

The end of zero-hit queries: query previews for NASA's Global Change Master Directory

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Abstract. The Human-Computer Interaction Laboratory (HCIL) of the University of Maryland and NASA have collaborated over three years to refine and apply user interface research concepts developed at HCIL in order to improve the usability of NASA data services. The research focused on dynamic query user interfaces, visualization, and overview + preview designs. An operational prototype, using query previews, was implemented with NASA's Global Change Master Directory (GCMD), a directory service for earth science datasets. Users can see the histogram of the data distribution over several attributes and choose among attribute values. A result bar shows the cardinality of the result set, thereby preventing users from submitting queries that would have zero hits. Our experience confirmed the importance of metadata accuracy and completeness. The query preview interfaces make visible the problems or gaps in the metadata that are undetectable with classic form fill-in interfaces. This could be seen as a problem, but we think that it will have a long-term beneficial effect on the quality of the metadata as data providers will be compelled to produce more complete and accurate metadata. The adaptation of the research prototype to the NASA data required revised data structures and algorithms.

Key words: Query preview – Graphical user interface – Browsing – Earth science – Metadata

1 Introduction

Soon, users (scientists, teachers, students, etc.) will be able to access NASA's Earth Observing System Data

Information System (EOSDIS) to retrieve earth science data from hundreds of thousands of datasets containing pictures, measurements, or processed data, from centers around the country. Data about the datasets (called metadata) is available and is searched as a preliminary step before retrieving the huge datasets. Standard EOSDIS metadata includes spatial coverage, time coverage, type of data, sensor type, campaign name, level of processing, etc. Existing EOSDIS prototypes use classic form fill-in (or form-completion) interfaces. They allow users to search the already large holdings but zero-hit queries are a problem, and it is difficult or impossible to estimate how much data are available on a given topic and what to do to increase or reduce the result set.

More robust querying interfaces are needed for a system that will support intermittent users with extensive or limited computer experience and domain knowledge. Users will come to the EOSDIS with problems that vary according to several factors, including: how well defined the solution to the problem is (e.g., ranging from simple facts to interpretations for complex phenomena) and how well defined the problem is in the information seeker's mind. Such information systems must accommodate different levels of experience with the content area, with the information system itself, and with information seeking in general.

Our approach is to employ overview + preview representations of metadata [8] that allow users to rapidly and dynamically eliminate undesired datasets, while at the same time previewing result set sizes to avoid zero-hit queries [7, 16, 19]. The reduced volume of the metadata allows queries to be previewed and refined locally before they are submitted over the network. This two-step approach of query preview and query refinement extends the technique of dynamic queries [1, 26] to large distributed information systems.

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In this paper we describe our original design and prototype, then discuss the technology transfer process from our research prototype to an operational prototype by reviewing the issues and problems encountered, the options examined, and the solutions adopted.

1.1 Related work

The growth of the internet and the formidable push to make information available online or to digitize existing materials has been only partially matched by the development of tools to assist users in their tasks. Generic improvements to the browsing of web pages have been proposed using a book metaphor [5], the “decks of cards” metaphor [3], or tiled elastic windows [12].

Search interfaces are being refined. Research is being conducted to improve the search engines which rely on the analysis of machine readable textual materials, while powerful tools are created for specialized formats (e.g., Infomedia for videos [25]). Other projects combine the text search with visualization methods to display the result of the searches (e.g., tilebars [9] or Envision [10]). When no metadata or text is available to be searched, browsing becomes essential [14, 15, 17].

[4] and [6] provide several examples of large digital libraries projects, and show that the focus of many projects remains on digitization and infrastructure. Comprehensive evaluations will be the key to understanding the benefits of new designs [11, 13].

2 From research prototype to operational prototype: issues and solutions adopted

2.1 Original research prototype

After a rudimentary interface mockup in Visual Basic [7] we implemented a prototype in Tcl-Tk and then in Java when it became available. The research prototype used simulated data, randomly generated to illustrate our concept for a possible EOSDIS interface.

2.1.1 Query preview

Our original query preview prototype features a single-screen overview of all earth science datasets available from a designated information service provider (Fig. 1). The data are characterized with three high-level attributes: location, temporal coverage, and topic content. For each attribute value in the user interface, the number of available datasets bearing that attribute value is shown (Fig. 1a). This gives users an overview of the distribution of the available datasets. By clicking on combinations of attribute values, users can prune to reflect only those data items that satisfy selected attributes (Fig. 1b). When the preview indicates a reasonable result set size, users submit the query and move the query to a refinement phase.

2.1.2 Query refinement

During the refinement phase, the user interface operates on the result set of the preview phase and shows all the metadata. In our research prototype, each dataset is represented as a line in an overview display, whose axes are the size (vertical axis) and the time period (horizontal axis) of the datasets respectively. Users further refine the query by selecting more precise values for the parameters for sensor, platform, project, data archive centers, processing data level, etc. (Figs. 2a,b). When they think the query is sufficiently refined, users submit the query and retrieve full dataset records and can be directed to the web location where the data are made available.

2.1.3 Evaluation of the prototypes

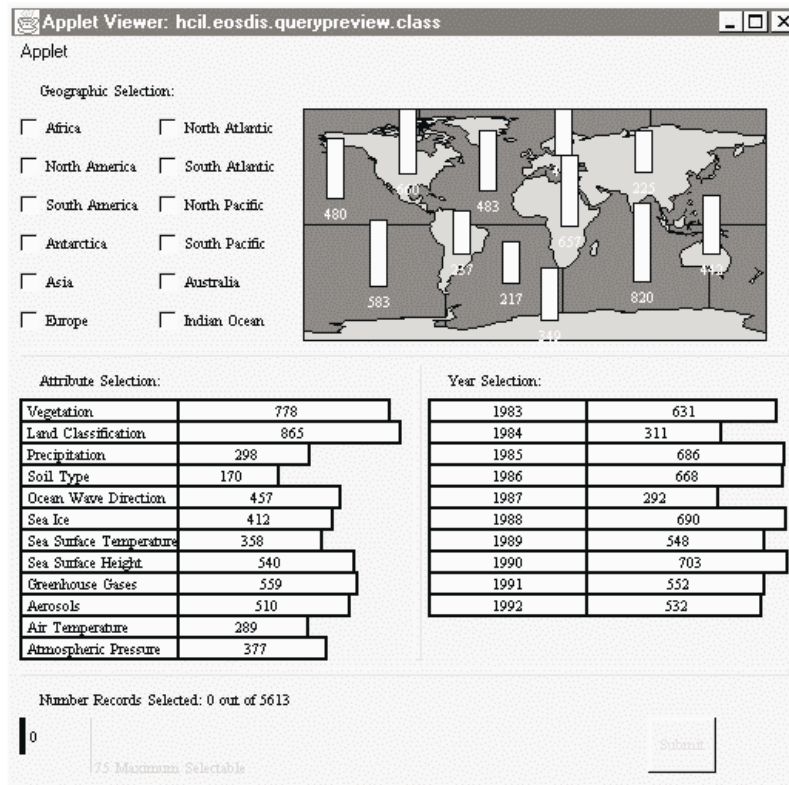
The original research prototype was informally evaluated during one of the prototype workshops organized by NASA and Hughes. It received positive feedback and showed that users understand the interface without training. A controlled experiment evaluated the benefits of query previews [23]. Twelve computer science students searched a database of films either with a form fill-in interface or with a query preview followed by a form fill-in. Results indicated that the query preview led to 50% faster task completion times when query preview attributes were related to the tasks, and higher subjective satisfaction.

2.2 Development of the operational prototype for the GCMD

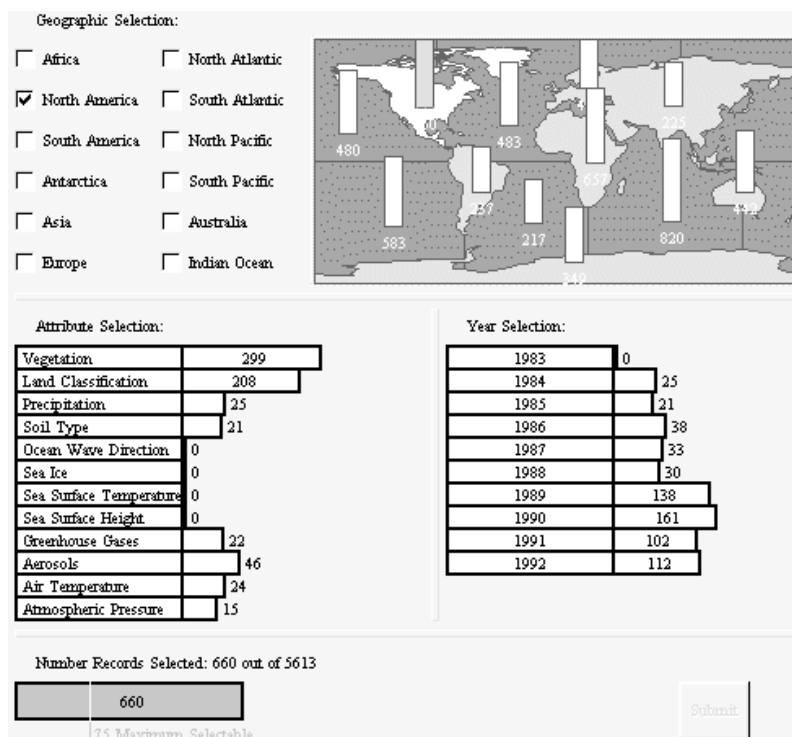
We now describe the operational prototype and the issues involved in its development for the query preview and then for the query refinement. The prototype is implemented in Java, based on code from the final version of the research prototype, and uses a series of Perl scripts to generate the query preview tables and the result set html pages. In appearance the query preview operational prototype is very similar to the research prototype, but several underlying features had to be redesigned. The query refinement is very different from the research prototype as it was replaced by a second phase of previewing with a second set of attributes followed by a more traditional result screen using frames.

2.2.1 Query preview issues

Attributes and attribute value choices. An early task was to capture the GCMD database in a manner appropriate for representation in the interface. The three attributes of location, temporal coverage, and topic area, as used in the prototypes, were confirmed by GCMD earth science specialists and database administrators as the most salient



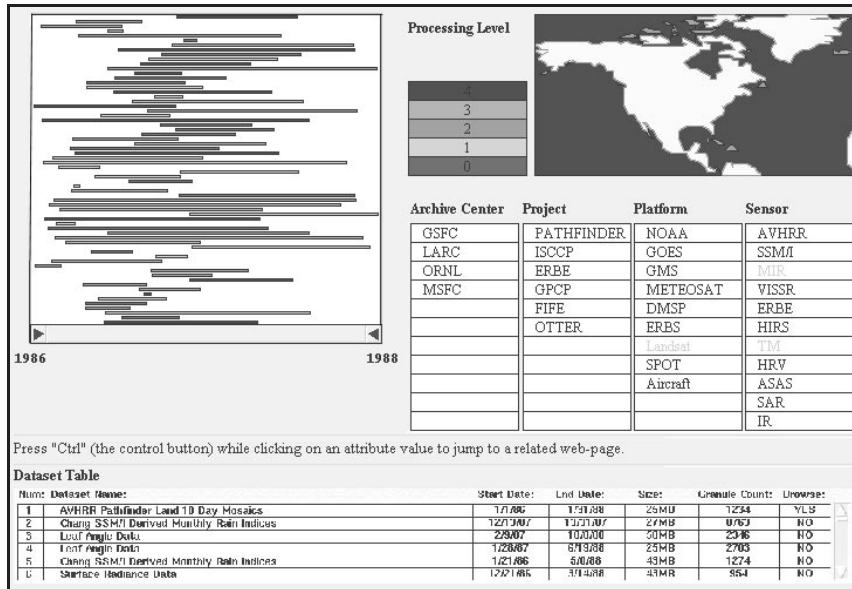
a



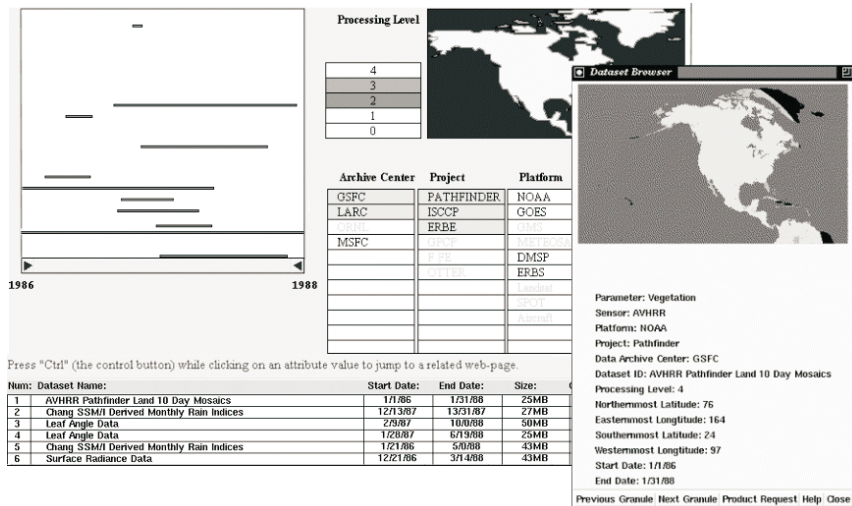
b

Fig. 1.

- a Research prototype: the query preview screen displays summary data on preview bars. Users learn about the holdings of the collection and can make selections over a few parameters
- b Research prototype: following the principles of dynamic queries, the preview bars are updated immediately (in less than 100 ms) when users select an attribute value (here North America). The result bar at the bottom shows the total number of selected datasets



a



b

Fig. 2.

a In the research prototype of query refinement, users can browse more information about individual datasets. The result set can be narrowed again by making more precise selections on more attributes

b Here the query has been refined by selecting 2 archive centers, 3 projects and 2 processing levels. More filtering could be done by zooming on the timeline or on the map. The timeline overview and the dataset table reflect the remaining datasets. Details and sample images can be downloaded from the network (*window on the right*) before the long process of ordering the large datasets

and universal from among all the attributes typically associated with earth science data resources. These were kept as the main attributes for the interface. For each of the three attributes, the large set of attribute values was aggregated up to around ten high-level attribute designations. A domain expert selected date ranges, high level topics and regions (Fig. 3). The granularity of the attribute values chosen for use in the interface is deliberately crude, in order to be able to represent vast amounts of diverse scientific data in a single overview. The careful choice of appropriate attribute values and attribute value aggregations represents a significant portion of the design effort.

Query preview algorithm improvements. Our original plan was to duplicate datasets as needed to account for multiple attribute values (e.g., a dataset covering North and South America would be counted twice within the attribute totals for area). Our assumption was that there would be a maximum of 20 to 30 percent duplication. At this rate, duplication would be barely noticeable by users reviewing the values on the bars. However, we discovered that on average, each dataset had to be duplicated seven times, which made the problem overly apparent in the interface (e.g., the total result bar could be 150 datasets, while individual bars showed up to 1000 datasets). Because GCMD has a reasonable number of

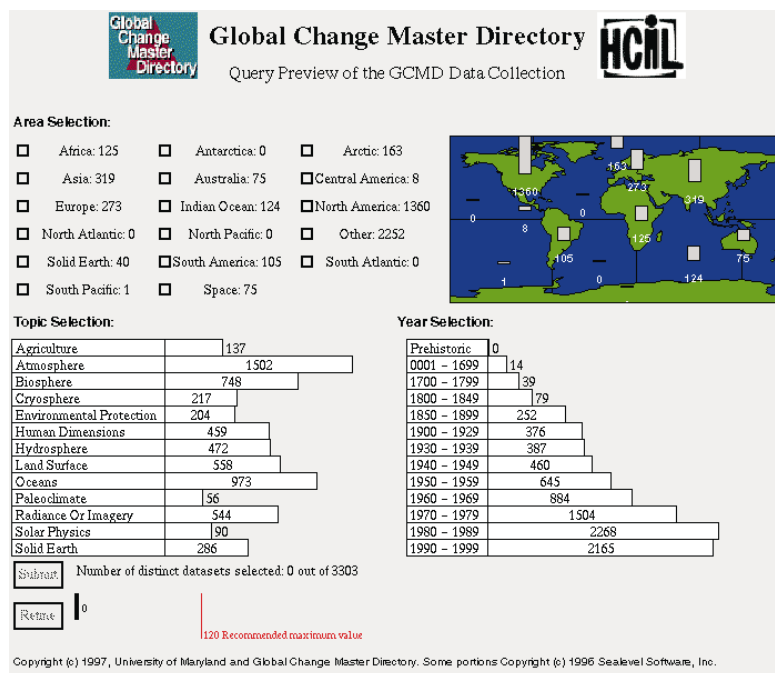


Fig. 3. First operational query preview interface for GCMD

datasets (around 5000) we were able to correct this problem by listing the dataset IDs in the preview table and calculating the exact number of distinct datasets after each user selection. The additional calculations of this hybrid technique first introduced unacceptable time delays, and required improvements to the data structures and algorithms used to determine exact dataset counts. The bars are now adjusted in less than 100 ms on a PC when users make a selection, easily meeting the requirements of dynamic query interfaces.

In recent work we have developed and tested alternative techniques to deal with multivalued attribute data and scale up to any number of records [18]. One technique, called binary previews, reveals only the presence and absence of data, and a second technique deals with range queries such as temporal or geographic coverage.

Query preview table generation and database adjustments. An input data generation module was written in Perl. It sends SQL queries to the GCMD data server and generates a series of query preview tables and a master file describing those files. These files in turn generate the interface. One relation was added to the database to reflect the mapping between data attributes and preview attributes.

Correction of values in data. Some inconsistencies and missing values were discovered during the process of both generating the data tables and visualizing them in the new user interface. The query preview design crucially provides a complete overview of a database. Implementing it can thus be expected to reveal problems that would likely remain unnoticed in a traditional text interface.

This brings benefits to database administrators as well as users attempting to understand the data for the first time. Until the metadata is repaired, a temporary method to deal with those problems is to add ad hoc attribute values such as “not specified”.

Interface design changes. Numerous adjustments were needed in the interface to accommodate the structure and distribution of GCMD data. Overall, the datasets were more numerous, more intricate, and less uniformly distributed than the simulated data used in the early prototypes. First, the preview bars were changed to use logarithmic scales when necessary, and the map and other display widgets were generalized to accommodate dynamic size requirements and layout changes.

Once it became clear that this interface was feasible for GCMD and was likely to be made available to users, we conducted a final detailed review of the user interface and found improvements in the area of layout, consistency, feedback and window coordination.

- Headers were revised and made consistent in the preview, refinement and results screens.
- “Help” and “About...” buttons were added in each screen in a consistent location. They lead to normal HTML pages, which can be edited easily. A short instruction sentence was added the preview and refinement screens.
- The result bar was modified to also use a non-linear scale and was labeled appropriately. The “recommended number” was removed since there was no basis for it in this implementation. The result bar was changed to yellow to match the attribute preview bars.

- The labels of the buttons were made more descriptive: e.g., “refine with 3 other attributes”.
- The “area” check boxes (see Fig. 3) were replaced with a third set of bars for the location (Fig. 5) This was found to be more consistent. Even though some of the areas cannot be shown on the map we decided to keep the map for its visual properties giving users an immediate way to deal with most area selections.
- The attribute labels were changed to mixed case (instead of upper case, which is known to be hard to read). But this should really be done at the data level, not the interface level.
- The generation date of the preview table is mentioned next to the total number of datasets in the result.
- To facilitate the browsing of the results a frame version was prepared.
- A reset button was added.

Most of those changes can be seen when comparing:

- Fig. 1 (research prototype)
- Fig. 3 (first operational prototype)
- Fig. 5 (current version as of June 1999)

Results generation. The query preview returns the list of records corresponding to the query. Because of the relatively small number of records in GCMD, we facilitated rapid result generation by including the list of record identifiers in each cell of the query preview table. This

technique is not appropriate for holdings with constant updates and a real search will have to be performed. The HTML pages showing results sets are generated by another Perl script that sends an SQL query to the database to retrieve full record names.

2.2.2 Query refinement issues

Returning the list of datasets immediately after the query preview phase is only effective if the number returned is small. Otherwise, a refinement phase is needed. Implementing an elaborate query refinement interface as designed in the original research prototype was found to be a significant implementation effort. Since our goal was to have an operational prototype by the end of 1997 we examined four alternatives for the refinement phase:

- provide a second preview step with 3 additional attributes
- include two or three more attributes in the query preview (to increase its discriminating power)
- connect to the existing form-based interface
- explore the use of off-the-shelf systems (such as Spotfire, a visualization and data mining product based on HCIL research – see www.ivee.com)

The first option was selected and will be described in detail below. The second option (i.e., including more attributes) was rejected because it would generate a large

Global Change Master Directory HCIL
Query Refinement

Data Center Selection:

Commercial	5
Doc	0
Dod	5
Doe	21
Doi	4
Epa	0
Federal Agencies	0
Institutions	8
International Agencies	42
Nasa	83
Noaa	141
Non-profit Organizations	0
Nsf	20
Universities	13
Usda	5
World Data Centers	5

Source Name Selection:

Aircraft	12
Balloons	3
Field Experiments	3
Ground Stations	66
Manned Spacecraft	0
Maps	1
Models	1
Moonings	27
Ocean Stations	6
Other	3
Satellites	78
Ships	49
Shuttle	0

Sensor Name Selection:

Altimeters	0
Cameras	3
Infrared Sensors	1
Insitu	67
Lasers	0
Lidars	2
Magnetometers	0
Microwave Sensors	3
Photometers	3
Radars	14
Radiometers	25
Scatterometers	1
Sounders	48
Spectrometers	8
Ultraviolet Sensors	2
Visible Sensors	7

Submit Number of distinct datasets selected: 141 out of 317

141

Applet hcil.eosdis.querypreview running

Fig. 4. First query refinement design, with three additional attributes

Global Change Master Directory

Query Preview

[Help](#)
[About...](#)

Area Selection:

Select attributes of interest by clicking on map areas or preview bars.

Agriculture	594
Atmosphere	2655
Biosphere	1367
Cryosphere	363
Human Dimensions	808
Hydrosphere	806
Land Surface	1206
Oceans	2724
Paleoclimate	157
Radiance Or Imagery	858
Solar Physics	132
Solid Earth	542
Not Specified	0

Prehistoric	165
0001 - 1699	28
1700 - 1799	63
1800 - 1849	116
1850 - 1899	374
1900 - 1929	535
1930 - 1939	554
1940 - 1949	649
1950 - 1959	907
1960 - 1969	1245
1970 - 1979	2258
1980 - 1989	3592
1990 - 1999	4076
Not Specified	878

Africa	191
Antarctica	240
Arctic	280
Asia	465
Atlantic	1989
Australia	112
Central America	185
Europe	501
Indian Ocean	174
North America	2562
Other	3013
Pacific	789
Solid Earth	60
South America	173
Space	82
Not Specified	127

RESULT: datasets selected = 0 out of 6836, based on data as of 05:02 on Monday, June 14, 1999

0

a

Global Change Master Directory

Query Preview

[Help](#)
[About...](#)

Area Selection:

Select attributes of interest by clicking on map areas or preview bars.

Agriculture	594
Atmosphere	2655
Biosphere	1367
Cryosphere	363
Human Dimensions	808
Hydrosphere	806
Land Surface	1206
Oceans	2724
Paleoclimate	157
Radiance Or Imagery	858
Solar Physics	132
Solid Earth	542
Not Specified	0

Prehistoric	3
0001 - 1699	0
1700 - 1799	1
1800 - 1849	2
1850 - 1899	9
1900 - 1929	15
1930 - 1939	17
1940 - 1949	25
1950 - 1959	37
1960 - 1969	71
1970 - 1979	228
1980 - 1989	385
1990 - 1999	580
Not Specified	76

Africa	68
Antarctica	56
Arctic	72
Asia	87
Atlantic	110
Australia	27
Central America	30
Europe	84
Indian Ocean	28
North America	288
Other	578
Pacific	103
Solid Earth	13
South America	62
Space	37
Not Specified	30

RESULT: datasets selected = 858 out of 6836, based on data as of 05:02 on Monday, June 14, 1999

858

b

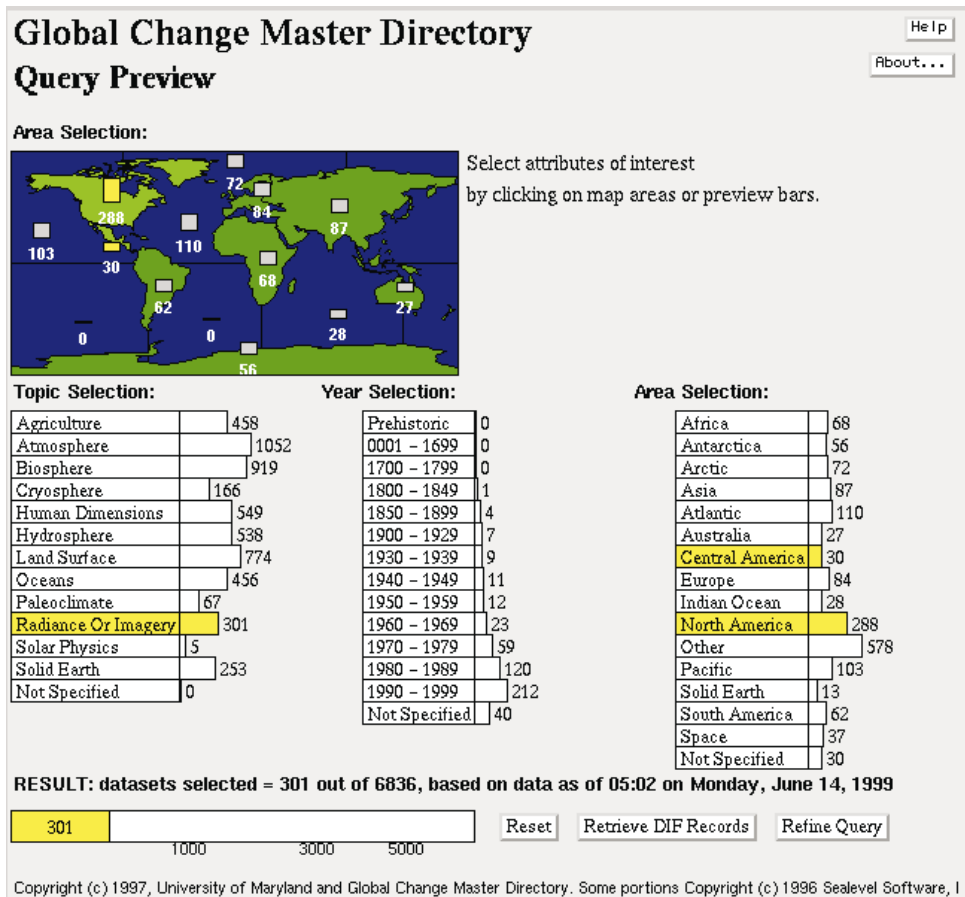


Fig. 5.
a The query preview screen displays summary data on preview bars. Users learn about the holdings of the collection and can make selections over three parameters
b Following the principles of dynamic queries, the preview bars are updated immediately (in less than 0.5 s on a PC) when users select attribute values (here Radiance or Imagery). The result bar at the bottom shows the total number of selected datasets
c Additional attribute values are selected (here Central or North America)

query preview table that would lead to long loading time and slow preview updates. The third option (connecting to existing form-based interface) was judge to have a high implementation cost for little return. The use of Spotfire was rejected because no Java version was then available.

The first option was implemented rapidly and provides a second preview step with 3 other attributes (Fig. 4). This progressive refinement, where overviews lead to previews of subsets and in turn serve as overviews for more fine-grained objects illustrates how interactive overviews and previews can scale to large, complex digital information spaces. Moreover, it can be implemented with significant reuse of existing software (for GCMD a single applet is used for query and refinement, and the data in the table triggers changes in the interface).

A domain expert chose the attributes. They are: data center, source, and sensor. There were no major problems with the Java interface development but once again the development of this interface made visible underlying problems of metadata incompleteness.

2.2.3 Maintenance issues

The query preview approach relies on the availability of up-to-date query preview tables.

Those tables are generated in less than an hour. They can be generated at regular intervals or whenever new datasets are added. The date of last update must be available to users.

2.2.4 Providing alternative preview tables

In the early phase of the GCMD project we designed an interface offering alternative query preview tables (e.g., for different science categories such as ocean science or atmospheric science, or data origin such as GCMD vs. CIESIN). To simplify the GCMD interface we chose to provide only one table but the Java applet is still capable of handling several tables, providing buttons for them at the top of the screen to select alternative tables.

2.3 Final version

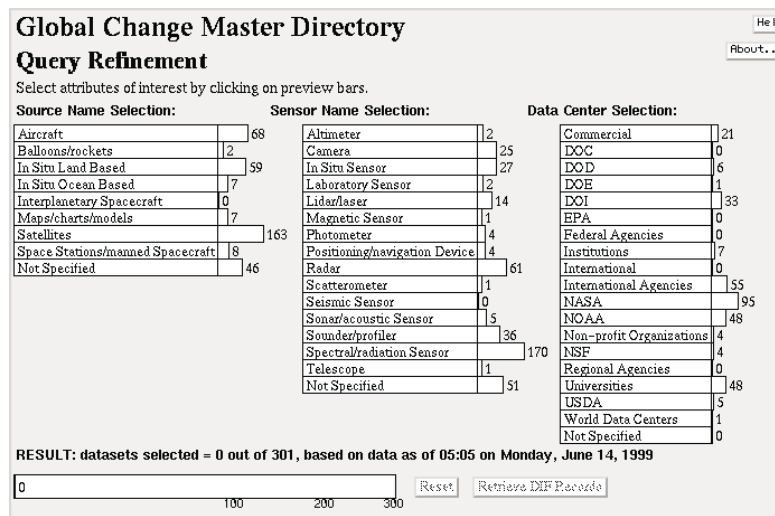
The GCMD staff has taken over responsibility for completing the final version and making it publicly available. Figures 5–8 show the latest version of the screens and Fig. 9 summarizes the architecture of the system implementation.

3 Lessons learned and new research

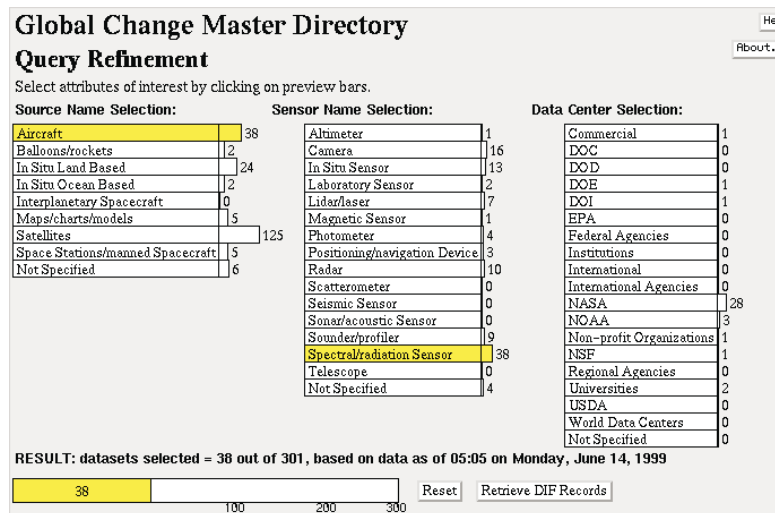
We believe that query preview and query refinement interfaces have substantial benefits to users. This project demonstrated that the concepts are feasible in a large operational system, such as the EOSDIS directory environment. Consensus was reached on attributes and values selection and performance is satisfactory (speed issues

were all solved). Our experience confirmed the importance of metadata accuracy and completeness. The query preview interfaces make visible any problems or gaps in the metadata that are undetectable with classic form fill-in interfaces. This could be seen as a problem but we think that it will have a long-term beneficial effect on the quality of the metadata as data providers will be compelled to produce more complete metadata.

In going from a research prototype to an operational system, our data management algorithms and graphical user interface mechanisms all required modification to accommodate unanticipated data characteristics. We have begun to deal with the challenge of scaling up the software architecture to accommodate much larger and more varied data collections [19]. NASA has made this interface publicly available since 1997 and is monitoring its use. As the number of Java capable workstations grows and



a



b

Fig. 6.

- a The query can be refined with three other attributes
- b Refinement by selecting a Source and a Sensor, reducing the results to 38 datasets

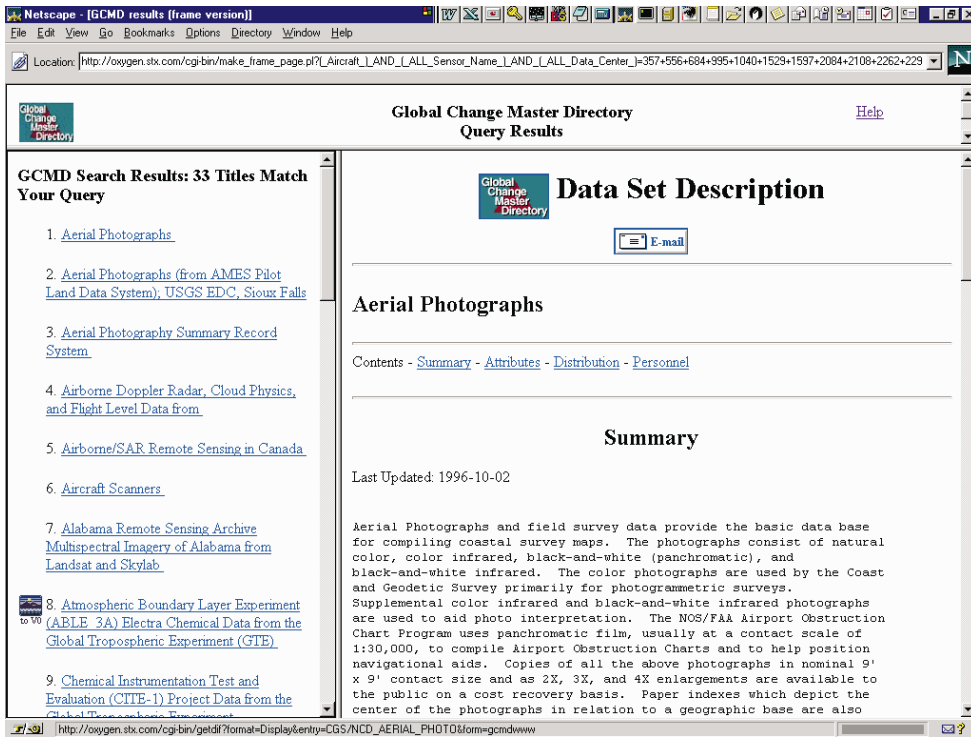


Fig. 7. Results are displayed in a frame window to facilitate the browsing of the records. Links to the NASA V0 interface are available when an inventory search is possible for the dataset (i.e., the search can be continued within the dataset)



Fig. 8. When clicking on the NASA V0 logo next to the dataset name, users can jump directly to a V0 inventory search. Here we see that the name of the dataset was passed to the V0 search. Other values such as location or time could be passed as well

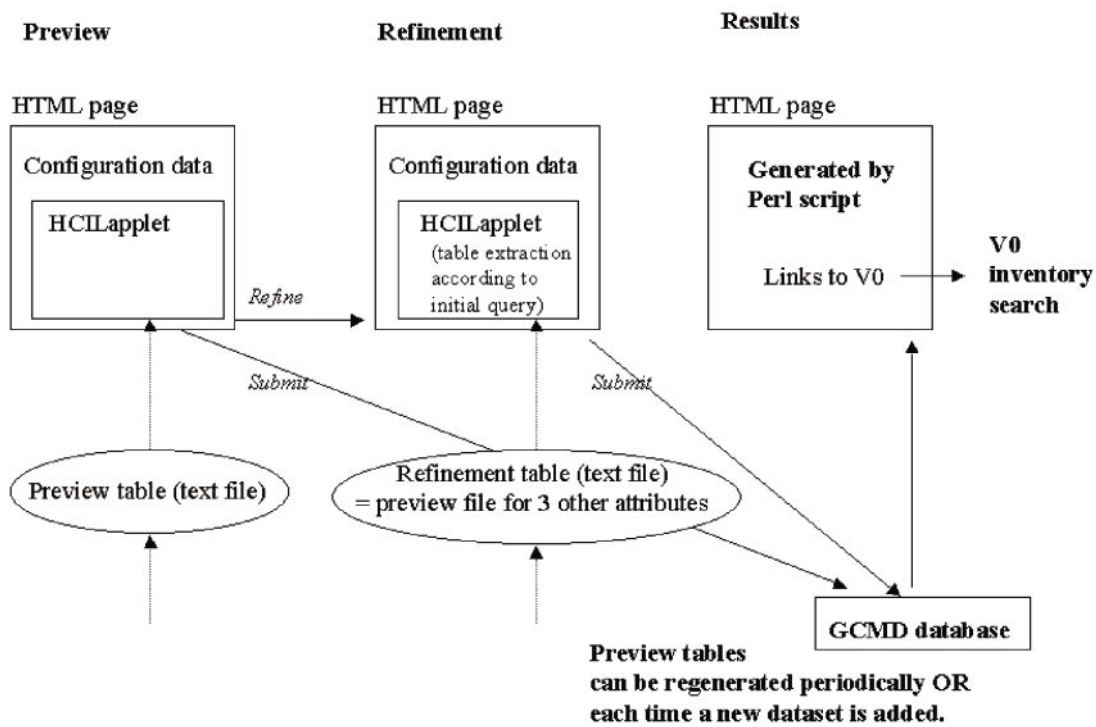


Fig. 9. Summary of the system architecture

the capabilities of browsers stabilize, usage is likely to increase. A second implementation using binary previews, also in Java, is now publicly available for the Global Land Cover Facility (<http://glcf.umiacs.umd.edu>) a member of the NASA Earth Science Information Partnership (ESIP) Federation.

This work illustrates that the number of queries processed may not be the most appropriate measure of the success of a query system. The query preview interface will most likely reduce the number of queries sent to the database server as users will be able to refine their query formulation locally before submitting it. A high number of queries might very well indicate that users are not finding what they need. Measuring the average size of returned result sets for queries might be a more reasonable benchmark. And measuring the proportion of zero-hit queries and mega-hit queries to the total number of queries submitted would also begin to more effectively measure the success of search system user interfaces.

Project website: Project URL at HCIL (prototypes and technical reports) <http://www.cs.umd.edu/hcil/eosdis>
GCMD address: <http://gcmd.nasa.gov>

Video demonstrations: A video demonstration of the GCMD interface as well as other query preview interface is available from HCIL as part of the 1999 HCIL video report (<http://www.cs.umd.edu/hcil>)

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