# Managing Complexity in a Distributed Digital Library

With multiple collections, languages, and media, digital libraries are becoming more difficult to maintain and develop. Researchers at New Zealand's University of Waikato have developed a software architecture that deals with this complexity.

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As the capabilities of distributed digital libraries increase, managing organizational and software complexity becomes a key issue. How can collections and indexes be updated without impacting queries currently in progress? When users can communicate with the system in different natural languages, how can software cope with the display of various versions of text? With multimedia collections, how can a uniform, extensible software framework accommodate different kinds of search engines required to search various media types? How can the system handle several user-interface clients for the same collections? How do these clients learn about new collections created in different physical locations?

We have developed a software structure that successfully manages this complexity in our own digital library. It dynamically handles additions of new collections in different locations without requiring a centralized list. Its novel, flexible macro language manages interfaces to many collections in many languages, and the structure allows development of experimental user interfaces. It accommodates radically different search engines within a uniform structure and communication protocol. The architecture has met our goal of minimizing maintenance while allowing our digital library to easily expand its offerings.

## THE NEW ZEALAND DIGITAL LIBRARY

The New Zealand Digital Library (http://www.nzdl.org) currently offers about 20 collections, varying in size from a few documents up to 10 million documents and several gigabytes of text. These collections

- use different browsing and indexing structures;
- are accessible by computers in different locations;
- support interaction in a variety of languages; and
- contain text, graphics, and audio components.

Some, such as our music collection, require special retrieval engines for nontextual information.

Many collections are updated automatically every few days, but a few—such as the Oxford Text Archive—rarely change. Most collections are created from electronic source texts, but some—notably the Historic New Zealand Newspaper Collection—require scanning and the use of optical character recognition (OCR) to capture the source material. Some collections and their contents are well structured and lend themselves well to browsing, but many have little or no easily discernable structure.

### Multiple languages

The library's documents are written in many different languages, including English, French, German, Arabic, Maori, Portuguese, and Swahili. Many collections contain several languages, as do some documents. For example, the Historic New Zealand Newspaper Collection, illustrated in Figure 1, is bilingual, with parallel Maori and English articles.

The library also provides interfaces to the collections in several languages. For example, the Computer Science Technical Reports collection has English, French, German, and Maori interfaces. The Arabic interface to the Arabic Library, shown in Figure 2, requires storage and search mechanisms that can handle non-ASCII alphabets. Because the code that produces Web pages is divorced from text strings appearing on them, new languages can be added by merely translating all phrases and menu terms used in the interface.

To accommodate blind (with speech synthesizers) and partially sighted users (with large-font displays), we provide text-only versions of the interface for each language. For this, we follow standard guidelines for Web-page accessibility.[1]

### Multiple media

Some collections contain more than just text. For example, the Local Oral History Collection includes recorded interviews and photographs that illustrate them. Users query summary transcripts. Figure 3 shows results for a query about VE Day.


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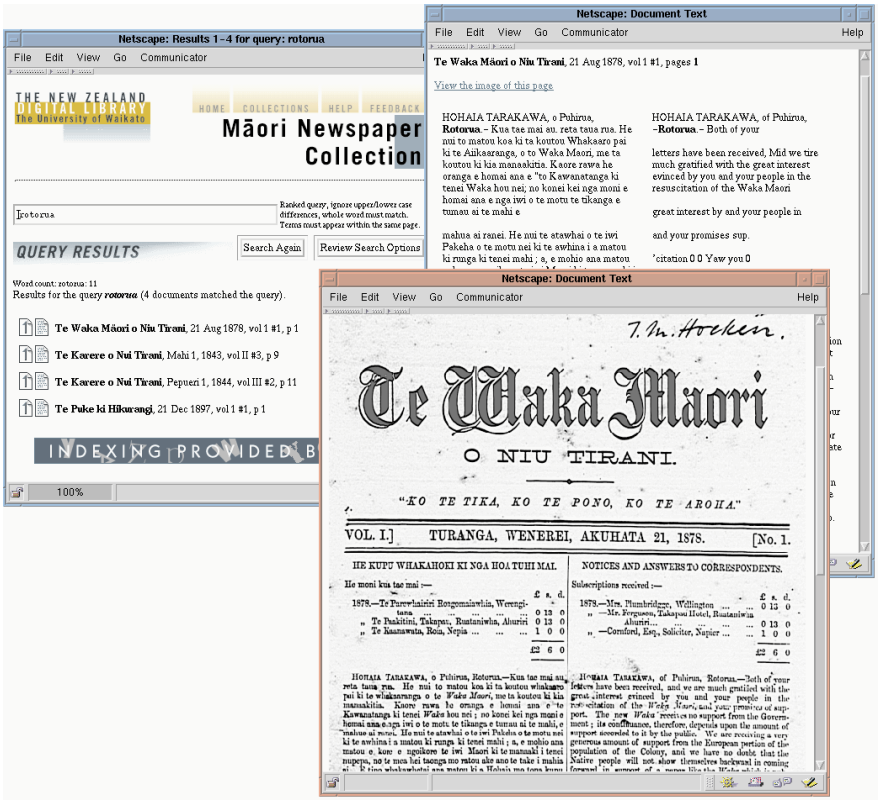



*Figure 1. Searching the Historic New Zealand Newspapers Collection. The collection is bilingual; all articles are retrieved in Maori and English.*

The Music Library demonstrates a technically more significant multimedia capability. Users can sing or hum a tune, then upload their audio file to find a match in a tune database. Figure 4 shows the results when a user sings the first eight notes of "Auld Lang Syne." The transcribed input appears at the top left, and titles of similar items, ranked according to how closely they match the query, appear below. Any of the tunes may be selected for audio replay or visual display, as shown on the right.

The Music Library database includes nearly 10,000 folk tunes from North America, Ireland, Britain, Germany, and China. Users can search the entire database or limit their searches to individual countries. The Music Library is a good example of how the digital library's single unifying architecture can encompass radically different search regimes.

## SYSTEM DESIGN

Our design is based on *collections*—sets of like *documents*.[2] These documents come in a variety of formats: plain ASCII, PostScript, PDF, HTML, SGML, and Microsoft Word for textual documents; Refer, BibTex, and USMarc for bibliographic information; and various formats for graphics and sound.

Collections invariably undergo a *building process* to make them suitable for search, retrieval, and display. This often involves converting the documents to a different format and identifying subparts that require their own indexes. Among the current collections are indexes for complete documents, individual pages, paragraphs, articles, abstracts, authors, titles, subjects, publication details, references, and motions in meetings.


*Figure 2. Arabic interface for the Arabic Library.*

Collections are *rebuilt* when new documents are added to them. To avoid disrupting active users, rebuild-

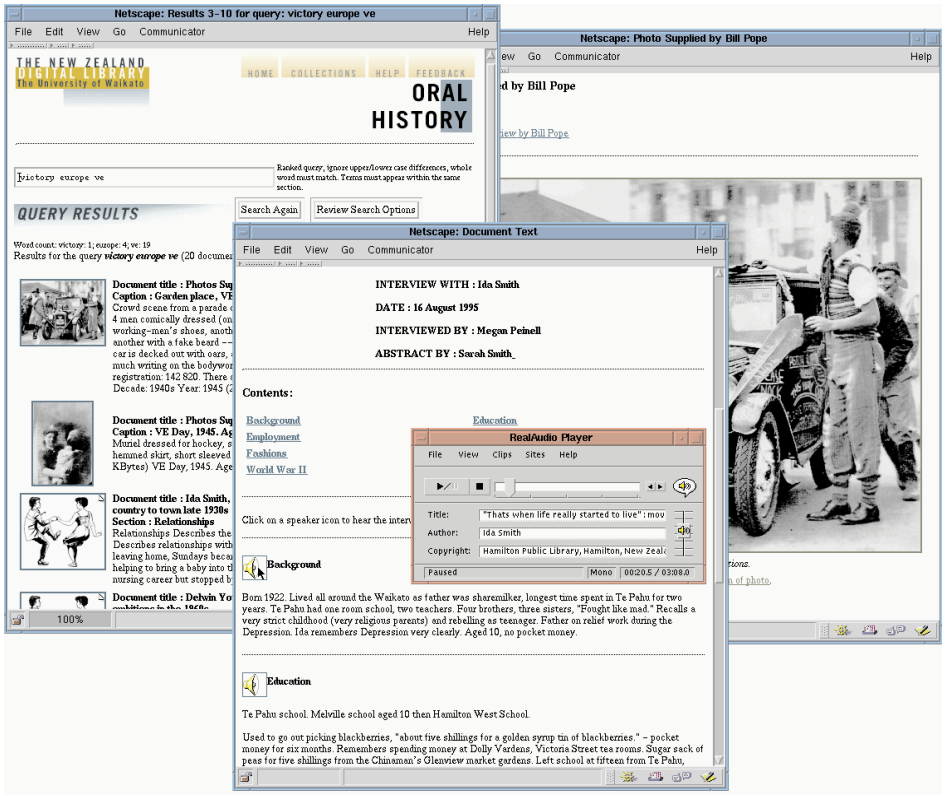



***Figure 3. Results of a query about VE Day from the Local Oral History Collection. The small gray panel controls audio playback of a sound bite or relevant section from a participant's interview.***

ing takes place in a separate file directory, and when it is complete, the directory is moved in one fell swoop to the live file area. The query engine automatically manages the transition to the new version. Current users experience only a brief delay while the query process reinitializes. References on a query results page, however, may become incorrect after the update occurs. To resolve this, we could simply warn users, but our plan is to instead use persistent document identifiers.

Normally, several collections operate on the same server machine—by convention in one directory—and each server machine runs its own copy of the collection server software. Collections are active objects, receiving and processing messages, such as search requests and document display requests. Therefore, they can be instructed to look for other collections in their own directory—which avoids a high-maintenance centralized list. Adding a new collection merely involves inserting it into a directory with an already known collection.

Whenever a user-interface client starts up (and periodically while it is running), it messages collections on all machines, requesting information on other collections in their directories. When a collection is added, all interface clients will eventually realize it. This automatic notification process greatly simplifies the process of adding new collections.

## Managing complexity

Managing the complexity of multiple collections, multiple languages, and multiple interface options presents a significant challenge. For example, document items that have not yet been translated to other languages need to default to English. Non-ASCII languages like Arabic and Chinese need special text positioning and justification. Text-only pages require a structure different from corresponding text-and-graphics pages. Page headers and footers must allow some collections to override them. Directory names and URLs should be referenced symbolically, facilitating the system's configuration to different environments.

For easily maintained, easily augmented, and consistent interfaces to collections, commonality must be abstracted out and represented in just one place. We design Web pages, then, with a model based on structure, content, and reusable items:

- The *structure* allows different versions of the content. For example, a page might contain some sort of heading, a main information section, and a footer with navigation aids. The heading in turn might have its own structure, with masthead and navigation aids at the top and an advertisement underneath.
- The *content* comprises the principal information elements of the page—text, graphics, sound clips, and video—separated from the page structure in separate resources. Many content items are language-specific, and all resources pertaining to a particular language are collected together for easy maintenance.
- *Reusable items* include pathnames of certain directories and frequently used icons. Isolating these items renders Web pages more portable.

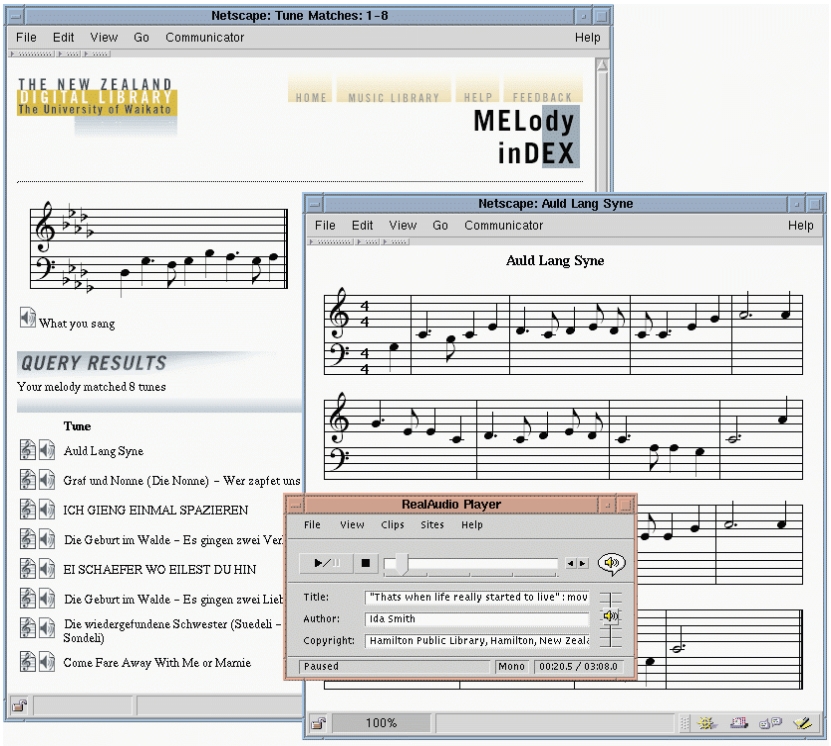



*Figure 4. Using the Music Library to find "Auld Lang Syne."*

We meet these requirements using a flexible, specially designed macro language. While standard macro languages are often used to maintain large collections of Web pages,[3] such languages only support different page versions through the conditional inclusion of text. This quickly becomes cumbersome as the number of options increases.

Our macro language, however, allows many variants of the same macro, each with different parameter values. Our three basic parameters are collection name, text-and-graphics or text-only format, and language. At expansion time, the macro processor searches the database for a variant matching all three parameter values for the generated page's environment. If it does not find an exact match, it uses the closest match based on each parameter's priority. For example, if a user seeks a German text-and-graphics format, but the database contains only English and German text-only versions, the processor calls up the German text-only version.

Macros also support essential maintenance operations. Each week an automatic process scans the macros, locates those that have been flagged as needing translations, and mails the material to appropriate translators.

## Facilitating searches

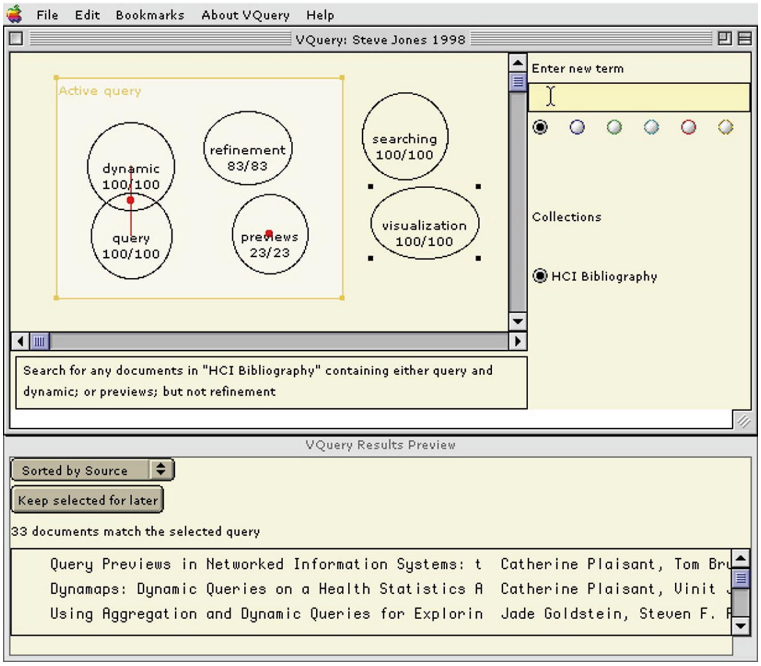
Because collections run on different computers, our system is distributed, but searching is not distributed: Each collection handles its own searches. Cross-collection searching would be relatively easy for collections on the same server, but searching across servers would involve a more difficult distributed search process (which is addressed to an extent by some information retrieval systems[4]). Our goal, however, has not been to advance the state of the art in information retrieval, but to provide a flexible structure that can accommodate the latest advances.

While searches in some multimedia collections can be done on textual descriptions of the media objects, different media types generally require different search mechanisms. Presently the system includes two search and retrieval methods—one for text and the other for music. Our uniform architecture accommodates them and their vastly different document types. This structure is flexible, allowing us to incorporate other retrieval mechanisms in the future—for example, one for accessing an image collection through content-based queries.[5]

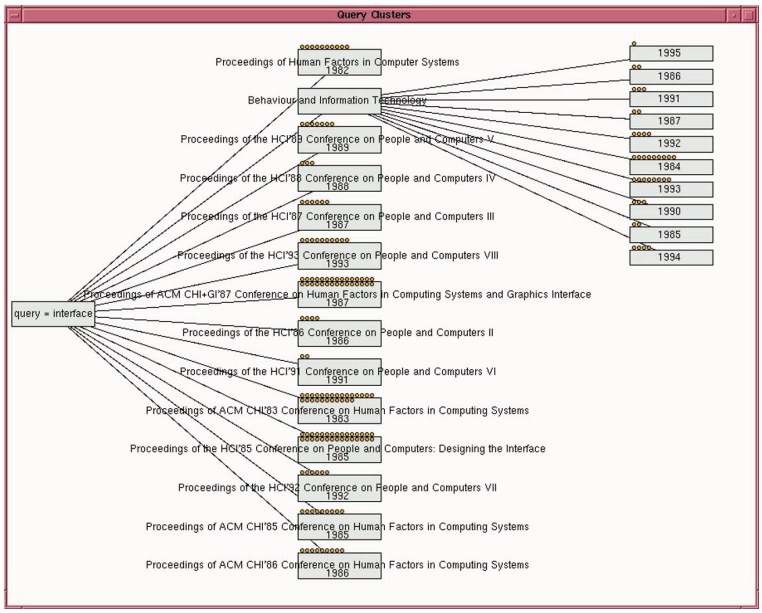
For text, we use MG, a full-text retrieval system that efficiently stores text and its index in compressed form.[6] MG typically compresses text to about 25 percent of its original size and compresses indexes to about 7 percent of the original text's size—making the total storage requirement about one-third of the original text's size.

For music, we use MR, a novel scheme for searching musical melodies.[7] MR matches sung (or hummed) input to a database of tunes, with various user options:

- Restricting attention to subsets of the database
- Choosing one of two matching algorithms
- Matching anywhere within a tune or to beginnings only
- Matching using musical intervals or coarser up-down-same pitch differential contour
- Ignoring or taking into account note duration, transcribing using fixed tuning, or trying to adapt to overall drift in the user's intonation
- Specifying minimum rest and note lengths
- Specifying music speed




(a)




(b)

***Figure 5. Two experimental interfaces to the New Zealand Digital Library. (a) A Java applet provides a graphical language for Boolean querying. (b) A Tcl/Tk application visualizes clusters of documents that are the result of a sequence of queries.***

Many of these options are needed because users differ in their musical ability and in the accuracy with which they remember tunes.

The process of building a collection is heavily dependent on the mechanisms used to search it because so much of the building involves creating an indexing structure. Consequently, for each collection there is a *builder process*, which performs the offline activity of creating the index and other supporting structures, and a corresponding *collection server process*, which manages user interaction.

To accommodate different index structures, often with widely differing needs, the builder and server processes use a flexible, object-oriented program structure. Object classes with all the basic features needed for building, document retrieval, and searching are defined, but the functionality they provide is selectively overridden by defining subclasses for particular search and retrieval systems. These defining subclasses are themselves finally overridden by collection-specific subclasses that accomplish any task peculiar to a collection.

## Improving interfaces

Internet search engines and online public-access library catalogs commonly provide textual query languages like Z39.58,[8] but such interfaces present problems for casual users, such as the need to learn the syntax of the language. Using various implementation platforms, we are developing several highly interactive, graphical, and direct manipulation interfaces to the library.

Figure 5a shows one example, a Java applet that provides a graphical language for Boolean querying and updates itself immediately as the query is modified. Figure 5b shows another, a Tcl/Tk application for visualizing clusters of documents resulting from a sequence of queries. A communication protocol defines how user-interface software communicates with collections through network connections established with collection servers.[2] These interfaces have been developed without modifying the collection server software and without close code integration between the user interface and the server.

Collection servers recognize three message types:

- Requests for general information, such as details of available collections
- Requests for document information, such as summaries or the full text of documents
- Requests for documents matching specified search criteria

User interface clients do not necessarily operate on any collection's host machine, and our Java implementations are independent of platforms. We have developed an application programmer's interface to a software library that contains routines to form and send requests to collections and manage the resulting responses. This makes it easy to integrate new interfaces, without any impact on collection servers. Both the standard Web interface and our experimental interfaces exploit the protocol, and different interfaces can coexist without any difficulty.

Dynamic query interfaces—in which displayed document-result sets change immediately whenever query parameters change—form the focus of our user interface research. Here, operations must be executed quickly on locally cached document information. The protocol allows close control over when information is sent from the collection server to the cache and how much is transferred. For example, in bibliographic collections, items such as author, title, and keywords can be retrieved individually for single documents. Only

the information that is desired is retrieved over the network. This improves response time, minimizes the size of the local data store, and allows information to be displayed incrementally as it arrives. Users can continue interacting while information is still arriving.

Our system successfully manages organizational and software complexity in a large, fully operational, and widely used digital library system. Our fundamental goal has been to minimize the effort required to keep the system operational and yet continue to expand its offerings. We can now easily build new collections with distinctive features and indexes—adding them at any time, on any existing server, while the system is running. We can accommodate new languages by translating phrases and images used in the interface and incorporating them into the collection server software. We can easily incorporate multiple media and initiate nonstandard search engines for them. We can apply new, highly interactive interfaces, implemented on the client side and using a variety of support technologies. The structure we have developed makes it easy to keep a digital library working and growing. ❖


### Acknowledgments

We gratefully acknowledge the help of Carl Gutwin, who developed one of the experimental user interfaces. Many thanks are also due to Stefan Boddie, Te Taka Keegan, Craig Nevill-Manning, and Lloyd Smith, who contributed to this work in various ways.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**Dialogue designers must be both very careful and very lucky, or interaction problems will remain during the implementation and testing stages.**