Information Display: Control of Visual Representations

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Abstract

To display large quantities of information in a form that the user can readily comprehend, we turn to visual techniques. But we must provide at least the same type of control here that the user has over textual displays -- an ability to modify and tune the visual display to his or her own particular interests and preferences easily. We describe two systems, GUIDO and VIBE, that provide this ability. Both systems allow the user to handle and organize larger amounts of information than is possible with traditional retrieval methods, with better control over the information organization.

Introduction

In response to a query, traditional information retrieval systems present the user with a sequential list of document references. This list may or may not be ordered by relevance, as computed by the system, but the system provides little additional help to the user. First, even if the list is ordered, the user generally does not know the system's measure of relevance. Second, the presentation of a limited list precludes the user from viewing other documents, short of formulating a new query. If the system does not have relevance feedback (as is the case for most commercial systems) the user has no help in reformulating the query. Third, the sequential list provides only one perspective from which the user can view the documents, and the user generally does not have a clear definition of this perspective. Thus, the first problem that we wish to address is: How can we present to the user a view of the document space that does not limit him away from potentially relevant documents and also enables him to see all of the more significant relationships among the documents?

During the second Visual Languages Workshop we discussed the concept of browsing by navigating through the document space [1]. Viewed as a vector space, the dimensionality of the document space equals the search term vocabulary size. Since the document space is of exceedingly high dimensionality, 5,000 or more, any such navigation is difficult to implement and even more difficult for the user to comprehend. This leads to our second problem: How can we enable browsing on the part of the user in a way that is easy to comprehend and easy to use?

Recently we have developed two visual models for information display, GUIDO and VIBE, both of which attack the two problems. They replace the high-dimensional document space by spaces of reasonable dimensionality. In this replacement there is some hiding of information, but greatly increased comprehension and ease of use. Our purpose in this paper is to describe these two visual models, and to discuss the issue of user control of the models.

The models are based on the vector space model for information storage and retrieval. In this underlying model, documents and queries are represented as vectors of term weights. These weights may be either binary, with 1 and 0 denoting the presence or absence of a given term, respectively, or values chosen from some predefined range of significance values. In the latter situation low values indicate the lack of significance (or even absence) of a given term in a document, while high values indicate the relative importance of those terms. Comparison between documents, or between a document and a query, may be based on any of several well-known functions, many of which are derived from distance measures within the space. The usual interpretation is that similarity of documents is inversely related to the distance between them.

As the query is simply another point in the document space, the measure of similarity between a document and a query is the same as that used for the similarity between any two documents. We can, in fact, identify a finite set of reference points, representing different factors related to the documents, and judge a document with respect to each of these points [2, 3, 4, 5]. The
query may be one such point; others include user profiles, alternative queries, known documents, or even synthetically defined points. In short, there is no reason why a user cannot use such reference points to delineate various aspects of the document collection that are of interest to him. For example, the user interested in classical music may wish to identify specific composers, types of music, instrumentations, performers, periods, and so forth. The user interested in databases systems might define reference points related to the underlying model, the programming language, the computer hardware, the data set, or even specific database systems that are on the market.

The key to reducing the dimensionality of the browsing space is recognition that the distances, not the specific terms and term weights, are the significant variables. If the criterion for similarity of documents is solely the distance between them, we may replace the document space with a distance space, in which the coordinates are distances from known reference points [4]. The dimensionality of this space is \( n \), the number of reference points, rather than the number of search vocabulary terms.

GUIDO

GUIDO, Graphical User Interface for Data Organization, models this distance space directly, projected onto a two- or three-dimensional computer display [6]. Because of the limitations of the computer display, the user chooses the two or three most significant factors in his concept of the data sought. These are used as the axes for the display, with any remaining factors being represented by various graphical properties and aspects. The locations of the reference points are fixed by the geometry of the document space. Using \( \mu_{ij} \) to denote the distance between reference points \( i \) and \( j \), the coordinates of reference point \( i \) will be \(<\mu_{1i}, \mu_{2i}, \ldots, \mu_{ni},\ 0,\ \mu_{i+1}, \ldots, \mu_{an}>\). Each document is represented by a point in the distance space whose coordinates are the distances from the document to the reference points. Thus two points have the same image if and only if they are equidistant from each of the reference points. (Note that in the original document space two points (documents) have the same position if and only if they have identical descriptions.)

Despite the great reduction in the dimensionality of the display, the GUIDO image would not be useful if it were difficult for the user to interpret. In fact, the interpretation is straightforward. With only two reference points the distance space is a half-infinite plank whose bottom edge is the line joining the images of the two reference points.

As similarity is inversely related to distance, the farther a document point is from this "base plate," the less significant the document is presumed to be.

For three reference points the base plate is a rounded and slightly convex triangle. The distance space is a three-dimensional prism whose cross sections are curvilinear hexagons.

For more than three reference points the distance space is completely analogous -- a curvilinear \( n \)-dimensional prism with an \((n - 1)\)-dimensional base plate spanned by the \( n \) reference points. In practice, as we have stated, these spaces are projected onto a three-dimensional subspace with the remaining coordinates shown as graphical attributes. We believe that we can represent up to seven or eight reference points this way,
and that this will be ample for all but the most arcane queries.

**VIBE**

While VIBE, Visualization By Example, is developed on the basis of the same distance paradigm as GUIDO, it carries the dimensionality reduction one step further [7]. A reference point, here called a point of interest, (POI), is represented as an icon on the screen, as are all of the documents in the collection. However, rather than position these icons according to their absolute distances from the POIs, they are positioned according to the ratios of their distances from the various POIs. Since it is meaningless to talk about the ratios of distances among the POIs themselves (one of these distances being zero for each POI), the positioning of the POIs is completely flexible and left to the user. Thus the user can define as many POIs as desired, and place them anywhere on the screen. The document icons are then placed in relation to the POI positions. If a document is influenced by only two POIs, it will be placed on the line joining them; under the influence of three POIs the document will appear in the triangle defined by them. The more influence that a POI has on a document in relation to the influence of the other POIs, the closer the document icon will appear to that POI.

Because of the ratio basis for VIBE, there is more potential overlap in document images. Any two documents whose distance ratios are identical will now have the same image point. The effect is a further reduction in the dimensionality of the display. Suppose, for example, that there is only one reference point, the classical query. In the original document space points at a fixed distance from the reference point lie on the surface of a sphere. In the GUIDO model the space is reduced to a ray anchored at the reference point, and all points at a given distance are mapped into a single point at the appropriate distance from the reference point. In VIBE all of these points and the entire document space are mapped directly onto the reference point. Thus we see that VIBE is of little use in classical retrieval from a single query, although by repeatedly opening the icon over the reference point the user will access the documents in order of decreasing relevance. In contrast, GUIDO presents a graphical representation of the list of documents ordered with respect to that query, spread out along the ray emanating from the query.

Now suppose that there are two reference points, and consider all points whose ratio of distances from these reference points is a given value. In the original document space these points lie on a surface, generally an n-dimensional ellipse about one or the other of the two reference points. In GUIDO these points fall on a straight line whose slope is the ratio. In VIBE these map onto a single point on the line between the POIs.

Thus we see that with respect to GUIDO, VIBE is characterized by complete flexibility in placing the reference points (in contrast to their fixed locations in GUIDO), and by the dimensional reduction associated with using ratios. Mathematically, the degrees of freedom available in the mapping from the distance space of

![Diagram](image-url)
GUIDO into VIBE provide the flexibility in the location of the POIs.

Controls and Embellishments

With either of these two visual environments, we have automatically solved the problem of hiding data from the user. Both GUIDO and VIBE can present as broad a view of the database as is desired, including display of the entire database. Due to the fact that the documents in the database are presented as points or icons, rather than as bibliographic listings, the user is not immediately faced with an overwhelming amount of data. Rather, the data are presented in a form that allows the user to obtain some sense of how they are related to each other, and to focus attention on specific individual documents or document groups that arouse interest. The user can then "open" these documents to examine them more closely. The user first sees the forest, then the individual trees.

The two systems that we have described exist in prototype; it is far too early to make firm statements about user acceptance of either visual metaphor. It is clear, however, that acceptance is closely tied to the control that the user has over the display, and to the embellishments that exist to show details of the display. To individualize the displays, and yet keep them simple, it appears that two fundamental principles should be followed. First, begin with as broad a display of the data as is possible. Traditional information retrieval systems begin with a very narrow view (only the most relevant documents), and provide the user little or no guidance in broadening. By beginning with a broad view, we enable the user to focus this view in response to the displayed information about the entire database.

The second principle is to keep the basic display as simple as possible. Any embellishments that exist should be actively invoked by the user, most likely from a menu of possibilities. In this way the display of the document points or icons is not masked by other graphic effects, until the user is ready to see and use those effects. At that time the user should be able to invoke any such effects easily, and to cancel them equally easily.

The embellishments fall into two general classes, those that relate to the data contained within the database, and those that relate to any viewpoint changes that the user invokes. In the first class, we have already mentioned the concept of opening a document icon or point to display the document contents. Another basic embellishment in this class is the use of document icons. In GUIDO the position of the document point indicates the strength of each of the defined reference points or factors with respect to the document. In VIBE this is not so -- only the relative strengths are indicated. Thus, a document point could be located close to a POI, and still contain relatively little information about that POI (although more than about other POIs). To show the strength of the relationships in VIBE we use icons are rectangular, with size proportional to the strength of the most significant POI.

Observe that the icon size in VIBE relates only to the most significant icon, whereas the position shows the relative strength of all POIs. We can make the strength of the various reference points more apparent by changing the rectangular icon to a star whose rays point to the various POIs and are of length proportional to the strength. The same device can also be used in GUIDO. In either setting, it seems to be of material help to the user, particularly when the display is crowded with many document points or icons.

The third embellishment that relates to the database contents is a means to indicate overlapping document points. Recall that in GUIDO documents (perhaps unrelated) will map to the same point if their distances from all reference points are the same, and that in VIBE this will occur when the ratios of the distances are the same. We have found, particularly in VIBE, that a significant number of overlaps of this sort can occur. The extent of this problem is dependent on the number of POIs, their definitions, and the type of documents or data in the collection. In GUIDO these documents are all represented by the same point; in VIBE the icons of the documents will all be masked by the icon of the most significant document. The user can think of the displayed icon as representing the top of a stack of documents. Several graphical devices are being tested as means of indicating the overlap. One is to spread the documents out slightly in a "tail" from the main point or icon. Another is to indicate the number of buried documents by rays emanating from the main point or icon. A third device is to attach a number to the point or icon whenever more than one document occurs there. Obviously, any of these devices clutters the display, and should therefore be invoked or canceled under user control. Finally, in situations where it is reasonable the user may choose to change the definitions of the reference points, thereby dispersing the overlapping documents so some extent.

The use of color in the display is being explored, but there are two major drawbacks. First, obviously any embellishment based on color will not be available on
monochrome monitors. As color monitors become more common, this should become less of a problem, and may ultimately disappear. Second, a certain percentage of users are colorblind to some extent. Unless some alternative to the use of color is developed for this group of users, they will not be able to take advantage of any embellishments based on color. Putting these problems aside, color can be used to highlight aspects of the document points -- say, red for points related to operas and blue for chamber music. Alternatively, for users who do not want to rely entirely on the displayed clustering of documents, color could be used to mark those whose score, by some measure, is above a given threshold; or invoked actively by the user to mark documents that are singled out for retrieval. Yet another possible use of color is to indicate the type of document involved. This is particularly useful in a mixed database, where green might indicate a full textual document, yellow an abstract, red a title and author citation only, blue an image, and so forth.

Other alternatives to color, or devices to use when color is used for a different purpose, include icon shape and texture. It is possible to define a great range of icon shapes and textures, just as it is possible to define many colors. With any of these devices there is a relatively low limit to the number of variations that the user can readily distinguish. Thus the sophisticated user may want to define six colors, six shapes, and six textures to indicate various aspects of the display. In any case, the definition and use of these should be, to the extent possible, under the user's control.

The second class of embellishments are those related to a user-defined change of viewpoint. In GUIDO, there are three fundamental controls. First, the user should be able to select the most significant reference points, those that will be used as the primary two or three dimensions of the display. Second, the user should have available all of the standard transformations, such as translation, rotation, and zooming, that are available in any geometric display system. These alone will provide the user with much flexibility in viewing the display. Third, the user should be able to define "caps" on the display, corresponding to retrieval thresholds. Beyond these three, the user should be provided with the ability to identify and capture any group of document points (presumably documents of importance), and have the display altered so that these appear near the base plate. The other side to this is the ability to delete from the display any documents that are clearly not wanted. For the purpose of marking documents one of the devices mentioned above -- icon size, shape, color, or texture -- could be used.

Another control that the user of GUIDO might want is the ability to change the underlying distance and similarity measures. Because the GUIDO display is a distance space, the fundamental shape of the space is unaltered by such changes. However, document points will be relocated when their distance measures change.

As these embellishments relate to changes in the display, it is important to include among the user abilities the ability to see the effect of any change, and to undo any change. The first of these abilities is perhaps most effectively provided either by dual displays or by graphical tracers. If the change is a major one, such as a redefinition of the main reference points, or an altered point of view, a "before and after" display can be used to show the change. Dynamically changing displays are another possibility. If the change is relatively small, such as that induced by a change of metric, the user should be able to display tracers on the screen, indicating the movement of each point from its previous location to the new one.

The display controls that the VIBE user needs are similar to those for GUIDO, with some significant differences. First, since the placement of the POIs is under user control, the user needs an easy way to effect a change in this placement. The changes are of three types: addition or deletion of a POI, movement of a POI to a different screen location, and change in the definition of a POI. At present, once the initial display has been generated a list of defined but unused POIs is presented to the user. At any time the user can choose to add any of these POIs to the display. Removal of a POI occurs in two ways. Since one may wish to see the effect of removal, a POI can be deactivated without being removed from the screen. Then it no longer affects the display, but is where it can be readily re-invoked. Second, a POI can be removed from the screen and placed back on the unused list.

Movement of a POI is effected simply by picking it with the mouse and moving it to a new location. The screen automatically reconfigures to conform to this change. Note that this change does not affect the measurements made on the data in the database, only how the data are displayed. This is useful to isolate groups of data for particular study, or to break up apparent groupings that are merely artifacts of the display configuration.

Redefinition of a POI requires editing the definition. Usually this involves the addition or deletion of terms, or the changing of term weights in the definition. In either case there must be a recalculation of the distances of each datum from the point of reference, and hence of the
distance ratios. These recalculations are then reflected as changes in the display.

The other embellishments of VIBE are similar to those suggested for GUIDO. It should be noted that since VIBE displays are based on distance ratios, rather than absolute distances, the effect of changing the metric will be less noticeable in VIBE than in GUIDO. Nevertheless, there will be a distinct effect, as not all distances are changed uniformly by a change of metric.

As with GUIDO, it is helpful for the user to be able to identify and mark groups of data easily. In addition to specific point marking, a "lasso" metaphor can be used to encircle related document icons for one purpose or another. Depending on the application, there may be significant overlap in the document display, so there is some chance of inadvertently lassoing unwanted documents along with the desired ones.

Conclusions

The work described represents a decided shift of approach in meeting information needs, from information retrieval to information display. Whereas the traditional information retrieval systems present the user with the documents that are supposedly most relevant to his need, and thereby deny him access to other documents, in both GUIDO and VIBE we have systems that attempt to present all available information to the user, letting him make the decision on which data are relevant and which are not. While the user ultimately makes this choice with any information retrieval system, with the systems that we have described the choice is made in the light of knowledge of the database contents. Because of the display limitations, the information is presented to the user in a highly abstracted form, points or icons; but the user can readily expand this representation to obtain a full description of any datum.

At the same time, both GUIDO and VIBE present the user with an opportunity that he does not have under traditional computer-based retrieval systems, that of browsing the database. Browsing, as it is usually conceived, is not a totally random activity. It is rather an examination of the database that is based loosely and dynamically on the database contents. As our two systems provide the user with an organized view of the database, it is possible for the user to undertake such browsing. Note that in contrast to browsing through a physical library, where the stack organization guides the browse, the user of either GUIDO or VIBE defines the organization of the database from his own point of view, and thus has a much more personal definition to guide the browse.

Both systems exist in prototype. They can be used with any database for which it is possible to obtain numerical valuations of the data with respect to the reference points or POIs. They have been used with both document collections and demographic data sets. Included in our study plans are the development of suitable measures enabling direct use of these systems with an image database.

References


