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Information Search: Introduction, Searching in Textual Documents and Database Querying, Multimedia Document Searches, Advanced Filtering and Searching Interfaces

Information Visualization: Introduction, Data Type by Task Taxonomy, Challenges for Information Visualization

Introduction

Information exploration should be a joyous experience, but many commentators talk of information overload and anxiety. However, there is promising evidence that the next generation of digital libraries and databases will enable convenient exploration of growing information spaces by a wider range of users. User-interface designers are inventing more powerful search and visualization methods, while offering smoother integration of technology with task.

Exploring information collections becomes increasingly difficult as the volume and diversity grows. A page of information is easy to explore, but when the source of information is the size of a book, or a library, or even larger, it may be difficult to locate known items or to browse to gain an overview. The strategies to focus and narrow are well understood by information-search specialists, and no these strategies are being implemented for widespread use.

A *multimedia document* consists of collections of documents that can contain images, scanned documents, sound, video, animations, datasets, and so on. *Digital libraries* are generally sets of carefully selected and cataloged collections, while *digital archives* tend to be more loosely organized.

Directories hold metadata about the items in a library and point users to the appropriate locations (for example, the NASA Global Change Master Directory simply helps scientists locate datasets in NASA's archives).

Task actions are decomposed into *browsing* or *searching* and are represented by *interface actions* such as scrolling, zooming, joining, or linking. Users begin by formulating their information needs in the task domain. Tasks can range from specific fact finding, where there is a single readily identifiable outcome, to more extended fact finding with uncertain but replicable outcomes. Relatively unstructured tasks include exploration of the availability of information on a topic, open-ended browsing of known collections, and complex analysis of problems.

- Specific fact finding (known-item search)
- Find the e-mail address of Hilary Clinton.
- Find the highest-resolution LANDSAT image of College Park at noon on May 26, 2004.
- Extended fact finding
- What other books are by the author of *Jurassic Park?*
- How do Maryland and Virginia counties compare on the Consumer Price Index in 20m?
- Exploration of availability
- What genealogical information is available at the National Archives?
- Is there new work on voice recognition in the ACM digital library?
- Open-ended browsing and problem analysis
- Does the Mathew Brady Civil War photo collection show the role of women in that war?
- Is there promising new research on fibromyalgia that might help *my* patient?

Once users have clarified their information needs, the first step in satisfying those needs is to decide where to search. The conversion of information needs, stated in task-domain terminology, to interface actions is a large cognitive step.

Searching in Textual Documents and Database Querying

The way users conduct searches has gone through dramatic changes over the past decade. Once reserved for search experts who had mastered cryptic languages, searching vast computer archives is now fully feasible for children preparing school reports, patients looking for possible medical treatments, or researchers looking for up-to-date results and experts to consult.

General World Wide Web search engines have greatly improved their performance by making use of statistical rankings and the information latent in the Web's hyperlink structure. For example, the search engine Google implements a link-based ranking measure called PageRank, to compute a query-independent score for each document, taking into consideration the importance of the pages that point to a given page. Because of the diversity of users, providing simple user interfaces to get started is important—Google starts 'with a simple search interface and offers advanced and specialized search interfaces as needed, including human-generated directory interfaces. Thanks to the redundancy of information on the Web, results almost always return some relevant documents, and they allow users to find answers by following hyperlinks.

For example, to find an expert on information retrieval, users might first find papers on that topic, leading to identifying a major journal publication, the editors of the journal, and their personal web pages. However, empirical evaluation of the current algorithms shows that the quality of the relevant documents retrieved still needs to be improved.

Database searches have become widespread as the general public turns to the World Wide Web to reserve travel packages, shop for groceries, or search digital libraries of children's books. Specialized databases also help lawyers find relevant court cases or scientists locate the scientific data they need. The Structured Query Language (SQU has become a widespread standard for searching such structured relational database systems and often remains the underlying query mechanism hidden under a more accessible front end. Using SQL, expert users can write queries that specify matches on attribute values, such as author, date of publication, language, or publisher. Each document has values for the attributes, and database-management methods enable rapid retrieval even with millions of documents. For example, an SQL-like command might be:

```
SELECT DOCOMENT#
FROM JOURNl>.L-DB
WHERE (DATE >= 2001 AND DATE <= 2003)
AND (LANGUAGE = ENGLISH OR FRENCH)
AND (PUBLISHER = ASIST OR HFES OR ACM)
```

SQL has powerful features, but using it requires training, and even then users make frequent errors for many classes of queries.

Natural-language queries (for example, "please list the documents that deal with ... ") are meant to be appealing, but the computer's capacity for processing such natural-language queries is too often limited to eliminating frequent terms or commands and searching for remaining words, leading to frustration for users. Research **continues** on this topic.

Form-fill-in queries have substantially simplified query formulation 'while still allowing some Boolean combinations to be made available. A more powerful approach that extends the form-fill-in idea is *query by-*

perform better and have higher subjective satisfaction when they can view and control the, but the lack of consistency between search interfaces means that users have to rediscover how to search each time they search in a different system.

An analogy to the evolution of automobile user interfaces might clarify the need for standardization of search interfaces. Early competitors offered a profusion of controls, and each manufacturer had a distinct design. Some designs such as having a brake pedal that was far from the gas pedal-were dangerous.

Furthermore, if you were accustomed to driving a car with the brake to the left of the gas pedal, and your neighbor's car had the reverse design, it might be risky to trade cars. It took half a century to achieve good design and appropriate consistency in automobiles; let's hope that we can make the transition faster for text-search user interfaces.

The success of a search service often depends on the degree to which user frustration and confusion are reduced. A *jive-phase framework* may help to coordinate design practices to satisfy the needs of first-time, intermittent, and frequent users who are accessing a variety of textual and multimedia libraries. The framework as shown in below gives great freedom to designers to offer features in an orderly and consistent manner. The phases are:

1. *Formulation:* expressing the search
2. *Initiation of action:* launching the search
3. *Review of results:* reading messages and outcomes
4. *Refinement:* formulating the next step
5. *Use:* compiling or disseminating insight

Five-phase framework to clarify user interfaces for textual search.

1. *Formulation*

- Provide access to the appropriate sources in libraries and collections.
- Use *fields* for limiting the source: structured fields such as year, media, or language, and text fields such as titles or abstracts of documents.

- Recognize *phrases* to allow entry of names, such as George Washington or Environmental Protection Agency, and concepts, such as abortion rights reform or gallium arsenide.
- Permit *variants* to allow relaxation of search constraints, such as case sensitivity, stemming, partial matches, phonetic variations, abbreviations, or synonyms from a thesaurus.
- Control the size of the result set.

2. Initiation* of *action

- Include *explicit actions* initiated by buttons with consistent labels (such as "Search *"),* locations, sizes, and colors.
- Include *implicit actions* initiated by changes to a parameter of the formulation phase that immediately produce a new set of search results.

3. Review* of *results

- Present explanatory messages.
- View an overview of the results and previews of items.
- Manipulate visualizations.
- Adjust the size of the result set and which fields are displayed.
- Change the sequencing (alphabetical, chronological relevance ranked, and so on).
- Explore clustering (by attribute value, topics, and so on).
- Examine selected items.

4. Refinement

- Use meaningful messages to guide users in progressive refinement; for example, if the two words in a phrase are not found near each other, then offer easy selection of individual words or variants.
- Make changing of search parameters convenient.
- Explore relevance feedback.

5. Use

- Allow queries, the setting of each parameter, and results to be saved and annotated, sent by e-mail, or used as input to other programs, such as visualization or statistical tools.

The formulation phase includes identifying the *source* of the information, the *fields* for limiting the source, the *phrases*, and the varian*ts.* Even if technically and economically feasible, searching all libraries or collections in a library is not always the preferred approach. Users often prefer to limit the sources to a specific library or a specific collection in a library. Users may also limit their searches to specific fields, and the sources might be further restricted by structured fields such as year of publication, volume number, or languages.

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In textual databases, Users typically seek items that contain meaningful phrases, and multiple entry fields should be provided to allow for multiple phrases. Searches on phrases have proved to be more accurate than are searches on words. Phrases also facilitate searching on names. Since some relevant items may be missed by a phrase approach, though, users should have the option to expand a search by breaking the phrases into separate words. If Boolean operations, proximity restrictions, or other combining strategies are specifiable, then users should also be able to express them. Users or service providers should also have control over stop lists.

When users are unsure of the exact value of the field (subject term, or spelling or capitalization of a name), they may need to relax the search constraints by allowing variants to be accepted. In structured databases, the variants may include a wider range on a numeric attribute. In a textual-document search, interfaces should allow user control over variant capitalization (case sensitivity), stemmed versions (the keyword teach retrieves variant suffixes such as teacher, teaching, or teaches), partial matches (the keyword biology retrieves sociobiology and astrobiology), phonetic variants from soundex methods, synonyms (the keyword cancer retrieves malignant neoplasm), abbreviations (the keyword IBM retrieves International Business Machines, and vice versa), and broader or narrower terms from a thesaurus.

The second phase is the ***initiation of action***, which may be explicit or implicit. Most current systems have a search button for explicit initiation, or for delayed or regularly scheduled initiation. The button label, size, and color should be consistent across versions. An appealing alternative is *implicit initiation*, in which each change to a component of the formulation phase immediately produces a new set of search results shown in below.

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The third phase is the ***review of results***, in which users read messages, view textual lists, or manipulate visualizations. Previews consisting of samples or summaries help users select a subset of the results for use and can help them define more productive queries as they learn about the contents of the collections. Translations may also be proposed. Users should be given control over the size of the result set, which fields are displayed, how results are sequenced, and how results are clustered. One strategy, used by Vivisimo as shown in below:

The Grokker, involves automatic clustering and naming of the clusters. Studies show that clustering according to more established and meaningful hierarchies, such as the Open Directory Project, might be effective.

The fourth phase is ***refinement*** *Search* interfaces should provide meaningful messages to explain search outcomes and to support progressive refinement.

For example, users could be encouraged to provide fewer terms to allow partial matches. If *two* words in a search phrase are not found proximally, then feedback should be given about the occurrence of the words individually. Corrections can be proposed; for example, asking "Did you mean Fibromyalgia?" when the keyword was misspelled. If multiple phrases are input, then items containing all phrases should be shown first and identified, followed by items containing subsets; if no documents are found with all phrases, that failure should be indicated. There is a fairly elaborate decision tree of search outcomes and messages that needs to be specified. Another aspect of feedback is that, as searches are made, the system should keep track of them in a *search history* to allow inward reuse of earlier searches. Progressive refinement, in which the results of a search are refined by changing the search parameters, should be convenient.

The final phase, ***use*** of the results, is where the payoff comes. Results can be merged and disseminated by electronic mail, or used as input to other programs-for example, for visualization or statistic tools.

The five-phase **framework** can be applied by' designers to make the search process more visible, comprehensible, and controllable *by* users. This approach is in harmony with the general move towards direct manipulation, in which the state of the system is made visible and is placed under user control. Novices may not want to see all the components of the five phases initially, but if they are unhappy with the search results, they should be able to view the settings and change their queries easily.

Multimedia Document Searches

Interfaces to structured databases and textual-document libraries are good and getting better, but search interfaces in multimedia-document libraries are still in their early' stages of development. Most systems used to locate images, videos, sound, or animation depend on descriptive documents or metadata searches to locate the items. For example, searches in photo libraries can be done by date, photographer, medium, location, or text in captions, but without captioning and costly human annotation, finding a photo of a particular ribbon-cutting ceremony or horse race is very difficult. Nevertheless, even if completely automatic recognition is not possible, it is useful to have computers perform some filtering.

As technology simplifies the creation and use of multimedia documents, multimedia-document search interfaces will have to rely on the integration of powerful annotation and indexing tools, improved search algorithms to filter the collections, and effective browsing techniques for viewing the results.

- ***Image search:*** Finding images of things such as the Statue of Liberty is a substantial challenge for image-analysis researchers, who describe this task as *query by image content* (QBIC). Lady Liberty's distinctive profile might be identifiable if the orientation, lens focal length, and lighting 'were held constant, but the general problem is difficult in large and diverse collections of photos. Two promising approaches are to search for distinctive features, such as the torch or the seven spikes in the crown, or to search for distinctive colors, such as red, white, and blue to look for an American flag. Of course, separating out the British, French, and other flags is not easy. More success is attainable with restricted collections, such as of glass vases or blood cells, for which users can draw a desired profile and retrieve items with matching features.

For smaller collections of personal photos, it is important to provide effective browsing and lightweight annotation mechanisms such as, for example, PhotoMesa, PhotoFinder, or Adobe Photoshop Album.

- ***Map search:*** Computer-generated maps are increasingly available online. Locating a map by latitude and longitude is the structured-database solution, but searching by features is now possible because geographical information systems preserve the structural aspects and the multiple layers in maps.

For example, users might specify a search for all port cities with a population greater than 1 million and an airport within 10 miles. Applications for mobile devices might allow users to locate Italian restaurants within two hundred yards of any station on a given subway line.

- ***Design or diagram search:*** Some computer-assisted design packages offer users limited search capabilities within a single design or across design collections. Finding red circles inside blue squares may help in some cases, but more elaborate strategies, such as for finding engine designs with pistons smaller than 6 centimeters, could prove more beneficial. Document-structural recognition and search tools already exist that allow searching, for example, for newspaper front pages with headlines that span the front page and no advertisements.

- ***Sound search:*** Music-information retrieval (MIR) systems can now use audio input, where users can query with musical content. Users can sing or playa theme, hook, or riff from the desired piece of music, and the system returns the most similar items. It is even becoming possible to recognize individual performers, such as "find Canlso". Finding a spoken "Yord or phrase in databases of telephone conversations is still difficult, but it is becoming possible, even on a speaker-independent basis .
- ***Video search:*** Searching a video or film involves more than simply searching through each of the frames. The video should be segmented into scenes or cuts and allow scene skipping. Gaining an overview of a two-hour video by a timeline oi scenes enables better understanding, editing, and selection. The Info-media project is an example library of digital video shown below

It uses a variety of visual features (for example, color, faces, or text superimpositions) as well as textual features such as speech-to-text transcripts to make a large volume of digital video retrievable.

- ***Animation search:*** Animation authoring tools are becoming prevalent with the success of Flash, so it might become possible to specify searches for certain kinds of animation, such as spinning globes or morphing faces.

Advanced Filtering and Searching Interfaces

Users have highly varied needs for advanced filtering features. This section reviews a few alternatives to the form-fill-in query interface.

- ***Filtering with complex Boolean queries:*** Commercial information-retrieval systems such as DIALOG and First Search permit complex Boolean expressions with parentheses, but their widespread adoption has been inhibited by their difficulty of use. Numerous proposals have been put forward to reduce the burden of specifying complex Boolean expressions. Part of the confusion stems from informal English usage. For example, a query such as "List all employees who live in New York and Boston" usually would result in an empty list, because the "and" would be interpreted as an intersection; only employees who live in both cities would qualify! In English, "and" usually expands the options; in Boolean expressions, AND is used to narrow a set to the intersection of two others. Similarly, in the English 'Td like Russian or Italian salad dressing," the "or" is exclusive, indicating that you want one or the other but not both; in Boolean expressions, however, an OR is inclusive, and is used to expand a set. The desire for *full Boolean expressions*, including nested parentheses and NOT operators, has led to novel metaphors for query specification.

Venn diagrams, decision tables, and metaphors of water flowing through a series of filters have been used, but these representations become clumsy as query complexity increases.

- ***Automatic filtering:*** Another form of filtering is to apply a user-constructed set of keywords to dynamically generated information, such as incoming electronic-mail messages, newspaper stories, or scientific journal articles (Belkin and Croft, 1992). Users create and store their profiles, which are evaluated each time that a new document appears. Users can be notified by electronic mail that a relevant document has appeared, or the results can be simply collected into a file until users seek them out. These approaches are a modern version of a traditional information-retrieval strategy called *selective dissemination of information* (SDD) ‘which was used in the earliest days of magnetic tape distribution of document collections’.

- ***Dynamic queries:*** The dynamic-queries approach of adjusting numeric range sliders, alpha-sliders for names or categories, or buttons for small sets of categories is appealing to many users for many tasks. Dynamic queries might be called *direct-manipulation queries*, since they share the same concepts of visual display of actions (the sliders or buttons) and objects (the query results in the task-domain display); the use of rapid, incremental and reversible actions; and the immediate display of feedback. Additional benefits are the prevention of syntax errors and an encouragement of exploration. A subset of Boolean queries are possible (ORs between attribute values and ANDs between attributes). The early Dynamic HomeFinder shown below:

After rough selections have been made, the metadata of the remaining items can be downloaded for refinement of the query. While the form-fill-in interfaces often lead users to waste time posing queries that have zero-hit or mega-hit result sets, a user study showed that query previews made performance 1.6 to 2.1 times faster and led to higher subjective satisfaction.

- ***Faceted metadata search:*** This type of search interface integrates category browsing with keyword searching, as demonstrated in Flamenco example shown below:

This interface makes use of hierarchical faceted metadata presented as simultaneous menus and dynamically generated numerical query previews. It allows users to navigate explicitly along multiple conceptual dimensions that describe the images and to progressively narrow or expand the scope of the query while browsing images. In the example of architectural photo browsing, users can look for photos of modern homes, narrow on front doors, narrow further on homes located in Virginia, then widen the query to show windows and doors, then switch to homes in Maryland, all the while staying in the flow and focusing their attention on the images. Many search interfaces are using selection in multiple menus as their primary search interfaces, but they often only allow refinements in one menu at a time.

- ***Collaborative filtering:*** This social form of filtering allows groups of users to combine their evaluations to help one another find interesting items in large collections. Each user rates items in terms of their interest.

Then, the system can suggest unread items that are close to users' interests, as determined by matches with other people's interests.This method can also be applied to movies, music, restaurants, and so on. For example, if you rate six restaurants highly, the algorithms will provide you with other restaurants that were rated highly by people who liked your six restaurants. This strategy has an inherent appeal, and dozens of such systems have been built for organizational databases, news files, music groups, and World Wide Web pages.

- ***Multilingual searches:*** In some cases users want to be able to search collections of multilingual documents. Current web search engines merely provide rudimentary translation tools, but prototypes of multilingual information systems allow users to select appropriate dictionaries, restrict keyword translations, and use more powerful translation systems to carefully identify documents that justify the cost of high-quality professional translation.

- ***Visual searches:*** The specification of query fields can sometimes be simplified by using specialized visual representations of the possible values.

For example, selecting dates on calendars or using a plane layout to select among available seats is useful. For vacationers seeking tourist information about Marseilles who do not know its location, a scrolling alphabetical list is needed;

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Visual search interfaces provide context and help users refine their needs. They are attractive and can reduce error messages such as IJdata out of range" while providing information about data availability and a feeling of thoroughness to users.

There is much in common between visual search interfaces and browsing interfaces that use combinations of menus. Enhanced with implicit initiation and immediate feedback, visual search interfaces can become powerful dynamic-query interfaces, while the addition of abstract data previews and overviews transforms visual search interfaces into potent information-visualization and exploration tools that help users explore the data visually before any search is even specified.

Information Visualization: Introduction

The success of direct-manipulation interfaces was a first step towards using the power of computers in a more visual or graphic manner. A picture is often said to be worth a thousand words, and for some tasks, a visual presentation-such as a map or photograph-is dramatically easier to use or comprehend than is a textdescription or a spoken report. As processor speeds and display resolution increase, designers are discovering how to present and manipulate large amounts of information in compact and user-controlled ways.

We can now argue that an interface is worth a thousand pictures. Information visualization can be defined as the use of interactive visual representations of *abstract* data to amplify cognition. The abstract characteristic of the data is what distinguishes information visualization from scientific visualization. For scientific visualization, three dimensions are necessary, because typical questions involve continuous variables, volumes, and surfaces (inside/outside, left/right, and above/below). However, for information visualization, typical questions involve more categorical variables and the discovery of patterns, trends, clusters, outliers, and gaps in data such as stock prices, patient records, or social relationships. Information-visualization researchers aim to provide compact graphical presentations and user interfaces for interactively manipulating large numbers of items, possibly extracted from far larger datasets. Sometimes called visual data mining, it uses the enormous visual bandwidth and the remarkable human perceptual system to enable users to make discoveries, make decisions, or propose explanations about patterns, groups of items, or individual items. Information visualization allows users to answer questions they didn't know they had.

Humans have remarkable perceptual abilities that are greatly underutilized in most current interface designs. Users can scan, recognize, and recall images rapidly, and can detect subtle changes in size, color, shape, movement, or texture.

The core information presented in graphical user interfaces has remained largely text oriented, so as more visual approaches are explored, appealing new opportunities are emerging. Perceptual psychologists, statisticians, and graphic designers offer valuable advice about presenting static information, but advances in processor speed, design tools, and dynamic displays take user-interface designers well beyond current wisdom.

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Many users resist visual approaches and are satisfied with potent textual approaches, such as multiple menus and numerical query preview's in faceted metadata searches. Their resistance may be appropriate, since these textual tools use compact presentations that are rich with meaningful information and comfortingly familiar. Successful information-visualization tools have to be more than "cool"; they have to provide measurable benefits for realistic tasks. They also have to be built to satisfy universal-usability principles of working on a variety of platforms, display sizes, and network bandwidths, while enabling access for users with disabilities and users speaking differing languages.

As information visualization matures, guidelines, principles, and theories will emerge for this area. Among them will probably be this widely cited principle, usually known as the, 'visual-information-seeking-mantra'*:*

Overview first, zoom and filter, then details on demand
Overview first, zoom and filter, then details on demand
Overview first, zoom and filter, then details on demand
Overview first, zoom and filter, then details on demand
Overview first, zoom and filter, then details on demand
Overview first, zoom and filter, then details on demand
Overview first, zoom and filter, then details on demand

The repetition suggests how often the principle has been applied and the recursive nature of the exploration process. Information-visualization researchers and commercial developers may be able to sort out the numerous tools and identify new opportunities by using a ***data type by task taxonomy*** *table shown below*.

As in the case of searches, users are viewing collections of items, where items have multiple attributes. The data type by task taxonomy includes seven basic data types and seven basic tasks. The basic data types are one-, two-, three-, or multidimensional, followed by three more structured data types: temporal, tree, and network. This simplification is useful to describe the visualizations that have been developed and to characterize the classes of problems that users encounter. For example, with temporal data users deal with events and intervals, and their questions are concerned with before, after, or during. With tree-structured data, users deal with labels on internal nodes and values at leaf nodes, and their questions are about paths, levels, and subtrees. The seven basic tasks are: overview, zoom, filter, details-on demand, relate, history, and extract. Our discussion begins with the seven data types, followed by the seven tasks.

1**D linear data:** *Linear data types* are one-dimensional; they include program source code, textual documents, dictionaries, and alphabetical lists of names, all of which can be organized in a sequential manner. For program source code, the substantial compressions of one pixel per character produce compact displays of tens of thousands of lines of program source code on a single display. The attributes, such as the date of most recent modification or the author name, may be used for color-coding. Interface-design issues include what colors, sizes, and layout to use, and what overview, scrolling, or selection methods to provide for users.

2D map data: Planar data include geographic maps, floorplans, and newspaper layouts. Each item in the collection covers some part of the total area and mayor may not be rectangular. Each item has task-domain attributes, such as name, owner, and value and interface-domain features, such as size, color, and opacity. Many systems adopt a multiple-layer approach to dealing with map data, but each layer is two-dimensional.

User tasks are to find adjacent items, regions containing items, and paths between items, and to perform the seven basic tasks. Examples include geographic information systems, which are a large research and commercial domain. Information-visualization researchers have used spatial displays of document collections organized proximally by term co-occurrences, such as ThemeView shown below.

Such displays seem useful to give users an overview of the collection, but they may not necessarily be as useful as a textual representations to find documents, because relevance is difficult to judge without reading some text .

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3D world data: Real-world objects such as molecules, the human body, and buildings have volume and complex relationships with other items. Computer-assisted medical imaging, architectural drawing, mechanical design, chemical structure modeling, and scientific simulations are built to handle these complex three-dimensional relationships. Users' tasks typically deal with continuous variables such as temperature or density. Results are often presented as volumes and surfaces, and users focus on relationships of left/right, above/below, and inside/outside.

In three-dimensional applications, users must cope with their position and orientation when viewing the objects and must handle the potential problems of *occlu*sion and *navigation.* Solutions using enhanced 3D techniques, such as overviews, landmarks, teleportation, multiple views, and tangible user interfaces, are finding their way into research prototypes and commercial systems. Successes include medical imagery from sonograms that helps doctors in planning surgery and architectural walkthroughs or Highthroughs that give home buyers an idea of what a finished building will look like.

Examples of three-dimensional computer graphics and computer-assisted design tools are numerous, but information-visualization work in three dimensions is still controversial. Some virtual-environment researchers and business Such displays seem useful to give users an overview of the collection, but they may not necessarily be as useful as a textual representations to find documents, because relevance is difficult to judge without reading some text.

Multidimensional data: Most relational- and statistical-database contents can be conveniently manipulated as multidimensional data, in which items with 11 attributes become points in a multidimensional *space.* The interface representation may be a dynamic two-dimensional scatter gram, with each additional dimension controlled by a slider. Buttons can be used for attribute values when the cardinality is small-say, less than 10. Tasks include finding patterns, such as correlations among pairs of variables, clusters, gaps, and outliers. Multidimensional data can also be represented by a three-dimensional scatter gram, but disorientation and occlusion can be problems. The early Home Finder and Film Finder developed dynamic queries on zoomable, color-coded, user-controlled scatter grams of multidimensional data and laid the basis for the commercial product Spotfire shown below.

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Parallel coordinate plots are one of the few truly contact multidimensional techniques. Each parallel vertical axis represents a dimension, and each item becomes a line connecting values in each dimension. Training and practice are particularly helpful to become a "multidimensional detective." Other techniques include matrices that combine series of small bivariate representations. K-means clustering starts by users specifying how many clusters to create, then the algorithm places every item into the most appropriate cluster. Surprising relationships and interesting outliers can be identified *by* these techniques.

Temporal data: Time series are very common and merit a data type that is separate from one-dimensional data. The distinctions of *temporal data* are that items (events) have a start and finish time, and that items may overlap. Frequent tasks include finding all events before, after, or during some time period or moment, and in some cases comparing periodical phenomena, plus the seven basic tasks. Many project management tools exist; novel visualizations of time include the Perspective Wall shown below.

Temporal-data visualization components are included in applications for editing video data, composing music, or preparing animations such as Flash, and they are appearing in search interfaces. Space-time data have been a focus of great attention in geo-visualization.

Time Searcher combines multiple time series, such as stock-market prices over time, or other linear data series, such as temperature in an oil-well bore hole. Users draw boxes on the display to specify combinations of ranges, and Time Searcher shows series whose data all fall within the range.

Tree data: Hierarchies or tree structures are collections of items, in which each item (except the root) has a link to one parent item. Items and the links between parent and child can have multiple attributes. The basic tasks can be applied to items and links, and tasks related to structural properties become interesting-for example, for a company organizational chart. Is it a deep or shallow hierarchy, and how many employees does each manager supervise? Interface representations of trees can employ the outline style of indented labels used in tables of contents or the Windows file explorer, or a node-and-link diagram such as the Degree-of Interest Tree as described bleow:

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Although many special cases of networks exist, it is convenient to consider them all as one data type. In addition to performing the basic tasks applied to items and links, network users often want to know about the shortest or least costly paths connecting two items or traversing the entire network. Interface representations include node-and-link diagrams and matrices of items with each cell representing a potential link and its attribute values.

Network visualization is an old but still imperfect art, because of the complexity of relationships and user tasks. Specialized visualizations can be designed to be more effective for a given task and there are a number of useful geographical applications. New interest in this topic has been spawned by attempts to visualize the World Wide Web shown below:

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The seven data types reflect an abstraction of the reality. There are many variations on these themes (two-and-one-half or four-dimensional data, multi-trees, and many prototypes use combinations of these data types). The second framework for analyzing information visualizations covers seven basic tasks that users typically perform.

Overview task: Users can gain an overview of the entire collection. Overview strategies include zoomed-out views of each data type that allow users to see the entire collection plus an adjoining detail view. The overview might contain a movable field-of view box with which users control the contents of the detail view, allowing zoom factors of 3 to 30. Replication of this strategy with intermediate views enables users to reach larger zoom factors.

Another popular approach is the fisheye strategy, whose distortion magnifies one or more areas of the display, but geometric zoom factors have to be limited to about five or different levels of representations must be used for the context to be usable. Since most query-language facilities make it difficult to gain an overview of a collection, the provision of adequate overview strategies is a useful criterion to judge such interfaces.

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Zoom task: users can zoom in on items of interest. Users typically have an interest in some portion of a collection, and they need tools to enable them to control the zoom focus and the zoom factor. Smooth zooming helps users to preserve their sense if position and context. Users can zoom on one dimension at a time by moving the zoom bar controls or by adjusting the size of the field-of-view box. A satisfying way to zoom in is to point to a location and to issue a zooming command, usually by holding down a mouse button. Jazz and its successor Piccolo are popular user interface toolkits that allow programmers to quickly create zooming environments. Zooming is particularly important in applications for small displays.

Filter task: Users can filter out uninteresting items. Dynamic queries applied to the items in the collection constitute one of the key ideas in information visualization. When users control the contents of the display, they can quickly focus on their interests by eliminating unwanted items. Sliders, buttons, or other control widgets coupled with rapid display update is the goal, even when there are tens of thousands of displayed items. Similarly, brushing and linking techniques allow users to dynamically highlight items of interest across displays.

Details-on-demand task: Users can select an item or group to get details. Once a collection has been trimmed to a few dozen items, it should be easy to browse the details about the group or individual items. The usual approach is to simply dick on an item and review details in a separate or pop-up window. In Spot fire, the details-on demand window can contain HTML text with links to further information.

Relate task: Users can relate items or groups within the collection. The attraction of visual displays, 'when compared to textual displays, is that they make use of the remarkable human perceptual ability for visual information. Within visual displays, there are opportunities for showing relationships by proximity, by containment, by connected lines, or by color coding. Highlighting techniques can be used to draw attention to certain items in a field of thousands of items. Pointing to a visual display can allow rapid selection, and feedback is apparent. The eye, the hand, and the mind seem to work smoothly and rapidly as users perform actions on visual displays.

In lifelines for example, users can click on a medication and see the related visit notes or test results. Designing user interface actions to specify which relationship is to be manifested is still a challenge.

In Spot-fire, details-on-demand window users can select an attribute, such as a film's director, and cause the director alpha slider to be reset to the director's name, thereby displaying only films by that director in a query-by-example style of interaction. Users may also want to combine multiple visualization techniques that are tightly coupled. Tools are being developed to allow users to specify what visualizations they need and how the interaction between the visualizations should be controlled.

History task: Users can keep a history of actions to support undo, replay, and progressive refinement. It is rare that a single user action produces the desired outcome. Information exploration is inherently a process with many steps, so keeping the history of actions and allowing users to retrace their steps is important. However, most products fail to deal adequately with this requirement. Designers would do well to model information-retrieval systems, which typically preserve the sequence of searches so that these searches can be combined or refined.

Extract task: Users can allow extraction of sub-collections and of the query parameters. Once users have obtained the item or set of items that they desire, it is useful for them to be able to extract that set and to save it, send it by electronic mail, or insert it into a statistical or presentation package. They may also want to publish that data for others to vie\v with a simplified version of the visualization tool.

Challenges for information visualization

The data type by task taxonomy helps organize our understanding of the range of problems, but there are still many challenges that information-visualization researchers need to face to create successful tools:

- ***Import data:*** Deciding on how to organize input data to achieve a desired result often takes more thought and work than expected. Then, getting data into the correct format, filtering out incorrect items, normalizing attribute values, and coping with missing data can be burdensome tasks.

- ***Combine visual representations with textual labels:*** Visual representations are potent, but meaningful textual labels have an important role. Labels should be visible without overwhelming the display or confusing users. Mapmakers have long wrestled with this problem, and their work offers valuable lessons. Often, user-controlled approaches such as ScreenTips and eccentric labels can help.

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- ***See related information:*** Additional information is often needed to make meaningful judgments. Patent lawyers want to see related patents, other filings by the same people, or recent filings by competing companies. Genomics researchers want to see how clusters of genes work in harmony during the phases of cellular processes, and then view similar genes in the Gene Ontology or read research papers on relevant biological pathways. The pursuit of meaning during discovery requires rapid access to rich sources of related information.

- ***View large volumes of data:*** A general challenge to information visualization is the handling of large volumes of data. Many innovative prototypes can only deal with a few thousand items, or have difficulties maintaining real-time interactivity when dealing with larger numbers of items. Dynamic visualizations showing millions of items demonstrate that information visualization is not yet close to reaching the limits of human visual abilities, and user-controlled aggregation mechanisms will push the envelope even further. Larger displays can help because additional pixels enable users to see more details, while maintaining a reasonable overview.

- ***Integrate data mining:*** Information visualization and data mining originated from two separate lines of research. Information-visualization researchers believe in the importance of letting users' visual systems lead them to hypothesis making, while data-mining researchers believe that statistical algorithms and machine learning can be relied on to find interesting patterns. Sometimes consumer purchasing patterns stand with when properly visualized, such as spikes in demand before snowstorms or correlations between beer and pretzel purchases. However, statistical tests can be helpful in finding more subtle trends in consumer desires or demographic linkages for product purchases.

- ***Collaborate with others:*** Discovery is a complex process that depends on knowing what to look for, verifying assumptions by collaboration with others, noticing anomalies, and convincing others of the significance of a finding.

Since support for social processes is critical to information visualization, software tools should make it easy to record the current state and send it to colleagues or post it to a web site with annotations and data.

- ***Achieve universal usability:*** Making visualization tools accessible to diverse users regardless of their backgrounds, technical disadvantages, or personal disabilities is necessary when the tools are to be used by the public, but it remains a huge challenge for designers.

For example, visually impaired users may need to use text-based alternatives to the visual display; a good example is provided by the National Cancer Institute's cancer atlas. Encouraging results have been found with the sonification of graphs, scatterplots, and tables, and in the future, spatial sound might help sonify more