WebDB: A System for Querying Semistructured Data on the Web

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Abstract

The World-Wide Web can be viewed as a collection of semistructured multimedia documents in the form of Web pages connected through hyperlinks. Unlike most Web search engines, which primarily focus on information retrieval functionality, WebDB aims at supporting a comprehensive database-like query functionality, including selection, aggregation, sorting, summarization, grouping, and projection. WebDB allows users to access (1) document level information, such as title, URL, length, keywords, types, and last modified date; (2) intra-document structures, such as tables, forms, and images; and (3) inter-document linkage information, such as destination URLs and anchors. With these three types of information, comprehensive queries can be answered for complex Web-based applications, such as Web mining and Web site management, can be answered. WebDB is based on object-relational concepts: Object-oriented modeling and relational query language. In this paper, we present the data model, language, and implementation of WebDB. We also present, the novel visual query/browsing interface for semistructured Web and Web documents. Our system provides high usability compared with other existing systems.

Key words. WWW, semistructured data, Web database, Web query language, SQL3, object-relational DBMS, visual user interface

1 Introduction

The World-Wide Web can be viewed as a collection of semi-structured multimedia documents (pages) connected through hyperlinks. The Web contains not only the information explicitly displayed on each Web page but also intra-document structures and inter-document linkage information. For example, the fact that “owners of Web pages with links pointing to www.nba.com are more likely to be NBA fans” would make such a query asking for such pages would be valuable for marketing purposes. Similarly, the result for the query “retrieve the pages in the IRS Web site that contains the keyword 1040 tax form and an HTML Form” can be used to locate and download the electronic version of the 1040 Tax Form.

Most existing WWW query systems focus on searching document level information. As a result, the queries listed above are not supported. For instance, in the tax form example, the users would specify

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the keyword “1040 tax form” but then they would need to browse through the results, including less relevant pages, such as those pages explain the purposes of Form 1040, in order to find the page where an electronic format of the 1040 Tax Form is available for downloading.

We categorize information available on the Web as follows:

- Document information, such as type, size, last modified date, URL, page title, keywords, etc. Most Web search engines support searching only on this information.

- Inter-documentation information including links from/to/within a page and anchor labels. Links within a page are through so-called labels.

- Intra-document information, such as forms, images, tables, and links. For some of these, we can further explore their internal structures. For example, there may be forms, tables, images, or links within the cells of a given table.

We illustrate the structure of Web pages in Figure 1. We view the Web as a graph, in which pages are vertices and the links among them are edges. By exploring the Web document internal structures, we view Web pages as hierarchical structures. Most existing Web search engines primarily support simple information retrieval. With all these three types of information, our work aims at supporting functionality beyond existing Web search engines support, such as follows:

- **Extracting the Web structure and applying searches to inter-document linkage information:** For example, results of the query “Retrieve all pages with a link pointing to the NEC Web site” can be used to explore the potential customer base for NEC products. Alternatively,
results of the query “List the top ten sites to which pages link on the NEC Web site, sorted by numbers of links” can be used to find popular sites on the Web.

- **Extracting Web document internal structures and applying searches to intra-document structures:** For example, the query “retrieve all pages that have the keyword “Michael Jordan” and have the keyword statistics within a table” can be used to retrieve pages that may contain Michael Jordan’s statistics. A query “retrieve all pages that have the keywords Chicago Bulls and Fan Registration and have an HTML form in the pages” can be used to retrieve documents associated with on-line registration information for the Chicago Bulls Fan Club.

- **Multimedia search capabilities:** Since Web pages contain multimedia information, users need to be able to search Web documents based on media contents. An example query of this type is “retrieve all documents with an image similar to a Chicago Bulls logo (bulllogo.gif) within a table”.

- **Supporting more comprehensive query capabilities:** Most Web search engines support keyword-based page retrieval. WebDB aims at supporting more comprehensive query capability, including aggregation, sorting, select, and projection on document-level metadata as well as inter- and intra-document information. In other words, WebDB is a Web search system which provides full-fledged database-like query functionality. An example comprehensive query that WebDB can process is “retrieve all pages, modified after 1997, which are linked from www.nba.com with depth of 10, sort the results by their URLs, and remove duplicate pages.” This query can be used as a spider to collect documents from www.nba.com and to organize the results. The query “retrieve all pages which have links to www.nba.com, group them by country of url locations, and display the numbers of pages for each country” can be viewed as using a query to conduct a market survey for geographic locations of NBA fans. WebDB also supports queries on complex intra-document structures, such as “retrieve documents with a form within a table”.

- **Providing computer-human interaction:** Some systems provide database-like Web query functionality. However, these systems are generally not practical since they do not provide their end-users with appropriate tools that can not formulate such complex queries. WebDB provides higher usability through strong emphasis on computer-human interaction design. A visual query interface (WebIFQ) and a query statement generator to assist users in formulating complex queries are essential parts of WebDB.

WebDB aims at provide tools that will allow users to access the data available over the net despite its semi-structured nature. In fact, by providing different levels of access, WebDB allows users to extract and exploit the information captured in the structure itself.

### 1.1 System Overview

WebDB project, at NEC C&c Research laboratories in San Jose, WebDB project aims at building a hypermedia database system for various types of semistructured data, such as Web documents and SGML documents. Compared with other existing systems, WebDB provides a more comprehensive
approach with focuses on modeling, language design, query processing, and usability. Consequently, WebDB has a strong emphasis on query interface design and computer human interaction issues such as query expansion and interactive query reformulation. Let us look an example. A user wants to retrieve all Web pages containing both an HTML form and the keyword multimedia (or other terms related by semantic similarity or co-occurrence relationship) which have links to the NEC Web sites in www.ccrl.neclab.com within link depth of 3. Users are specifically interested in the URLs of the NEC pages which are accessible through these outside pages.

WebDB is based on the object-relational concept, which can be viewed as an extended ER model. The Web contains documents (entities) and hyperlinks connecting these documents (relations). The intra-document structures are modeled using the object-oriented model. The inter-document linkage is modeled through join operations between source document URLs and destination document URLs. The above query can be specified using the Web Query Language (WQL - in the object-relational implementation we translate this query language to SQL3) that WebDB provides as follows:

Select Doc D2.URL, ”→”, Doc D1.URL
From WebDB
Where
D1.URL like ”www.ccrl.neclab.com”
and D1.Keyword mentions ("multimedia" or s-like("multimedia",5) or cooccurrence("multimedia",5))
and D1 contains Form F1
and F1 mentions "*"
and D2 contains Link L1
and L1.URL = D1.URL Depth 3
and L1.TextualAnchor mentions "NEC"

Note that the projected string “→” is for the purpose of output presentation and mentions is a string matching function for a set of strings, such as a keyword list. Figure ?? shows that users use a visual query interface, WebIFQ (Web In-Frame-Query), to specify queries, rather than using the complex query language directly. The corresponding query statements are automatically generated by WebIFQ. The query statement in WQL is then processed by the WebDB query processor. The result of the above query may be as follows:

http://www.ece.nwu.edu/~shimjh → http://www.ccrl.neclab.com/
http://www.ece.nwu.edu/~shimjh → http://www.ccrl.neclab.com/Anecdote
http://www.ece.nwu.edu/~shimjh → http://www.ccrl.neclab.com/nec_sj/
... 

Note that the result of this query is not a collection of URLs, but reorganized information: pairs of Web pages. Additional reorganization functionalities are also supported for sorting, aggregating, or filtering out information. The result is presented to the user through a browser, such as Netscape

1Please note that URL and domain are different. For example, www.ccrl.neclab.com/forum97/index.html is a URL while www.ccrl.neclab.com is a domain. WebDB stores documents' URLs, rather than domain names, to support queries with fine granularity.
Navigator. The user can click on any of the presented URLs to browse a particular page or can save these URLs as bookmarks for later use. WebDB also supports slide-show functionality, i.e., automated display of all pages or selected pages (e.g., first 10 pages).

WebDB supports services beyond existing Web search engines can and features many additional query supporting services to provide better usability than existing Web query systems with limited database-like functionality. WebDB features the following novel query supporting services: (1) WebDB provides a visual query interface and query generator, WebIFQ. Users are not required to know the underlying complex modeling schemes or language syntax. WebIFQ can be used as a general purpose Web query interface for WebDB and Web related applications built on top of ORDBMSs; (2) Recursively exploring and modeling intra-document structures; (3) WebIFQ visualizes user query specification, including intra-document structures and linkage information; (4) WebDB can be used through existing browsers as browsing interfaces; (5) WebDB supports query relaxation through semantically relevant term index and cooccurring term index; and (5) it provides database query functionality while maintaining file system-based implementation level response time through the use of advanced indexing techniques.

1.2 Paper Organization

The rest of this paper is organized as follows: We first review related work. In Section 3, we present our Web modeling scheme and the corresponding data model for implementing WebDB. In Section 4, we give the formal definitions and syntax of WQL. In Section 5, we present the design and operations of WebIFQ, the visual query and browsing interfaces in WebDB. In Section 6 we give our conclusions in Section 6.

2 Related Work

In [1], we introduced a hybrid multimedia database system, SEMCOG, to support content-oriented integration through the integration of semantics and cognition-based approaches. In SEMCOG, images are modeled based on the object-oriented concept and the query language is based on SQL3: multimedia is modeled as user-defined data types and user-defined functions are defined to extend SQL for manipulating multimedia data types. SEMCOG provides a visual query interface, IFQ (In Frame Query)[2], to support complex SQL3-based multimedia database query statements. WebDB’s system architecture is similar to SEMCOG: it is based on object-relational concept and its language, WQL, is based on SQL3. The modeling methodology in WebDB is more complicated than in SEMCOG because both intra-document structures and inter-document linkage are modeled. WebDB also features a visual query interface and a query generator similar to IFQ to assist users in specifying complex SQL3 queries.

Our work integrates image retrieval, semi-structured data modeling and retrieval, information retrieval, and user interfaces. In this section, we review related work in these areas and compare it with WebDB.
2.1 Text-based Web Search

Most information retrieval engines provide search capabilities only by keyword or phrase and criteria combinations using Boolean expressions. This type of system is meant for simple information retrieval from a large amount of information. Examples of these systems include Altavista[3], InfoSeek[4], Yahoo[5], and Excite[6]. They provide information retrieval without considering the Web structure and multimedia components of Web documents. Altavista is distinct as it includes a query refinement interface called Live Topiè. WebDB supports query refinement as well as query relaxation and query reformulation.

Many search engines rank query results by how well they match the original query. [7] discusses strategies for solving the so-called “meta-ranking” problem and proposes a method for merging ranks from heterogeneous Internet sources, particularly in an integrated environment of multiple digital libraries. Similar to [7], I.SEE[8] also addresses the functionality of searching multiple resources. I.SEE is an integrated interface to search engines on the Internet developed at Rensselaer Polytechnic Institute. It translates user queries and forwards them to multiple search engines including AltaVista, Excite, HotBot, Infoseek, and Yahoo!. These two systems’ functionalities are limited by the search engines where queries are forwarded to, while WebDB aims at supporting additional functionalities.

2.2 Multimedia-based Web Search

Yahoo’s Image Surfer[9] includes a collection of images that are available on the Web. The images from the Web Site are categorized manually; in these categories, users can retrieve images based on color histograms.

WebSeer[10] connects the textual information and images in HTML documents. By integrating an analysis about the images, WebSeer provides the multimedia search based on the image contents and keywords.

In Yahoo! and WebSeer, the integration is at the level of the whole image. WebDB provides image multimedia searches at the object level, as described in [1], since WebDB’s underlying media processing capability is supported through SEMCOG[1].

2.3 Complex Search on the Web or the Intranet

LORE[11] at Stanford University is an effort to develop a lightweight object repository. The query language for LORE, LOREL, is an SQL-like query language designed for querying semi-structured heterogeneous information on the Intranet environment. LOREL extends the concept of column names to information/object path descriptions and provides function calls, such as grep to support more flexible string matching in information retrieval. DataGuides[12] is a graphical interface for LORE. LOREL is similar to WQL in syntax and DataGuides is similar to the visual query interface in our system. WebDB supports additional multimedia search functionalities, visual query/browsing interfaces, and a SQL3 language generator. [13] extends LOREL’s functionalities by representing changes in semistructured data for users to query.
WebSQL[14, 15] is a project at University of Toronto to develop a Web query facilitation language. It views the Web as a table of documents, in which URL, Title, Type, Last Modified Date are treated as columns. WebSQL extends standard SQL by adding information related to Web documents, such as URL and Title, as column names for queries. Some user-defined functions, such as “mentions”, are supported for more fuzzy textual string matching. The query interface provided for WebSQL is form-based, as opposed to the visual query interface and query generator provided by WebDB: we feel it is difficult for end-users to pose these complex queries directly. Additionally, WebDB supports query relaxation. WebOQL[16] is an extension of WebSQL. WebOQL further supports reorganization of Web pages.

Strudel[17, 18, 19] is a Web-site management system. It applies familiar concepts from database management systems to the process of building Web sites. The Web site manager can separate the logical view of information at a Web site, the structure of that information in linked pages, and the graphical presentation of pages in HTML. First it defines the data available at that site as an integrated view from multiple (external) sources. Second, it defines the structure of the Web-site, as a view over the underlying information: different versions of the site can be defined by specifying multiple views.

UnQL[20, 21], developed at AT&T, has been specifically designed to query semistructured data. It has two levels: a declarative and a functional level. The declarative level consists of a Select-Where construct, much like the SQL Select-From-Where, with some additional OQL-like constructs to deal with nested objects, including regular expressions to access attributes which may be nested arbitrarily deep. The functional level consists of a language allowing the definition of mutually recursive functions, based on pattern matching. Substantial amount of work has been focused on query optimization[22, 23, 24]. Compared with UnQL, WebDB uses a language based on SQL3 to take advantages of both OO modeling and relational languages.

WebLog[25], developed at Concordia University, is intended to be a more complete language to support both query and result rendering formatting. Due to the complexity of this language and lack of query interfaces, WebLog is difficult to use. No implementation of WebLog has been reported.

TSIMMIS[26] is a project at Stanford University to support query heterogeneous information resources. TSIMMIS is similar to WebLog, but also provides many pre-defined queries for information retrieval so that users need not pose complex queries directly. But, this also restricts searches using a limited set of queries.

W3QS (WWW Query System)[27] at Technion (Israel Institute of Technology) is a project to develop a high level SQL-like Web query language, W3QL, which views the Web as an ultra large database. W3QL is capable of addressing both structure and content. W3QS allows users to specify the starting page for the search, the search domain, and the file names using Perl regular expressions and file types (i.e. extensions gif, tiff, ps) for page contents. W3QS allows users to specify the depth of links for search. In comparison, WebDB also allows users to specify queries with arbitrary Web structures; it is not limited to one link-in or one link-out. Moreover, WebDB’s query interface is more visual and user-friendly and WebDB also supports query relaxation.

SuperPages[28] discusses a loosely coupled architecture to construct the yellow pages service of
GTE SuperPages. It enables Web users to search through listings of 11 million businesses in over 17000
categories. It uses an Information Retrieval (IR) engine, Verity[29], to search through complex listing
objects while the objects themselves are stored in an object database. The complex objects are modeled
as a hierarchical structure with various SGML tags for the IR engine to perform query processing.

The Araneus Project[30] addresses the issue of views in the Web context. It introduces a set of
languages for managing and restructuring data coming from the Web and presents a specific data
model, the Araneus Data Model, to describe the scheme of Web hypertext. Based on the data model,
it develops two languages, Ulixes and Penelope, to support a view definition process. Ulixes is used to
build database views of the Web, which can then be analyzed and integrated using database techniques.
Penelope is used to define derived Web hypertext from relational views, which can be used to generate
hypertextual views over the Web. These languages have been used to develop a scheme for the DBLP
Bibliography Server[31].

Similar to DBLP Bibliography Server, HyperFile[32] is a data and query model for hypertext doc-
ments. It introduces sophisticated modeling scheme and discusses its query processing technique.
Compared with HyperFile, WebDB is a query system hypermedia documents on the Web and WebDB
supports additional functionalities, such as a visual query interface, multimedia search capability, and
query relaxation, to provide higher usability.

3 Modeling World-Wide Web

We view the Web as a collection of HTML documents connected by hyperlinks. To support more
comprehensive and complex query functionalities, such as those described in Section 1, WebDB stores
not only Web document level metadata, but also intra-document and inter-document information. In
this section, we present our modeling scheme for the Web and Web pages followed by the operations on
the data model.

3.1 Web Modeling

We view and model the Web as a labeled directed graph $G_{web} = (V_{web}, E_{web})$, where the vertices
$(V \in V_{web})$ denote the pages and the edges $(E \in E_{web})$ denote the hyperlinks between these pages. The
vertices are labeled by the URLs of the pages and other document level information, including title,
URL, content length, data types, last modified date, and keywords. The edges are links from source
pages to destination pages and are labeled by the descriptive text or image: anchors. Hence, if there is
an edge $e_j \in E_{web}$, of the form $n_i \rightarrow n_k$, with an anchor $label(e_j)$, the page corresponding to vertex $n_i$
has a link to the page corresponding to vertex $n_k$ and the descriptive text associated with this link is
the anchor $label(e_j)$.

Each page, $V \in V_{web}$, is modeled as a graph $G_{page} = (V_{page}, E_{page})$, where the vertices $(V \in V_{page})
denote the content of the page and the directed edges $(E \in E_{page})$ denote the containment relationship.
$V_{page}$ includes a special vertex (root) $v_0$, which denotes the page itself; every other vertex is reachable
from $v_0$. The vertices in this graph are labeled as Table, Form, Image, and Link. For Table and Form,
they may further contain Table, Form, Image, and Link. Therefore, only those vertices which are labeled as Table, Form, Link, or \( v_0 \) (i.e. page) can have outgoing edges.

The vertices of images have no outgoing edges to Table, Form, or other pages\(^2\). Each vertex, labeled as Image, is modeled as a tree \( T_{\text{image}} = (V_{\text{image}}, E_{\text{image}}) \). The vertices of this tree are image objects. The edges are the containment relationship. For more details about the image modeling, please refer to [1].

In the next subsection, we show how we map the above Web modeling to a data model for implementation on database systems.

### 3.2 Data Model

The design and implementation of WebDB is based on the object-relational concept; the Web is modeled using the object-oriented model and the query language is based on SQL3. The Web modeling in WebDB is illustrated in Figure 3 and is as follows:

- A Web document, Doc, is modeled as a compound object with a hierarchical structure. Document level information, such as title, URL, content length, file types, last modified date, collected date, and keywords, are the attributes of Doc object. These attributes are listed in Table 1 and examples of attribute values are given in Appendix C.

- Intra-document structures are modeled as sub-objects of Doc, including Form, Image, Table, and Link. The relationship between Doc and the sub-objects is contains. Sub-objects also have their own attributes and structures. The attributes for Image include Metadata, Format, Caption, and Size. The attribute for Form and Table are contents contained and captions.

Since there may be forms, images, tables, and links within a form or a table, we further model its internal structure recursively as attributes: pointers to other subobjects Form, Image, Table, and Link. For example, if Table A contains Table B and Image I, Table A, Table B, and Image I are three separate subobjects and there are pointers from Table A to Table B and Image I. If there is no other subobject within Table B, the attributes ContainedTable, ContainedImage, ContainedForm, and ContainedLink have a Null value. This modeling scheme allows users to explicitly search internal structures of subobjects, such as retrieving documents containing a table which has an image in the gif format within it”. However, the users can also implicitly perform such search through a text-based search on Table.Contents as follows:

```
Select Doc D1
From WebDB
Where
and D1 contains Table T1
and T1.contents mentions "imgs[rc]*gif"
```

\(^2\)The images mentioned here do not include images used as anchors.
<table>
<thead>
<tr>
<th>Attribute Name</th>
<th>Data Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doc.Title</td>
<td>List of Strings</td>
<td>Document title</td>
</tr>
<tr>
<td>Doc.URL</td>
<td>String</td>
<td>Document’s universal resource locator</td>
</tr>
<tr>
<td>Doc.Keyword</td>
<td>Set of Strings</td>
<td>Keywords associated with the document</td>
</tr>
<tr>
<td>Doc.Length</td>
<td>Integer</td>
<td>Document size in bytes</td>
</tr>
<tr>
<td>Doc.Type</td>
<td>String</td>
<td>File MIME type</td>
</tr>
<tr>
<td>Doc.Last_modified_date</td>
<td>Date</td>
<td>Document last modified date</td>
</tr>
<tr>
<td>Doc.Collcted_Date</td>
<td>Date</td>
<td>Document collected date</td>
</tr>
<tr>
<td>Doc.Image</td>
<td>Sub-object of Image data type</td>
<td>Image contained in the document</td>
</tr>
<tr>
<td>Doc.Form</td>
<td>Sub-object of Form data type</td>
<td>Forms contained in the document</td>
</tr>
<tr>
<td>Doc.Table</td>
<td>Sub-object of Table data type</td>
<td>Tables contained in the document</td>
</tr>
<tr>
<td>Doc.Link</td>
<td>Sub-object of Link data type</td>
<td>Hyperlink references in the document</td>
</tr>
<tr>
<td>Image.Metadata</td>
<td>Image Metadata</td>
<td>Visual characteristics for image matching</td>
</tr>
<tr>
<td>Image.Size</td>
<td>Integer</td>
<td>Image size in byte</td>
</tr>
<tr>
<td>Image.Format</td>
<td>String</td>
<td>Image format, such as gif, jpg, bmp, etc.</td>
</tr>
<tr>
<td>Image.Caption</td>
<td>List of Strings</td>
<td>Description of an image</td>
</tr>
<tr>
<td>Table.Contents</td>
<td>List of Strings</td>
<td>Contents within a table</td>
</tr>
<tr>
<td>Table.Caption</td>
<td>List of Strings</td>
<td>Description of a table</td>
</tr>
<tr>
<td>Table.ContainsImage</td>
<td>Pointer to Image data type</td>
<td>Images contained in a table</td>
</tr>
<tr>
<td>Table.ContainsTable</td>
<td>Pointer to Table data type</td>
<td>Tables within a table</td>
</tr>
<tr>
<td>Table.ContainsLink</td>
<td>Pointer to Link data type</td>
<td>Links within a table</td>
</tr>
<tr>
<td>Form.ContainsForm</td>
<td>Pointer to Form data type</td>
<td>Forms within a table</td>
</tr>
<tr>
<td>Form.Caption</td>
<td>List of Strings</td>
<td>Description of a form</td>
</tr>
<tr>
<td>Form.ContainsImage</td>
<td>Pointer to Image data type</td>
<td>Images within a form</td>
</tr>
<tr>
<td>Form.ContainsTable</td>
<td>Pointer to Table data type</td>
<td>Tables within a form</td>
</tr>
<tr>
<td>Form.ContainsForm</td>
<td>Pointer to Form data type</td>
<td>Forms within a form</td>
</tr>
<tr>
<td>Form.ContainsLink</td>
<td>Pointer to Link data type</td>
<td>Links within a form</td>
</tr>
<tr>
<td>Link.TextualAnchor</td>
<td>List of Strings</td>
<td>The label of links</td>
</tr>
<tr>
<td>Link.ImageAnchor</td>
<td>Pointer to Image data type</td>
<td>The image logo of links</td>
</tr>
<tr>
<td>Link.URL</td>
<td>String</td>
<td>URL of the document referenced</td>
</tr>
</tbody>
</table>

Table 1: Attribute Classification, Types, and Descriptions

We have formally defined a complete set of attributes of Image, Form, and Table. Since Image.metadata, Form.Contents, and Table.Contents are frequently used, these attribute names are default attributes for Image, Form, and Table respectively in our query statements for the simplicity reasons.

- Inter-document information is represented by Link, which is a sub-object of Doc. Link has three attributes: URL for the destination URL, TextualAnchor, and ImageAnchor\(^3\). They are used for modeling inter-document linkage information. Inter-document links are modeled through Join operations on Link.URL and Doc.URL. For TextualAnchor, WebDB supports text-based search, while image match operations are supported for ImageAnchor. For a given Web document which we view as the main page, there are three types of Web documents:

  - Link-in pages: The pages can reach the main pages.
  - Link-out pages: The pages can be reached from the main page.

\(^3\)There are two types of anchors for users to click; namely, an image or a list of strings.
Figure 2: Data Model for Hierarchical Multimedia Web Page

- Unrelated pages: These pages can not be reached from the main pages and these pages can not reach the main page neither.

We illustrate the relationships between the main page and its link-in/link-out pages in Figure 3.

These attributes of Image, Form, Table, and Link are shown in Table 1 and examples of attribute values are also given in Appendix C. Note that Table .Contents, Form .Contents, Link .Anchor, and Doc .Title are of type list of strings, while Doc .keyword is of type Set of strings. In a list of strings, the sequence of string appearance is stored, but the sequence of string appearance in a set of strings is not stored. The reasons why the Doc .keyword is of type Set of strings are as follows:

- Keywords are associated with documents, not with each other;
- Many keywords appear multiple times in a document, but their sequence may vary;
- Many keywords are derived from the document contents. As a result, keywords used for indexing may not be the same as the terms used in the document.

An example of HTML documents and its parsing results are given in Appendix B and Appendix C. The statistics of Web document parsing is provided in Appendix D.
3.3 Operations on Web Document Hierarchical Structure and Links

Through this modeling scheme presented in the previous subsection, the Web can be represented as shown in Figure 3. In Section 3.1, we define the Web as a labeled directed graph $G_{\text{web}} = (V_{\text{web}}, E_{\text{web}})$, where the vertices ($V$) denote the pages and the edges ($E$) denotes the links. Using the model scheme in Figure 3, the vertex ($V$) is represented as a compound object with a hierarchical structure for modeling its internal structure.

The edge ($E$) is modeled implicitly through join operations on $\text{Doc1}.\text{Link}.\text{URL}$ and $\text{Doc2}.\text{URL}$, where $\text{depth}$ is a parameter for join operations, defining the number of join operations to be performed recursively. Given $\text{Doc1}$ and $\text{Doc2}$, which correspond to two vertices on $G_{\text{web}} = (V_{\text{web}}, E_{\text{web}})$, the $\text{depth}$ from node $\text{Doc1}$ to $\text{Doc2}$ is the shortest distance from $\text{Doc1}$ to $\text{Doc2}$ through links.

SQL is suitable to manipulate only traditional textual or numeric data stored as tables. SQL3 extends SQL to support user defined data types and user defined functions to manipulate user defined data types. By viewing objects as entities and links as relations, we can map the modeling representation in Figure 3 to the Entity-Relational (ER) model for designing a SQL-based query language. Since we
model Web documents as compound objects, we need to extend the capabilities of the traditional SQL with the following functionalities:

- **Traversal of the intra-document structure:** The intra-document structure traversal is by way of the predicate *contains*. For example, after the statement “Document Doc contains Tables T” is issued, the system can access sub-object, represented by the variable T, which is contained by the document object Doc. In our system, “Document Doc” and “Tables T” in the statement “Document Doc contains Tables T” are actually viewed as variable declarations. An example statement for traversal intra-subobject structures, such as a link within a table, is as follows:

  Select Doc D1
  From WebDB
  Where
  and D1 contains Table T1
  and T1 contains Link L1
  and L1.TexualAnchor mentions ”NEC”

  Note that *contains* is an overloaded operator. The statement *D1 contains Table T1*, the system defines *T1* is a table subobject of document *D1*, while the statement *T1.containsLinkL1* defines the link subobject *L1* is pointed by the attribute *ContainedLink* of the table subobject *T1*.

- **Traversal of the Web (inter-document links):** The Web structure, on the other hand, is modeled through hyperlinks and depth restriction information. Traversal of the Web from page *Doc_x* to page *Doc_y* through a link with depth of 2 is by way of the following join operations:

  \[
  Doc_x.Link.URL = Doc_y.URL \\
  \text{or} \\
  (Doc_x.Link.URL = Doc_z.URL \text{ and } Doc_z.Link.URL = Doc_y.URL)
  \]

- **Query relaxation:** WebDB supports keyword-based search in conjunction with both syntactic similarities (e.g. term cooccurring frequency) and semantic similarities (i.e. semantic meaning).

- **Similarity-based image matching:** WebDB provides an *i-like* (image like) predicate to perform image matching. The image matching functionality is carried out by an image database SEMCOG and users can specify image related queries using the IFQ visual query interface. Detailed information of SEMCOG and IFQ is available in [1].

- **Searches on the contents within forms and tables:** WebDB provides a *mentions* predicate for searching information within forms and tables in a document. Given that the contents of forms and tables are of type list of strings, users can specify the sequence of appearance for multiple terms to explore row and column structures in tables although row and column structures are not *explicitly* defined here. For forms, tables, images, and links within subobjects of *Form* and *Table* data types, the users can *explicitly* (i.e. using pointers) or *implicitly* (i.e. using string matching) pose queries to explore.
3.4 Query Modeling

We model a Web query as a partially-labeled subgraph, $G_{query} = (V_{query}, E_{query})$. The problem of finding an answer to a user's query can then be regarded as finding a subgraph of $G_{web}$, $G_{sub} = (V_{sub}, E_{sub})$, such that $G_{sub}$ is isomorphic to $G_{query}$ and the specified labels in $G_{query}$ matches those labels on $G_{sub}$.

For example, the query “list all Web pages in the domain of .edu which have links to pages in NEC Web site, www.ccr1.sj.nec.com, containing a keyword “multimedia” within depth of 3” can be posed as follows (formal definition will be given in next section):

```
Select Doc D1
From WebDB
Where D1 contains Link L1
    and L1.URL = Doc D2.URL Depth 3
    and D2.URL like "www.ccr1.sj.nec.com*"
    and D2.Keyword mentions "multimedia"
```
Figure 5: User Query Criteria as Boolean Expression of Strings

and D1.URL like "*.edu/\*"

Based on the data model shown in Figure 2, we can model this query as shown in Figure 4(a). The query statement is a subgraph of the Web data model in Figure 3 with projection operators to project values of attributes URL. In Figure 4(b), we show another way to model the query, where the NEC Web site is the main page and the Web pages in the domain of .edu are link-in pages. Since the relationship between the main window, link-in window, and link-out window are relative, and not absolute, the results for these two types of query models are equivalent. We next give the formal definition of WQL.

4 Query Language Design - WQL

WQL (Web Query Language) is the language we developed for Web query specification. WQL is a descriptive language based on SQL3 to allow users to access and manipulate document structures and attribute values of objects and their sub-objects.

WQL matches the Web model described in Section 3. Being a descriptive language, WQL’s syntax is model-dependent, but not schema-dependent. As a result, WQL simplifies the process of query generating; i.e. the translation of visual query specification into WQL query statements, as described in Section 5.

4.1 Query Definitions

In Table 1, we give the basic type definitions: String, List of Strings, Set of Strings, Date, and Integer. In addition, we introduce a new data type, Boolean Expression of Strings, which is a set of string combination using AND, OR, and NOT. Note that the data type String is equivalent to type Boolean expression of Strings with no AND, OR, and NOT.

Boolean Expression of Strings includes the criteria specification for Doc.URL, Doc.Title, Doc.Keyword, Table.Contents, and form.Contents. Examples are shown in Figure 5. An example of its usefulness is as follows: A user wants to retrieve documents containing keywords Multimedia or Hypermedia, but not Agent. This query may be posed as follows:

Doc.Keyword mentions “Multimedia”
or Doc.Keyword mentions “Hypermedia”
and Not(Doc.Keyword mentions “Agent”)
In order to simplify the users’ specification process for complex queries of Boolean expression, most query interfaces let users pose only Boolean expression of Strings as shown in Figure 5. For the above query criteria, WQL allows users to pose all expressions together using a simplified format as follows:

Doc.Keyword mentions “((Multimedia or Hypermedia) and (not Agent))”

The query criteria is then converted back into the correct Boolean expression format for internal query processing. However, a query optimizer would more likely process the query criteria based on its simplified form since an “intelligent” query processor would scan through the table only once to check all four conditions, rather than scan through the table four times.

Given two arguments, S1 and S2, WQL allows the following operations of comparisons:

- S1 like S2 where like is a popular vendor implemented SQL predicate for string match. S1 is of type string, such as URL, and S2 is Boolean expression of strings. In the case that S2 is Boolean expression of strings with AND, OR, and NOT, queries are translated into Boolean combinations of multiple statements and each statement is in the form of S1 like S2i, where S1 and S2i are of type of string.

- S1 mentions S2: The functionality of the predicate mentions is to test if S2 is sub-set of S1 where S1 is of type set of strings or list of strings, such as Doc.Title, Doc.Keyword, Table.Contents, and form.Contents. S2 can be string or Boolean expression of strings. In the case of S2 is of Boolean expression of strings, queries are translated into Boolean combinations of multiple statements and each statement is in the form of S1 mentions S2i, where S1 and S2i are of type of string.

With WQL, users can explore internal structures of forms and tables, such as rows, columns, or containment other media and data types. For example, if a user wants to retrieve pages containing images in the gif format within a table, the query can be specified as:

Select Doc D
From WebDB
Where D contains Table T
and T mentions “img*src*gif”

WebDB also support the following two functions to allow users to specify a query relaxation scheme:

- sLike(S, N) (Semantic Like) where S is a string and N is the number of semantically similar terms requested: The output of this function is of type of list of strings. For example, a function call sLike(car, 3) may return sedan, coupe, and truck. This function is supported through an on-line lexicon dictionary, Wordnet[33].

- Cooccurrence(S, N) where S is a string and N is the number of terms requested which are related based on their co-occurrence frequency in the same document: The output of this function is of type of list of strings. For example, a function call sLike(“Michael Jordan”, 3) may return “NBA”, “Chicago Bulls”, and “Scotty Pippen”. This function is supported through pre-built indices for co-occurring terms in documents.
4.2 Selection Criteria

Each WQL query is in the following format:

```
Select {projected attributes | [aggregation functions(attributes)]}
From { database names }
Where { selection criteria }
[Group by] { grouping criteria }
[Order by] { ordering criteria }
```

The first line of the this format describes the attributes to be projected or aggregated values. The second line describes the database to be used for search. Note that users do not need to specify table names, which are hidden from the users. In WebDB, users are not required to know schema design, but need to specify the database space for search. The third line provides the selection criteria, as described above. The last two (and optional) lines describe the grouping and ordering criteria for the aggregation operators. The complete language syntax is given in Appendix A. We categorize query selection criteria based on the types of information involved in as follows:

- **Page level metadata selection criteria**: This type of search criteria is based page level metadata, including **Title**, **URL**, **Keyword**, **Last_modified_date**, **Collected_date**, **Size**, and **Type**, associated with a given document. An example query of this type is as follows:

```sql
Select Doc D1.URL, D1.Title, D1.Last_modified_date
From WebDB
Where D1.Title mentions "forum"
    and D1.URL like "(www.ieee.com* or www.acm.com*)"
    and D1.Last_modified_date >= "07/01/1997"
Order by D1.Last_modified_date
```

This query retrieves all documents in the IEEE Web site or the ACM Web site whose titles contain "forum" such that these documents are last modified after July 1, 1997. This query also requests the system to output (project or compute aggregated values) **D1.URL** (default projected attribute), **D1.Title**, and **Last_modified_date** and to sort the output by **Last_modified_date**.

- **Intra-document structure and metadata selection criteria**: This type of search criteria is based on the attributes of subobjects **Form**, **Link**, and **Table** data types. An example query of this type can be as follows:

```sql
Select Doc D1
From WebDB
Where D1.Title mentions "membership"
    and D1.URL like "www.ieee.com*"
    and D1 contains Form F1
```
and F1 mentions "**".

This query retrieves all documents in the IEEE Web site containing forms and keyword “membership”. Note that URL is a default projected attribute if no attribute of document objects is specified. Note that the last statement

F1 mentions "**"

is a simplified version of the statement

F1. Contents mentions "**"

- Inter-document linkage selection criteria: This type of selection criteria requires Doc.URL (information at the document level), Link.URL, and Link.Anchor since inter-document linkage is modeled through join operations and string comparisons on the attribute Anchor. An example query for finding out the most popular Web search engines among Yahoo!, InfoSeek, and AltaVista used at the NEC Web site can be posed as follows:

Select Doc D2.URL, count(*)
From WebDB
Where Doc D1.URL like "www.ccr1.neclab.com**"
   and D1 contains Link L1
   and L1.URL = D2.URL
   and D2.URL like "(www.yahoo.com/index.html or www.altavista.com/index.html
      or www.infoseek.com/index.html)"
Group by D2.URL
Order by 2

Note that this query may alternatively be posed as follows:

Select Link L1.URL, count(*)
From WebDB
Where Doc D1.URL like "www.ccr1.neclab.com**"
   and D1 contains L1
      or www.infoseek.com/index.html)"
Group by L1.URL
Order by 2

One difference between these two queries is that the first query implicitly requests the system to validate the existence of www.yahoo.com/index.html, www.altavista.com/index.html, and www.infoseek.com/index.html, while the second query does not; the system only examines if the URLs of these Web search engines are specified in the documents at NEC Web sites.
5 WebIFQ as Query and Browsing Interfaces

Most existing systems focus on query capability or query optimization for semistructured data. We feel that most of their query languages, based on either datalog, first logic, SQL, or SQL3, are too complicated for non-system designers to use directly. As a result, usability of these systems are low.

WebDB features a visual query interface, WebIFQ, to assist users in specifying queries, which can be complicated. With WebIFQ, icons and menus are used in a drag-and-drop fashion to specify document level selection criteria, linkage conditions, and document information associated with link-in or link-out pages. The corresponding query statements are generated by the system automatically. With WebIFQ, users of WebDB are not required to be aware of the complex query syntax and the underlying schema.

We now present some window dumps to demonstrate how users specify Web queries in our system.

5.1 Query Specification

In Figures 6 and 7, we show a query specification for retrieving documents in the NBA Web with the keyword Bulls or top 5 related terms by co-occurrence statistics, a table containing a word “statistics” and a link to other documents in the NBA Web site with an anchor like “NBA*50” with depth of 3.

Select Doc D1
From WebDB
Where
D1.URL like "www.nba.com*"
and D1.Keyword mentions "Bulls or cooccurrence("bulls",5)"
and D1 contains Image I1
and D1 contains Table T1
and T1 mentions "statistics"
and D1 contains Link L1
and L1.URL = Doc D2.URL
and D2.URL like "www.nba.com*"

There are three types of windows, namely, main, link-in, and link-out windows. WebIFQ allows users to switch between these windows to specify query criteria associated with each window by clicking the Main, Link-in, and Link-out buttons at the top of Search Specification Window. When users specify query criteria in one window, the system shrinks other windows but display their summarized query criteria.

Figure 6 shows the query specifications from the main window view while the link-in window is shrunk: the user specifies the search criteria for URL, Keywords, and Form. After the user clicks the Link-in button, Search Specification Window switches from the main window view (Figure 7) to the link-in window view (Figure 7). Figure 7 shows the query specifications from the link-in window view while the main window is shrunk: the user specifies the search criteria URL of the link-in window.

In Figure 6, there are 2 buttons, P and A, next to the attributes. Users can click on the P buttons to specify Projection operations on particular attributes. The projection on the URL for the main page
Figure 6: Query Specification Using WebIFQ (Main Window View)
Figure 7: Query Specification Using WebIFQ (Link-in Window View)
is default as indicated by the highlighted P button.

Users can click on the A button to apply Aggregation functions to particular attributes. Currently, WebDB supports 7 aggregation functions: Sum, Count, Avg, Stddev, Variance, Max, and Min. Since not all aggregation functions can be applied to a given attribute, when users click on the A button, a pull-down menu appears to show the users the available aggregation functions which can be applied to the attribute. For example, all 7 aggregation functions can be applied to Doc.Length, Doc.Last_modified_date, and Doc.Collected_date, but only Count can be applied to attributes associated with strings, such as Doc.URL, Doc.Title, Doc.Keyword, Table.Contents, and form.Contents. If projection operators or aggregation functions are applied, the corresponding buttons are highlighted.

The interface visualize users’ query specifications as follows:

- Linkage query criteria: In Figure 8, the system visualize the linkage relationship between the main window and the link-out window as well as the anchor and depth conditions.

- Document level and intra-document query criteria: There are three types of windows, namely, main, link-in, and link-out windows. Users can select any window to specify search criteria, while search criteria of other windows are summarized, as shown below the link-out window in Figure 8.

5.2 Browsing Query Results

After the query is processed, the result is displayed in an external result window. When users click on any candidate URL, the query interface interacts with existing Web browsers, such as Netscape Navigator, through remote procedure calls to display the selected home page. Users can also select the "automated display" mode for "slide-show-like" display of all or selected matching pages or simply store the result as a bookmark for further usage. In Figure 8, the user clicks on several documents (highlighted in this picture) that he/she is interested in browsing.

6 Conclusion

We views the Web as a database with semistructured Web pages. To support more comprehensive query functionalities, not only document level metadata but also intra-document structures and inter-document linkage information are collected in our system. This paper presents WebDB, a Web query system, and its modeling, language, and implementation. WebDB is based on object-relational concepts and features a query language based on SQL3. It provides access to all of these three types of information in a uniform manner. In addition, WebDB provides query facilities that traditional databases provide, including selection, projection, and organization (through aggregate functions) capabilities. We have demonstrated many useful applications of this system. WebDB provide services beyond existing Web search engines can. One significant contribution of WebDB is that it supports a visual query interface and a query generator for complex Web queries. WebIFQ makes WebDB more practical to use compared with other existing systems.
Figure 8: Example query Using WebDB Query and Browsing Interfaces

References


Appendix A: Query Language Syntax in BNF

```
query ← select output_description from database_name where query_description | 
            select output_description from database_name where query_description 
            group_by_description | 
            select output_description from database_name where query_description 
            order_by_description | 
            select output_description from database_name where query_description 
            group_by_description order_by_description 

query_description ← atomic_query_description| composite_query_description 

composite_query_description ← (query_description and query_description) | 
                              (query_description or query_description) | 
                              not(query_description) | 
                              (query_description) 

page_attribute_name ← title| keyword_list| url| type| size| last_modified_date| collection_date 

numeric_attribute_name ← size| last_modified_date| collection_date 

output_description ← output_term| output_term, output_term 

output_term ← output_document_term| output_image_term| 
                   output_table_term| output_form_term| 
                   output_link_term 

output_document_term ← document_variable.page_attribute_name | 
                       sorted document_variable.page_attribute_name | 
                       max document_variable.numeric_attribute_name | 
                       min document_variable.numeric_attribute_name | 
                       avg document_variable.numeric_attribute_name | 
                       cv document_variable.numeric_attribute_name | 
                       std document_variable.numeric_attribute_name 

output_image_term ← image_variable | 
                     semantic_variable | 
                     dual_variable.semantics | 
                     dual_variable.image | 
                     sorted semantic_variable | 
                     sorted dual_variable.semantics 

output_table_term ← table_variable.content | 
                    table_variable.caption | 
                    table_related_variable 

output_form_term ← form_variable.content | 
                    form_variable.caption | 
                    form_related_variable 

output_link_term ← link_variable.url | 
                    link_variable.textual_anchor | 
                    link_variable.image_anchor 
```
atomic_query_description ← page_based_query_description
  web_based_query_description
  media_based_query_description

page_based_query_description ← title_query | keyword_query | type_query | size_query | date_query |
  containment_query

title_query ← title_term mentions title_term

keyword_query ← keyword_term mentions keyword|
  keyword_term set_operator keyword_term

type_query ← type_term.type = type_term

size_query ← size_term num_operator size_term

date_query ← date_term date_operator date_term

title_term ← document_variable.title | title

keyword_term ← document_variable.keyword_list

type_term ← document_variable.type | type

size_term ← document_variable.size | size

date_term ← document_variable.last_modified_date |
  document_variable.collection_date | date

containment_query ← document_variable contains link link_variable| |
  document_variable contains table table_variable| |
  document_variable contains form form_variable| |
  document_variable contains image image_variable

media_based_query_description ← image_query | table_query | form_query

image_query ← nested_image_query|
  image_variable.caption mentions string

table_query ← table_variable.contents mentions string|
  table_variable.caption mentions string|
  nested_table_query

form_query ← form_variable.contents mentions string|
  form_variable.caption mentions string|
  nested_form_query

web_based_query_description ← url_descriptor = url_descriptor Depth number |
  link_variable.textualanchor mentions string |
  url_descriptor mentions string

url_descriptor ← document_variable.url | link_variable.url

set_operator ← ≤ | ≤ | ≥ | ≥ |

num_operator ← < > | ≤ | ≥ |

date_operator ← before | after | within_operator

within_operator ← within numeric

groupby_description ← groupby attribute_list

attribute_list ← document_variable.page_attribute_name | 
  document_variable.page_attribute_name , attribute_list

title ← [ term_list ]

caption ← [ term_list ]

contents ← [ term_list ]

keyword_list ← [ term_list ]

database_name ← string
keyword ← string
url ← string
type ← string
size ← numeric
last_modified_date ← date
collection_date ← date
term_list ← string | string, term_list

nested_image_query ← image_query_description
image_query_description ← atomic_image_query_description | (image_query_description and image_query_description)

atomic_image_query_description ← semantics_based_image_query_description | scene_based_image_query_description | cognition_based_image_query_description

semantics_based_image_query_description ← (entity_description is entity_description) | (entity_description isA entity_description) | (entity_description isLike entity_description)

scene_based_image_query_description ← (sd_entity_description to the right of sd_entity_description in entity_description) | (sd_entity_description to the left of sd_entity_description in entity_description) | (sd_entity_description above of sd_entity_description in entity_description) | (sd_entity_description below of sd_entity_description in entity_description)

cognition_based_query_description ← (id_entity_description isLike id_entity_description) | (entity_description contains dual_entity_description)

entity_description ← semantic_entity_description | dual_entity_description | image_entity_description

sd_entity_description ← semantic_entity_description | dual_entity_description

id_entity_description ← image_entity_description | dual_entity_description

semantic_entity_description ← semantic_constant | semantic_variable

dual_entity_description ← dual_variable

image_entity_description ← link_variable, imageanchor | image_constant | image_variable

semantic_constant ← term1 | term2

image_constant ← image1 | image2

semantic_variable ← Δ | Ε | ...
dual_variable ← Δ | Ε | ...
image_variable ← Δ | Ε | ...
nested_table_query  \leftarrow  table_query\_description

\text{table\_query\_description}  \leftarrow  atomic\_table\_query\_description \\
\phantom{table\_query\_description}  \leftarrow  base\_table\_query\_description \\
\phantom{table\_query\_description}  \leftarrow  \text{container}\_table\_query\_description \\

\text{containment\_table\_query\_description}  \leftarrow  table\_variable  \text{contains}  column\_variable  \\
\phantom{containment\_table\_query\_description}  \leftarrow  table\_variable  \text{contains}  column\_variable  \\
\phantom{containment\_table\_query\_description}  \leftarrow  row\_variable\_variable  \\
\phantom{containment\_table\_query\_description}  \leftarrow  cell\_variable\_variable  \\

\text{base\_table\_query\_description}  \leftarrow  \text{table\_related\_variable}  \text{mentions}  keyword  \\
\phantom{base\_table\_query\_description}  \leftarrow  \text{table\_related\_variable}  \text{contains}  link\_variable  \\
\phantom{base\_table\_query\_description}  \leftarrow  \text{table\_related\_variable}  \text{contains}  table\_variable  \\
\phantom{base\_table\_query\_description}  \leftarrow  \text{table\_related\_variable}  \text{contains}  form\_variable  \\
\phantom{base\_table\_query\_description}  \leftarrow  \text{table\_related\_variable}  \text{contains}  image\_variable  \\
\phantom{base\_table\_query\_description}  \leftarrow  \text{image\_query}  |  \text{table\_query}  |  \text{form\_query}  \\
\phantom{base\_table\_query\_description}  \leftarrow  \text{link\_variable\text{\_textual\_anchor}}  \text{mentions}  string  \\
\phantom{base\_table\_query\_description}  \leftarrow  \text{link\_variable\_url}  =  \text{uri\_descriptor}  \text{Depth}  \text{number} \\

\text{table\_related\_variable}  \leftarrow  column\_variable|\text{integer}  |  row\_variable|\text{integer}  |  \\
\phantom{table\_related\_variable}  \leftarrow  column\_variable|\text{row\_variable}|\text{cell\_variable}  \\

\text{table\_variable}  \leftarrow  \mathbb{A}  |  \mathbb{B}  \cdots  \\
\text{row\_variable}  \leftarrow  \mathbb{A}  |  \mathbb{B}  \cdots  \\
\text{column\_variable}  \leftarrow  \mathbb{A}  |  \mathbb{B}  \cdots  \\
\text{cell\_variable}  \leftarrow  \mathbb{A}  |  \mathbb{B}  \cdots  \\

\text{nested\_form\_query}  \leftarrow  \text{form\_query\_description}  \\

\text{form\_query\_description}  \leftarrow  atomic\_form\_query\_description  \\
\phantom{form\_query\_description}  \leftarrow  \text{form\_query\_description}  \text{and}  \text{form\_query\_description}  \\

\text{atomic\_form\_query\_description}  \leftarrow  \text{form\_variable}  \text{mentions}  keyword  \\
\phantom{atomic\_form\_query\_description}  \leftarrow  \text{form\_variable}  \text{contains}  link\_variable  \\
\phantom{atomic\_form\_query\_description}  \leftarrow  \text{form\_variable}  \text{contains}  table\_variable  \\
\phantom{atomic\_form\_query\_description}  \leftarrow  \text{form\_variable}  \text{contains}  form\_variable  \\
\phantom{atomic\_form\_query\_description}  \leftarrow  \text{form\_variable}  \text{contains}  image\_variable  \\
\phantom{atomic\_form\_query\_description}  \leftarrow  \text{image\_query}  |  \text{table\_query}  |  \text{form\_query}  \\
\phantom{atomic\_form\_query\_description}  \leftarrow  \text{link\_variable\text{\_textual\_anchor}}  \text{mentions}  string  \\
\phantom{atomic\_form\_query\_description}  \leftarrow  \text{link\_variable\_url}  =  \text{uri\_descriptor}  \text{Depth}  \text{number} \\

\text{form\_variable\_description}  \leftarrow  \mathbb{A}  |  \mathbb{B}  \cdots  \\

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Appendix B: Sample HTML Document

```html
<head>
<title>Bulls Player File: Dennis Rodman</title>
</head>

<body>

<TABLE border=0 width=620>
<tr>
<td valign=top width=90 height=100>
<img src="/Bulls/images/logo_sub.gif"/>
<a href="http://www.nba.com/Bulls/">Chicago Bulls</a>
</td>
</tr>
<tr>
<td valign=top width=310>
<font face=arial size=2 color="#000000">PLAYER&nbsp;&nbsp;FILE</font><br/>
<font face=arial size=6 color="#f0f0f0">Dennis Rodman</font>
</td>
</tr>
<tr>
<td valign=top width=75>
<img src="/playerfile/images/dennis_rodman.jpg" width=65 height=90 border=0 hspace=8 align=left/>
</td>
</tr>
<tr>
<td valign=top width=135>
<font size=2 face=arial color="#f0f0f0">Position: Forward</font><br/>
<font size=2 face=arial color="#f0f0f0">Born: 05/13/61</font><br/>
<font size=2 face=arial color="#f0f0f0">Height: 6-8</font><br/>
<font size=2 face=arial color="#f0f0f0">Weight: 220 lbs.</font><br/>
<font size=2 face=arial color="#f0f0f0">College: Southeastern Oklahoma State '86</font><br/>
</td>
</tr>
</TABLE>

<p>
<a href="/playerindex.html">NBA Player Directory</a><br/>
<a href="/index.html">NBA.com</a>
</p>

</body>
</html>

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# Appendix C: Parsing Result for Sample HTML Document

<table>
<thead>
<tr>
<th>Attribute Name</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doc.Title:</td>
<td>Bulls Player File: Dennis Rodman</td>
</tr>
<tr>
<td>Doc.URL:</td>
<td><a href="http://www.nba.com/playerfile/dennis_rodman.html">http://www.nba.com/playerfile/dennis_rodman.html</a></td>
</tr>
<tr>
<td>Doc.Length:</td>
<td>34443</td>
</tr>
<tr>
<td>Doc.Type:</td>
<td>HTML</td>
</tr>
<tr>
<td>Doc.Last_modified_date:</td>
<td>866277163 (Sat, 14 Jun 1997 08:32:43 GMT)</td>
</tr>
<tr>
<td>Doc.Collect_date:</td>
<td>Thursday, 23-Oct-97 19:09:37 Local time</td>
</tr>
<tr>
<td>Doc.Image:</td>
<td>/Bulls/images/logo_sub.gif</td>
</tr>
<tr>
<td></td>
<td>/playerfile/images/dennis_rodman.jpg</td>
</tr>
<tr>
<td>Doc.Form:</td>
<td>NULL</td>
</tr>
<tr>
<td>Doc.Table:</td>
<td>&lt;img src=&quot;/Bulls/images/logo_sub.gif&quot;/&gt; PLAYERFILE Dennis Rodman Position: Forward Born: 05/13/61 Height: 6-8 Weight: 220 lbs. College: Southeastern Oklahoma State 86’</td>
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<td></td>
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Appendix D: Statistic for Parsing HTML Documents

The statistic for our experiments on parsing HTML documents on three Web sites, www.nba.com, www.nfl.com, and www.majorleaguebaseball.com, are

- The number of documents parsed: 2914 in three Web sites.
- Forms are found in 13 documents.
- Tables are found in 2357 documents. Note that tables are frequently used for formatting purposes, rather than to express tabular information. This number includes tables used for both purposes. Using some type of filter to differentiate between "real" and "formatting only" tables is being investigated.
- There are 2324 distinct images found and every document has at least one image.
- There are 37030 links (including intra-document links) among documents.
- Keywords: 8402 distinct keywords are found and 3494 of them can be found in the dictionary.
- Size of the metadata for parsed documents:
  - 10.9M except tables and forms
  - Parsed metadata is 7.5M for tables and 7K for forms.
  - The original raw HTML file size is 23.4M for 2914 documents.

Note that the metadata here is used to provided full text search.
Author Bibliography

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