------------------------------

import sys, os

sys.path.append( '../shared' )
from util import *

if __name__ == '__main__':
   traverser, conn, cursor = setupForQuery( 'insert', 4, \
                                     'numberOfRepetitions' )
   numInserts = eval(sys.argv[3])

   def insert():
      for i in range( numInserts ):
         randNode = traverser.getRandomNonrootNode()
         traverser.insertSimpleNode( randNode, 'newElement' )

   doProfileAndPrintStats( insert, None )
```

VITA

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