Visualizing Search Results: Some Alternatives to Query-Document Similarity

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Visualizing Search Results: Some Alternatives To Query-Document Similarity

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Abstract

A digital library of computer science literature, Envision provides powerful information visualization by displaying search results as a matrix of icons, with layout semantics under user control. Envision's Graphic View interacts with an Item Summary Window giving users access to bibliographic information, and XMosaic provides access to complete bibliographic information, abstracts, and full content. While many visualization interfaces for information retrieval systems depict ranked query-document similarity, Envision graphically presents a variety of document characteristics and supports an extensive range of user tasks. Formative usability evaluation results show great user satisfaction with Envision's style of presentation and the document characteristics visualized.

1. Introduction

Envision [Fox et al., 1993] [Heath et al., 1995] focused on developing a digital library from the computer science literature, with full text searching and full content retrieval capabilities. Envision is a step toward fulfilling the dream of electronic libraries, providing remote access to research collections. Data used in Envision include publications of the ACM and other literature, including videos and animations. Named after Tufte's book [Tufte, 1990], Envision is a multimedia digital library of computer science literature that serves computer science researchers, teachers, and students at all levels of expertise. A substantial portion of project resources was devoted to development of Envision's user interface. We focus here on information visualization in the Envision search results display. Information visualization takes advantage of powerful human cognitive capabilities for parallel processing by presenting information using multiple graphical encodings With a graphical presentation of search results, more information about more retrieved objects can be conveyed in a small space since each attribute of a graphical object can be used to convey document characteristics.

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A variety of systems, a few of which are discussed below, have begun to bring together the advantages of information visualization and current information retrieval technology. Many visualization interfaces for information retrieval systems visualize ranked query-document similarity and clustering. The VIBE [Olsen et al., 1993] information retrieval system moves toward the goal of visualizing clustering patterns in a document space. VIBE allows users to specify several terms, each to be associated with a portion of the visualization window, with document icons distributed so as to reveal the relevance of documents to the selected terms. Both Vineta [Krohn, 1995] and Bead [Chalmers & Chitson, 1992] reveal clustering patterns using a three-dimensional scatterplot visualization. LyberWorld [Hemmje et al., 1994] also depicts clustering in three dimensions but constrains the visualization to a sphere. Kohonen's feature maps also have been used to visualize semantic distributions of a collection [Lin, 1992].

A recent development at Xerox PARC is the TileBars interface, which depicts distribution of query terms within each document of a retrieval set so that the most relevant parts of a work can be located quickly [Hearst, 1995]. TileBars is part of a larger digital library effort [Rao et al., 1995] that includes such developments as Snippet Searching [Pederson et al., 1991] and Scatter/Gather [Cutting et al., 1993] [Cutting et al., 1992] to assist in query reformulation, and the Butterfly workspace [Mackinlay et al., 1995] for searching and browsing. InfoCrystal [Spoerri, 1993], which works with both Boolean and vector-space queries, uses a graphical query language consisting of lines joining geometric shapes to reveal the number of query terms present in each retrieved document.

Only a few systems visualize other document attributes, usually for databases other than bibliographic or library collections. Building on users' recollections of objects that interest them, RightPages supports browsing with iconic representations of document title pages [Hoffman et al., 1993] Both Dynamic HomeFinder and FilmFinder [Ahlberg & Shneiderman, 1994] use a starfield display, or matrix of rectangular cells, to present the content of a database and support dynamic querying. For HomeFinder, each icon represents a home for sale. The starfield overlays a city map so that icon position shows geographic location. Built around a collection of videos available for rental, FilmFinder's icons are color-coded to depict genre, while lateral position shows year of release. The Table Lens [Rao & Card, 1994] visualizes multi-dimensional sorts to reveal patterns in a relational database of baseball statistics.

While Envision can visualize query-document similarity using both relevance rank and estimated relevance of each

document to the query, Envision is unique in the number of other document characteristics that are also represented graphically. Using a wide variety of layout semantics, Envision supports numerous different user tasks. Several visualizations, some of which are newly developed, are discussed in section 3.3 in terms of user tasks supported. Formative usability evaluation results, discussed in section 4, show outstanding user performance, as well as great user interest in and satisfaction with Envision's style of presentation and the document attributes visualized.

2. Development Of Envision

Envision serves computer science researchers, teachers, and students at all levels of expertise. Because a major goal of Envision was to create a user-centered product, we determined user needs by interviewing a dozen professionals in human factors engineering, library science, and computer science, including specialists in user interface design and information retrieval. The interviews and user task analysis based on them are detailed in [Fox et al., 1993].

A primary goal in the interviews was to elicit imaginative ideas about how the interviewees would like to work with literature, if limitations of known systems could be overcome. Interviewees responded to questions about current use of information sources, their future information needs, and their wish lists for the electronic library of the future. Beyond ready access from their offices, chief among interviewees' wishes was the ability to identify and explore patterns in the literature. Some asked for visual representations, while others wanted ways to see connections not visible with current tools. Users wanted to see documents their way — to explore the literature along dimensions of their choosing, to home in on particular areas of interest and explore those in detail, then move on to broader or sometimes very different views. Our interviewees wanted to:

- Identify trends in the literature, spotting emerging topics of research, as well as identifying peaks and valleys of research interest in topics.
- Locate highly influential works which have been frequently cited by others.
- Identify relationships among research topics that were not apparent.
- Discover communities of discourse in which authors regularly cite and respond to one another's work to form an ongoing conversation in print.

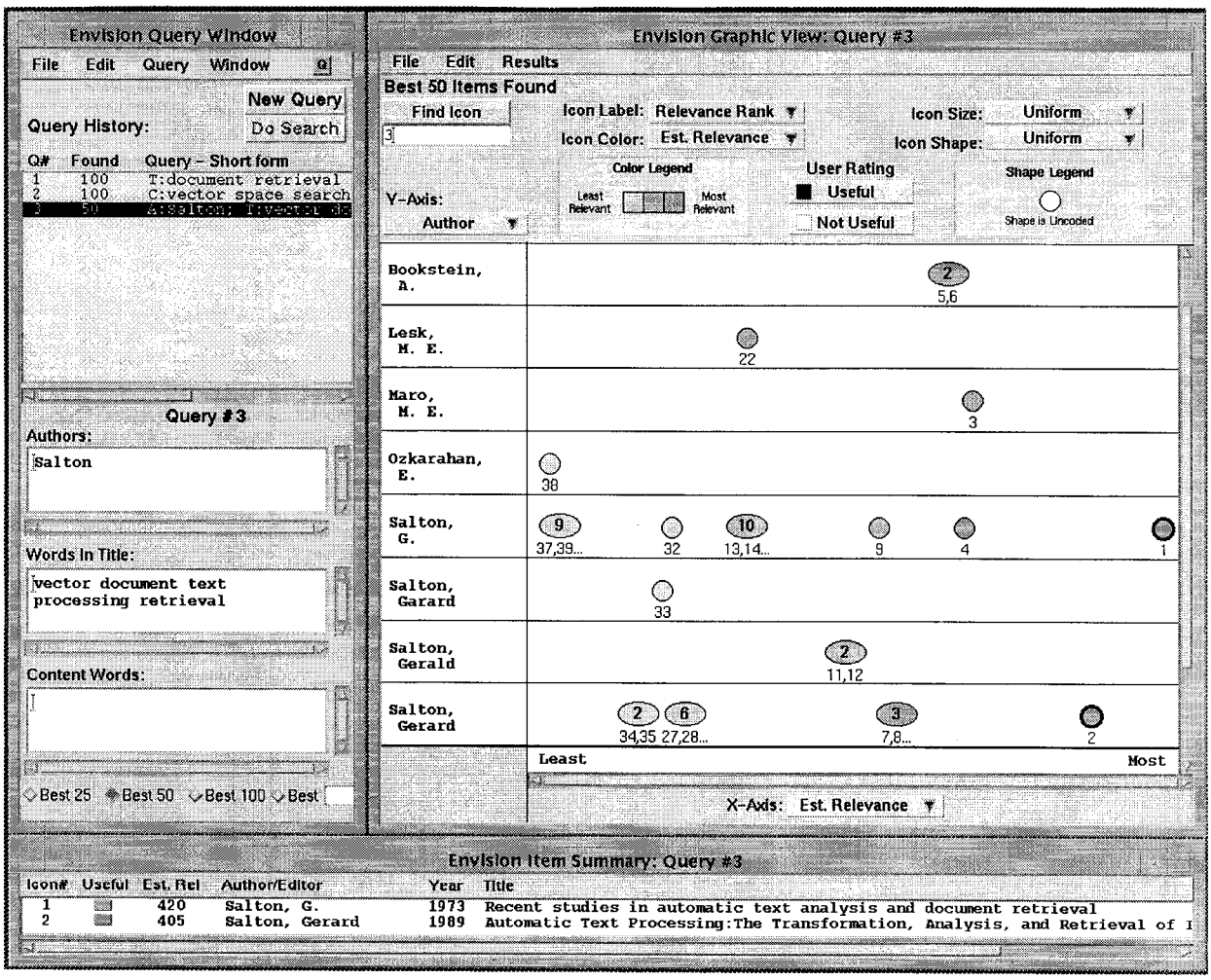

Figure 1. Envision search results display

Although initial planning for Envision did not call for development of an information visualization system, we turned to visualization in attempting to meet user needs. We have limited our efforts to two-dimensional visualization so that Envision is accessible on most current Unix desktop systems. Development has proceeded iteratively, with extensive usability evaluation involving a wide range of participants. Our design for information visualization, described in the next section, responds to the many ways users want to access information.

3. Design For Visualization

Shown in Figure 1, the basic Envision search results display consists of three interactive windows: 1) a small Query Window gives users access to an editable form of the query which led to the display; 2) the scrollable Graphic View Window, discussed in detail below, provides an iconic display of a full results set; and 3) the Item Summary Window displays bibliographic information about documents whose Graphic View icons have been selected. The query used in Figure 1 requests the best 50 works with Salton as author and up to five words in the title: vector, document, text, retrieval, processing. All the works retrieved have Salton as lead or other author and match some subset of the title words.

The Envision Graphic View Window design is modeled after scatterplot graphs. Each document in an Envision search results set is shown in the Graphic View Window as an icon. Space in the upper part of the Graphic View provides both a legend to explain current layout semantics and pop-up menu controls that allow the user to change the semantics. (See Figure 1.) When the user selects an icon, bibliographic information about the represented item appears in the Item Summary Window. Documents deemed useful may be marked by the user via boxes in the Item Summary Window lines or by selecting the icons and making menu choices in the Graphic View. Items thus marked might be used as the basis for a feedback search, or saved or printed in summary form. Double-clicking an icon or Item Summary line automatically launches XMosaic and provides access to any additional information about that document in the Envision database, including the full bibliographic entry, related descriptive information, abstract, and full content.

In Figure 1, the circular "bubbles" in the Graphic View represent single documents, with relevance ranks shown as labels below the circles. Elliptical cluster icons, discussed further in section 3.2, represent sets of documents that would display at the same point in the graph. The number of represented documents is shown inside the ellipse. Labels below these cluster icons show the ranks of the two most relevant documents in the cluster. The Item Summary Window at the bottom shows a text presentation of bibliographic data for documents whose Graphic View icons are selected by the user, indicated by bold outlines (e.g., documents with icon numbers 1 and 2 in Figure 1). Item Summary text lines are related to their icons by icon label

3.1 Information Visualization in the Graphic View

The Graphic View design gives users control over the semantics of six icon attributes, or *graphical devices*:

- icon position along the x-axis and y-axis,
- icon size,
- icon color (or saturation for gray-scale monitors),
- the shape of the icon itself, and
- the alphanumeric label associated with each icon.

These graphical devices may be used to present a variety of document characteristics, serving various user purposes. Like several other systems, Envision can present estimated query-document similarity, or *estimated relevance*, as well as *relevance rank*. *Author names* and *publication years* are central to citations and clearly of interest. *Index terms* are useful in query reformulation. Representation of *document type* allows users to easily locate such relatively rare objects as videos, but also allows users to distinguish publications of the type they believe to be most useful for their current task. Finally, a document's Envision *database ID*, while not inherently interesting to users, may be useful in comparing retrieval sets and can be used to retrieve a document directly.

The list of document characteristics associated with each icon attribute is extensible, pending further usability evaluation and user input. Design decisions to date include:

- Icon placement along the x-axis and y-axis each may indicate estimated document relevance, author names, index terms, document type, or publication year.
- Icon sizes may be uniform or may vary to indicate estimated relevance.
- Icon color may be uniform or may vary to indicate relevance or document type.
- Icon shape may be uniform or may vary to indicate document type; for an experimental version, icon shape also may represent estimated relevance.
- The label associated with each icon may signify either the relevance rank of the document or a unique Envision document identifier.

Other document attributes considered for visualization include the number of times an item has been cited by others, which might indicate the significance of the work; the number of items in a document's reference list, useful to those seeking bibliographies; and document size, as an indicator of depth of coverage and/or time required for perusal. These are discussed further in section 5.

For several reasons, estimated relevance and relevance rank may be represented by more graphical devices than any other document attribute. Our interviewees and users have told us they fear being overwhelmed by large retrieval sets Ranked results make them more comfortable with large results sets and more willing to use a computerized search tool. Though some users initially voice discomfort with our vector-space retrieval system, even brief experience with the system leads to praise for it. From using other systems, as well as from reading, many users are aware that estimated relevance values exist and want to see those values, even though they may not understand the numbers' significance. More sophisticated users believe the estimated relevance values give them insight into the collection and the nature of the retrieval system. Finally, it is simpler to visualize estimated relevance and relevance rank than most other document attributes, so it seems appropriate to allow users to select the visualization most comfortable for them.

3.2 Graphic View Layout Algorithm

The Graphic View Window provides a two-dimensional display of the set of documents retrieved by a query. The x- and y-axes of the display have two different scales representing document attributes such as author, year, or estimated relevance. Some scales (e.g., estimated relevance) vary continuously and do not partition the corresponding

axis. Most scales (e.g., author and year) take on discrete values and partition the corresponding axis into strips. The result of this partitioning is a matrix of cells such that each document in the results set belongs to a single cell. (For later versions of the Graphic View, when multiple authors and multiple index terms are visualized, each document may belong to multiple cells. See discussion in section 5.) Each document in a cell is represented by an icon. As a cell may have numerous icons to display, we devised a layout algorithm to place the icons within a particular cell.

Because of window size and user layout preferences, a cell has limited dimensions and may be unable to display all its icons. This limitation and other factors led to these requirements for the layout algorithm:

- Icons of the most relevant documents should have priority in the display.
- The layout should be uncluttered, yet make effective use of available space in the cell.
- No two icons may overlap.
- The layout should be reproducible; the same results set and the same scales in the same size cell should always yield the same layout.

To meet these requirements, we designed a special elliptical cluster icon to represent all the documents that cannot be displayed individually due to the non-overlap requirement. The number of documents it represents is shown within the cluster icon, while the label shows the ranks or identifiers of the two most relevant represented documents. As shown in Figure 2, use of the cluster icon does have drawbacks — its use masks information about represented documents that is encoded using icon shape and icon size, while the cluster icon's color is that of the highest ranked document in the represented shape (see Salton, G., in 1983).

3.3 Graphic View Visualizations And User Tasks

The Graphic View supports users in making decisions about which works to examine in large sets of documents. Users of Envision also benefit from having control over the semantics of each icon attribute, so they can change the layout to reflect document characteristics of greatest interest for a particular task. In Figures 1 through 6, for example, two typical results sets are presented in displays appropriate to a variety of tasks. In Figure 1, author names are shown on the y-axis, estimated relevance to the query is shown on the x-axis, and icon labels show relevance rank. Icon color also shows relevance, with documents in the top 35% of relevance values coded in orange, the next 35% green, and bottom 30% blue. These values have been chosen

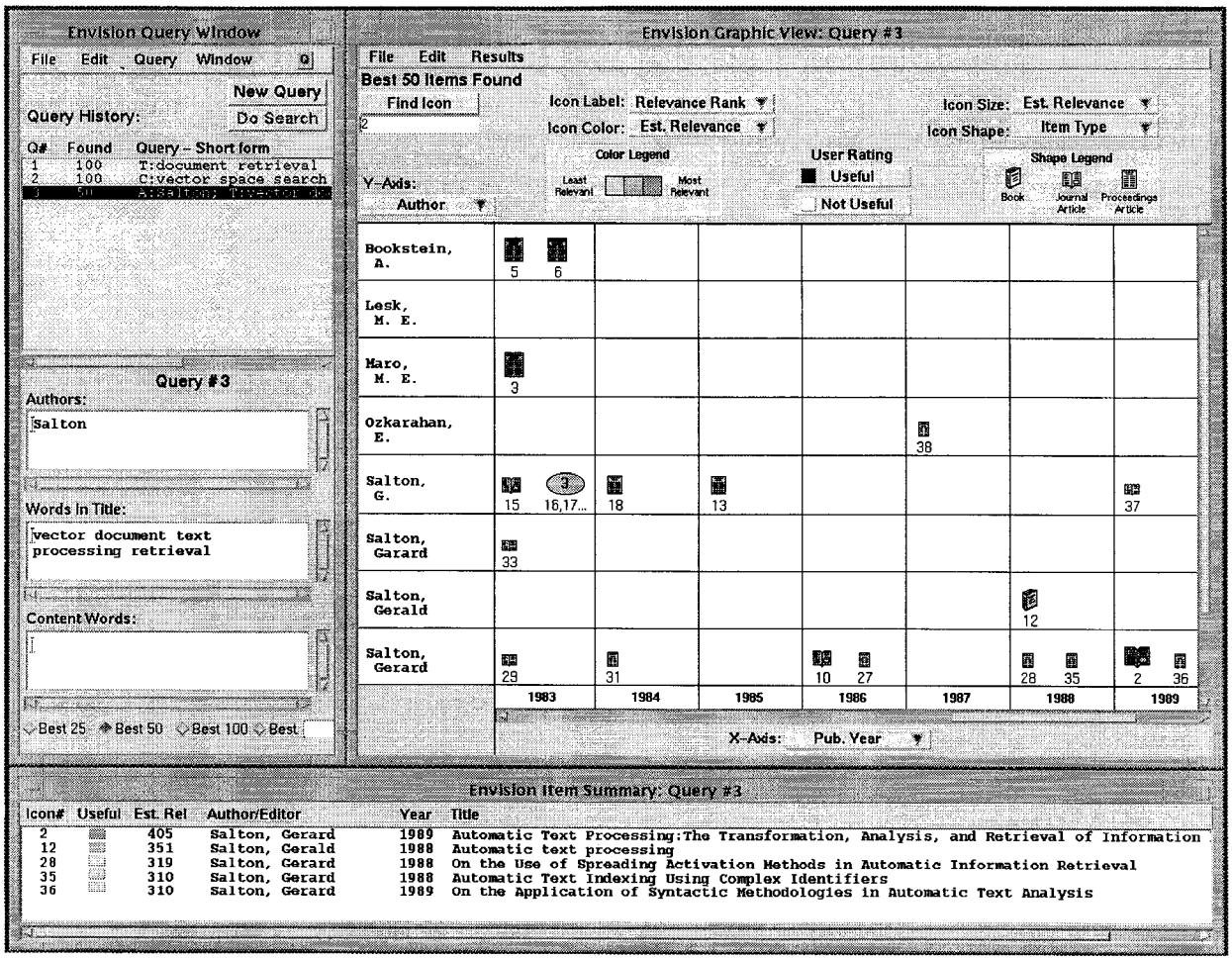

Figure 2. Placing author on the y-axis and publication year on the x-axis reveals individual publication patterns. Icon shape reveals document type, and icon color and size both show estimated relevance.

after study of system performance and display characteristics. (Legends for color and shape appear under the icon controls at the top of the Graphic View.) Using Figure 1, the user can rapidly identify authors who have produced many works relevant to the topic or identify the most relevant works by a single author. The user may also determine whether a highly relevant work is by an author already known and respected, or otherwise of special interest.

Researchers interested in comparing publication patterns among authors might choose the layout in Figure 2, showing authors on the y-axis and publication year on the x-axis. This display is fairly sparse, reflecting the reality of publication patterns in the topic and collection, but it presents much information about each document. Using this layout, in which icon shape shows document type, the user who believes that journal articles contain more significant work than proceedings, or that proceedings articles are more likely to contain cutting-edge research, can distinguish these items from books, which might contain more in-depth coverage. The layout uses icon color, size, and label to show relevance. Redundant encodings of this kind aid in quick, reliable perception of important features [Carswell & Wickens, 1987] [Wickens & Andre, 1990]. There are thus a total of four characteristics revealed for each document, yet the display remains aesthetically pleasing and uncrowded.

Putting publication year on the y-axis and estimated relevance on the x-axis, as in Figure 3, creates a graphic picture of increasing research within the area. Icon color again shows relevance, so that icons for the most relevant documents are orange and further right than other icons. In this display, the icons labeled 2 and 8 have been marked useful by the user and are thus colored red, while icon 38 has been marked not useful and is colored white.

A user seeking more terms to use in query revision might choose the layout in Figure 4, with assigned index terms on the y-axis and estimated relevance on the x-axis. Clustering of relevant documents in different index categories may reveal relationships among the categories. Pairing index terms with either author or publication year in the Graphic View (not shown) can reveal other commonalities among indexed topics. Utility of visualizing index terms obviously depends on the quality of indexing. Envision currently visualizes only index terms or keywords that have been assigned by authors or editors — clearly a major limitation, especially since our vector-space search system does full-text searching. Furthermore, both prevalence and quality of assigned index terms vary widely among segments of the collection, from copious to completely absent, and from controlled descriptors through ordinary language to cryptic abbreviations. Additionally, since Envision currently visualizes only one index term per document (the first listed)

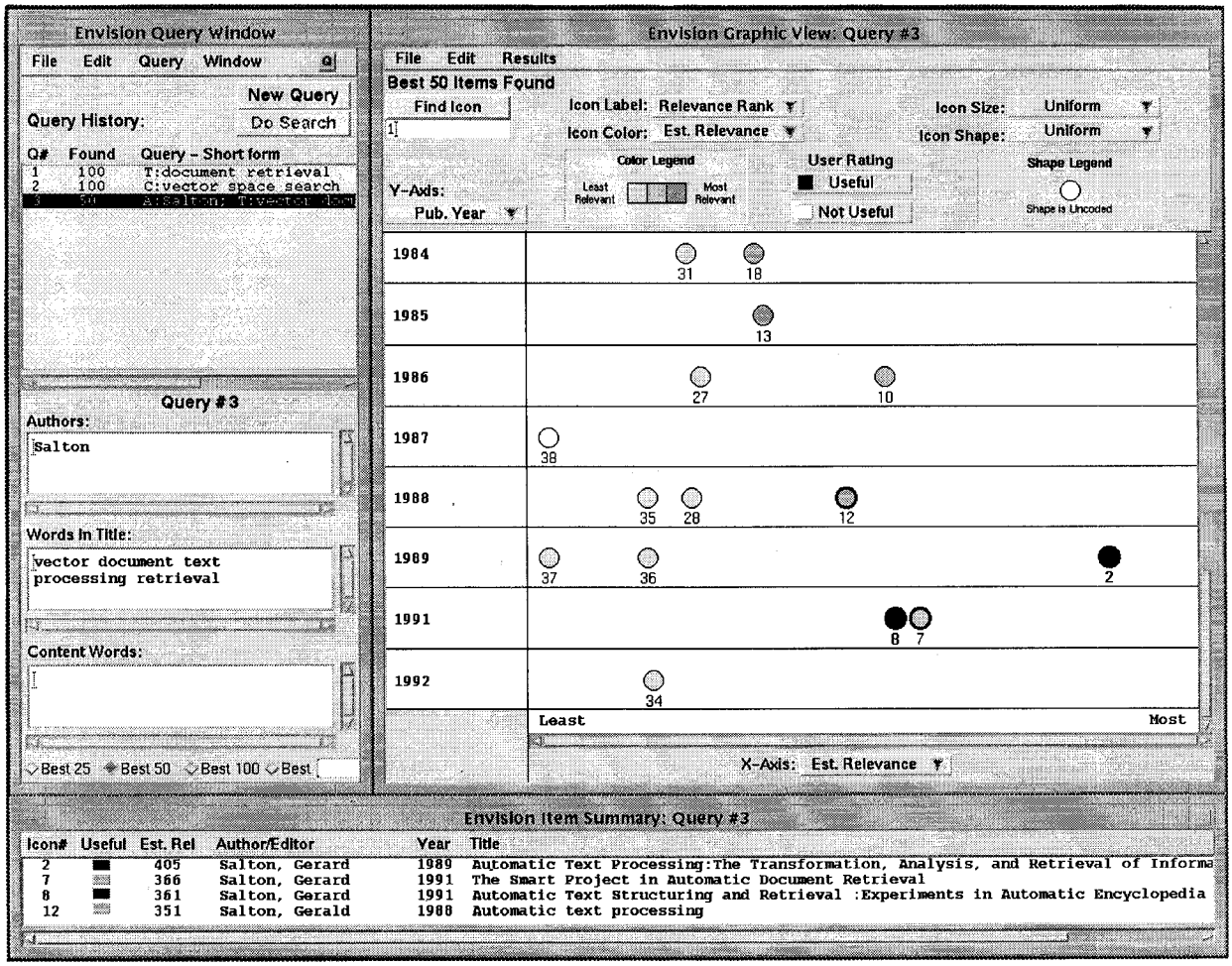

Figure 3. A year-by-relevance layout reveals peaks and valleys in related research.

neither the full range of assigned terms nor the true amount of overlap among them is available to users. Visualizing multiple index terms per document presents a number of usability problems, discussed in section 5.

In addition to color and x-axis position, shape also encodes relevance in Figure 4 — an encoding included to support Envision-based perceptual research. The partition is the same as that used for color: documents in the top 35% of relevance values are shown as stars, the next 35% as diamonds, and the bottom 30% as triangles. Icon size is uncoded.

Finally we present two configurations that allow the user to view the entire results set without scrolling. In the first (Figure 5), both x- and y-axes have been set to show estimated relevance. This display reveals drop-offs in the estimates, giving a researcher insight into performance of the underlying search engine on the query, and allowing an end-user to pick a highly ranked subset to examine. The second, shown in Figure 6, shows document type on the x-axis and estimated relevance on the y-axis. Putting relevance on the y-axis rather than the x-axis invokes a different metaphor: that the most relevant items, like cream, are rising to the top. Giving users control over layout allows them to chose comfortable metaphors. This may be one reason that users report high satisfaction with the Envision interface.

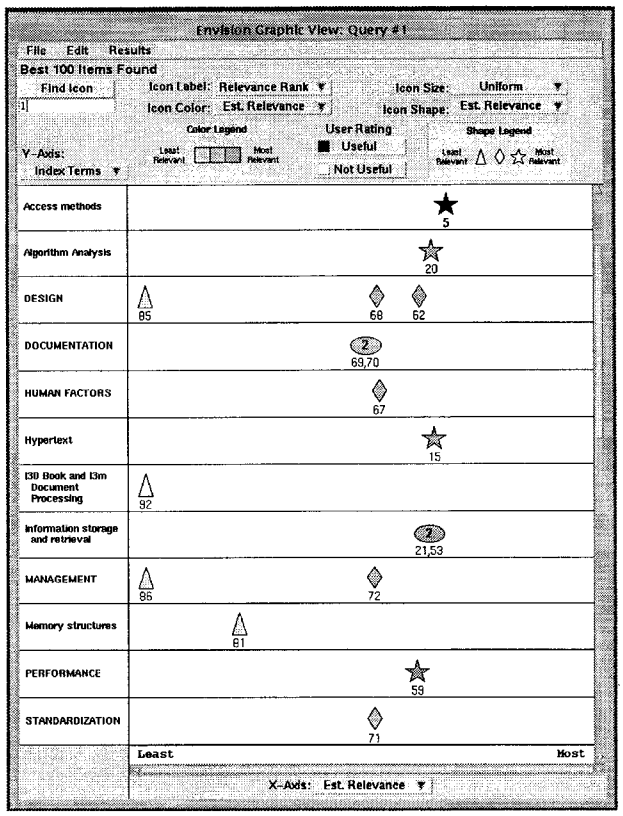

Figure 4. Showing index terms on an axis may facilitate query revision. Relevance is redundantly encoded with color, shape, and x-axis location.

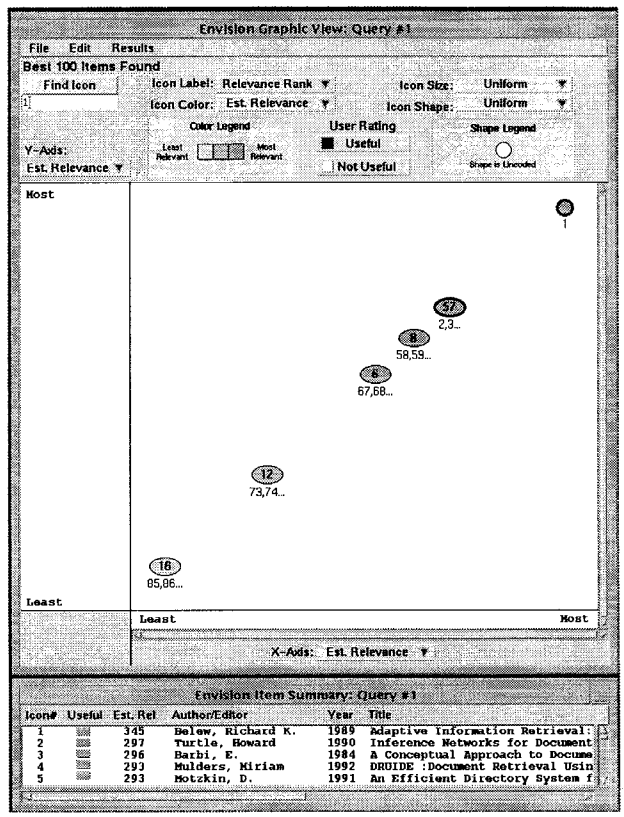

Figure 5. Presenting relevance on both x- and y-axes shows the entire results set, revealing drop-offs in estimated relevance.

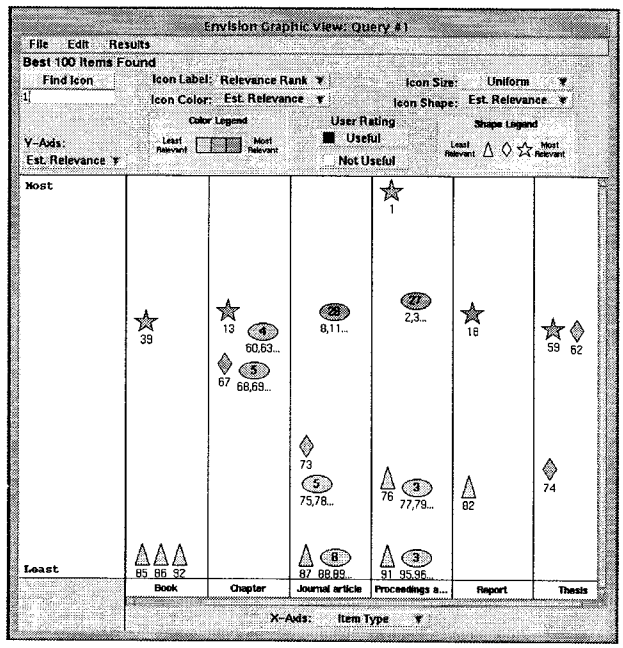

Figure 6. Placing relevance on the y-axis changes the metaphor, allowing the most-relevant documents to rise to the top.

Still working with your second set of search results,

a. Change the Graphic View so that the x-axis label shows you the years in which works were published.

b. Point to the icon for the most relevant work by Shneiderman.

c. Tell me in what year the work was published.

d. Change the Graphic View so it again shows relevance on the x-axis.

Figure 7. Sample task using the Graphic View

4. Formative Usability Evaluation Of Envision

The first response of many people on seeing Envision is that it is "busy" — three windows, with the Graphic View Window alone presenting many symbols. Nevertheless, our usability evaluations showed that the design is an effective, easy-to-use product that conveys much information in a dense display. In our early cycles of usability evaluation, we were specifically concerned with proof of concept: Could users understand relationships among the windows and the graphical objects within them? Did users make sense of the complex display, based on graphical devices used in the design, and find this a desirable way to view search results?

We used a SuperCard[1] prototype for our earliest usability evaluations. Participants performed assigned tasks (e.g., finding three works published by a given author in a specified year; locating the title and author of the most relevant work) and then responded to a subjective questionnaire. Details of that evaluation are in [Nowell & Hix, 1993]. None of the participants had any difficulty in recognizing relationships among the windows and objects in them, while all participants commented positively on the power the Envision interface provides to the user.

For our latest usability evaluations we used the X-Windows implementation of Envision. In addition to assessing design changes resulting from earlier prototype evaluations, we focused on features that were not fully implemented in the SuperCard prototype: controlling the number of items in a results set via buttons at the bottom of the query window, changing which document characteristics were represented by each icon attribute using pop-up menus, and more extensive exploration of relationships among windows. Participants also were asked numerous questions about their understanding of Envision search results and user interface features reflecting system behavior, such as displayed relevance values. We focus here on tasks and issues pertaining specifically to the Graphic View.

Because the Envision user interface was designed for a computer science library, all participants were computer scientists: one faculty member, two graduate students, and two undergraduates. Each was given a one-page "Getting Started" handout and was allowed ten minutes to explore Envision's features before performing 11 tasks, each consisting of several steps. A typical task required the participant to create a query meeting specified criteria, have Envision complete the search, and then use Envision's search results display to locate documents fulfilling various requirements. To ensure that participants used various aspects of the Graphic View, some tasks required participants to change the semantics of icon attributes (e.g., changing the x-axis setting to show publication years instead of estimated relevance), while for other tasks various icon semantics were left to participant discretion. A sample task is shown in Figure 7 above. In this example, items a, b, and d require use of the Graphic View; performance of item c may depend on either the Graphic View or the Item Summary Window. In all, 16 items required use of the Graphic View. Use of the Item Summary Window was required for some tasks, but many others could be completed using only the Graphic View. This is typical of the sorts of real research tasks Envision was designed to support. Upon completion of all tasks, users were given time for additional free exploration of the system. Throughout each usability evaluation session we recorded verbal protocol and critical incidents.

Six items were designated as benchmark tasks for objective measurement of user performance. Five benchmark tasks focused on initial use of a design feature, while the sixth studied learning curve. Performance measures included task completion time, number of errors, and number of questions asked (since the on-line Help system was not yet implemented). For task completion time, our goal was that mean participant time should not exceed the time required for one of the interface designers to complete the same task. For the initial task using a particular feature, we aimed for a mean error count and a mean number of participant questions equal to 0.2 — allowing for only one of the five participants to experience difficulty. Overall, each of the five participants performed 16 subtasks using the Graphic View, making a total of only five errors. (Time to task completion and use of help were not measured for non-benchmark tasks.) For the two benchmark subtasks using the Graphic View, participants made no errors, asked no questions, and all required less time than expected to complete the benchmark tasks — to our delight, surpassing the performance of an Envision designer!

Upon completion of the 11 tasks, each participant completed a questionnaire of 14 questions, with a scale of -3 (least satisfactory) to 3 (most satisfactory). Three questions about the Graphic View are shown in Figure 8. Other questions pertained to overall usability of Envision and to

[1] SuperCard is a registered trademark of Allegiant Technologies, Inc.

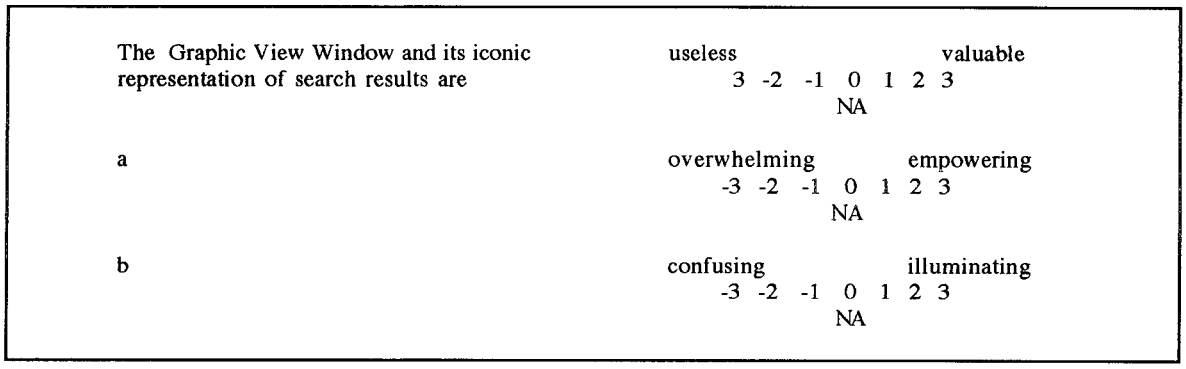

Figure 8. Sample items from usability evaluation questionnaire

specific features such as the query history. The lowest mean response for a single question was 1.6. The question shown in Figure 8 received a mean response of 3 for the main question, 2.6 for part a, and 2.4 for part b. Mean rating for the whole questionnaire was 2.3.

5. Current Status, Limitations, And Future Work

The first version of Envision is complete. The Envision database currently contains approximately 100,000 bibliographic records, 700 full-text articles, and 16,000 scanned pages. One hypertext and one video document are also available for experimentation. In addition to basic retrieval tasks, the user interface provides capability to explore patterns in the collection, visualizing such information as number of works published annually by an author or the number of works associated with an index term.

We plan further usability evaluation to determine the desirability of allowing users to change the document characteristic represented by an icon attribute during use of the display. That is, what happens to user performance when users are allowed to change layout semantics? Given results of our latest usability evaluation and other studies [Carswell & Wickens, 1987] [Wickens & Andre, 1990], we expect some temporary loss of speed and accuracy in use of the display immediately after users change the layout.

Issues of scalability pertain to the size of results sets the Graphic View can display. We have tested the current version with results sets as large as 500 documents. We found that for some icon attribute settings (e.g., authors on the y-axis and index terms on the x-axis, not shown), the display is quite sparse, reflecting the need for a "zoom" feature that is planned but not yet implemented. Zoom will allow users to see a larger area of the scatterplot in less detail or a smaller area in greater detail. Ideally, the Graphic View could then be used as a browser for the entire collection, allowing users to zoom in on selected areas of interest.

Full use of Envision's Graphic View requires access to a number of document characteristics that are infrequently available in a bibliographic database or library system, such as document size, the number of citations contained in a work, and the number of times a document has been cited in other works. Even when these characteristics are represented in the database in some form, a visualization may be difficult or misleading. Visualizing document size appears to be a straight-forward matter, dependent on page count, word count, or storage required. However, in a multimedia database, none of these is a consistent indicator of time required to use different types of works. For example, a video that can be viewed in five minutes may occupy more storage space than a book, and may have no word or page count. Some means of converting raw size values to a meaningful common scale is needed.

Visualizing "times cited by others" also presents challenges. We are developing a database of citation links for Envision that will ultimately provide not only the number of citations but hypertext links among related documents. Even so, our database will only provide information about citation links among documents in the database — a small percentage of the total number of documents about computer science. Since a visualization of "times cited by others" will show only citations from works in our collection, works heavily cited by publications not in the collection may appear to be less significant than they are. Accessing a citation index might be a solution to this problem.

One of the more interesting issues we are exploring is presentation of multi-sets — those instances when a single document belongs to multiple categories on either axis. For example, a document frequently has more than one author and is usually assigned more than one index term. Yet presenting multiple icons for one document has the potential to greatly increase display clutter, and we have questions about such a display: How will users respond when selecting or marking one icon causes several others to highlight or change color because they represent the same document? What about a document that occurs both as a single icon and as part of a cluster?

During usability evaluation and demonstrations of Envision, users have told us they especially like the flexibility and power of the Graphic View, they want many more visualizations. For example, we have been asked to reveal who cites whom by placing citing author on one axis and cited authors on the other — thus depicting communities of discourse, as users requested during our initial interviews. Musicians want to visualize by genre, style, and instruments required. For a medical collection, visualizations might present key symptoms, effectiveness of medications suggested per symptom, risk of drug interactions, etc. This user feedback, even more than success in formal usability evaluation, convinces us that library systems have much more to visualize than query-document similarity or semantic content and that the Envision Graphic View is a powerful, flexible design for increasing the range of characteristics visualized by a retrieval system.

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