Ideation Through Visualization: The Vibe System

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1. Introduction

Visualization is the process of forming a mental image of a domain space. It is a cognitive process performed by humans in an attempt to form a mental image of the nature of systems, functions and objects. The entity being visualized may be concrete such as an organ of the human body or abstract such as fields of force. In attempting to describe anything, whether it be a system, function, object or an event, we have two basic choices for representation: linguistic or visual. Natural language or a subset thereof is very powerful as a means of description and can describe a wide range of events or objects, but it also has limitations such as speed of processing, memory requirements, etc. Graphical descriptions can show spatial relationships among large numbers of objects much more quickly and with less memory required than natural language, but can be limiting in terms of the scope of objects and events that can be described in an understandable manner.

Many of us use the human mind's ability to organize and locate things spatially. We use the pile method in our offices for storing papers, books, articles, etc. When we need to retrieve a particular object, we easily identify the pile that it is in based upon a relationship we have made between the object and its location. We all tend to remember approximately where on our bookshelves a particular book is located or where on our desk objects are located.

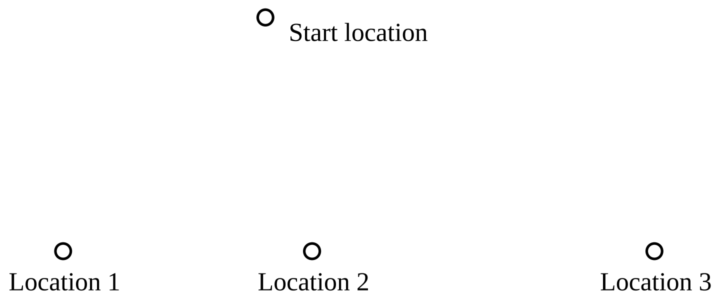

Figure 1. Distance discrimination

The ability to remember the location of items appears to occur almost without effort as part of the normal processing of information (see Hasher and Zacks, 1979; Naveh-Benjamin, 1987, for a full discussion of this issue). Other spatial abilities that humans have are those of comparing patterns of objects. For example, given the four locations in Figure 1, it is almost trivial to plan the shortest route from the starting point passing through the other three locations, yet if one is only given a table of interpoint distances this simple task becomes extremely difficult (Gärling, 1990). The human visual system is also remarkable at distinguishing among a large range of colors or hues. Visualization can use these human capabilities to aid in finding structures, relationships and patterns in large sets of data.

Visualization can be an effective form of explanation and communication. The human brain is particularly well suited for processing visual images and being able to recall the patterns formed by the images. Humans also have the ability to quickly form mental representations of relationships from visual presentations. With language based presentations, it can be difficult to discover patterns between items. However, details are best presented through text. Thus, visualization in concert with text is an ideal modality for explanation and communication.

The visual human-computer bandwidth is extremely high. For example, high quality 3-D animation is a problem even for our fastest computers, as humans process the displays much faster than they can be generated. This is in sharp contrast to presenting text and numbers where the problem is to slow down the computer, e.g., by inserting delays in scrolling algorithms or let the user control the speed by acknowledging every output message.

2. Visualizing information — traditional methods

Typically quantitative information is presented graphically as curves, bar charts, scatter diagrams, etc. These graphical diagrams are most often provided to explain or communicate information already known by the designer of the diagram. They will usually be supported, and sometimes made redundant, by text and numerical data.

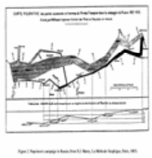

Figure 2. Napoleon's campaign in Russia (from E.J. Marey, La Méthode Graphigue, Paris, 1885)

The literature on graphical presentations expresses the need to present well-defined axes that make it possible for the readers of the graph to retrieve the actual values from the graphic presentation. In the “flatland” of paper and computer monitors the number of axes is limited to two. However, additional information — annotation in graphics or text — may be used to convey other information, thus reducing the number of display dimensions needed. Figure 2 presents an excellent example, made by a French engineer, Charles Joseph Minard in 1861 (Marey, 1885; Tufte, 1983). By the ingenuousness of the designer he has managed to present six variables simultaneously in a comprehensive and elegant two-dimensional display.

Previously, graphical diagrams demanded a lot of effort, both for creation and publication. However, the advent of computer graphics and desktop publishing have provided a dramatic change. With data available in an electronic format, diagrams can be produced automatically with a “touch of a button.” This has led to a widespread use of graphics in newspapers, television news, and business and research reports. Still, even with this powerful tool, graphical diagrams are used today much for the same reasons as before — to explain and communicate the meaning of quantitative data.

While most graphical diagrams are of an abstract nature, we find stronger real world connections in maps. Maps can be thought of as a special form of diagrams, where the locations of the data objects have a direct real world association. In maps, data are superimposed on a coordinate system by the use of special symbols, color or texture. Object attributes may be displayed by different colors, e.g., heights by changing from green to dark brown or depths by shades of blue (Fisher, 1982; Tufte, 1983, 1990).

Similar to for other statistical diagrams, computer technology has made it easier to produce maps. A standard technique is to superimpose thematic layers of data on a base map, e.g., a network of power lines, transformers, etc., on a city map. Computer technology has also made it possible to use a map to retrieve information — through a *geographic information system*. For example, a power company employee may get additional information on map items, such as power lines and transformers, by pointing at the visual representations of these objects. We see that these systems implement the concept of a *visual data interface*. The visualization is here not only a passive presentation, but a means to get to the underlying data.

3. Ideation

Ideation is a cognitive process aimed at the development of new ideas. During ideation, a human compares, rearranges, combines, reduces, isolates and evaluates concepts and data, which are present in cognitive processes. The vexing problem of ideation is that the mind has a relatively low capacity in terms of the number of entities that can be kept active at any one time. Therefore, a tool or technique that can activate additional concepts or data and make them available to the mind without losing those that were already present would be of great benefit to the ideation process.

Many people have utilized the technique of representing ideas as drawings or sketches as a way to record the results of the ideation process. This permits the mind to free itself from the data and concepts that have been recorded, since they can always be viewed when needed for reference. Also, the viewing of a sketch allows the mind to make active new data and concepts. Visualization can be thought of as a method for producing and viewing drawings or sketches based on conscious data and concepts.

4. Scientific visualization

The field of *scientific visualization* (McCormick and others, 1987; DeFanti and others, 1989; Warner, 1990) is based upon these ideas. Given hundreds or thousands of data points on several variables, it is literally impossible for a human to look at them in a tabular display or listing and derive any relationships among the data points. However, a visualization of these same points can be very quickly interpreted by a scientist or engineer. As the dimensionality of the space (number of variables) grows, special visualization techniques are required to aid the human in interpreting the data points.

Visualization software provides the capability to represent large datasets so that the structures, relationships and functions of possible systems or processes can be understood by humans. The datasets may have a high degree of entropy and visualization can be utilized to reduce the entropy and provide information contained in the data. Visualization as a human process must be supported by visualization tools that permit the human to actively and easily produce and manipulate visual representations.

Scientific visualization has become a powerful tool for many disciplines. The growth of the field is based on the dramatic improvements of computer graphics in the last decade, both in hardware and software technology. Simulation models on supercomputers, high-volume data sources (as satellites and medical imaging systems) and the analysis of complex algorithms produce huge amounts of data that are impossible to examine directly by humans. As an alternative to data reduction methods (as statistics), which will result in a loss of detail, visualization may be used. Traditional applications for scientific visualization, such as, molecular modeling, medical imaging, environment control, meteorology, gas and fluid dynamics and astrophysics are applications where data often have an inherent *position*. Other attributes of visualization may be more abstract, such as, visualizing force, stress or temperature. However, scientific visualization is also applied to problems where the graphics determine a completely abstract picture, i.e., where no natural mapping between the problem and graphical attributes exist (e.g., visualization of fractal algorithms).

Scientific visualization differs from most other graphical applications as it concentrates on the concept that visualization may be used for exploration and ideation. The interactivity of these systems illustrates another difference from the static world of traditional graphic presentations. However, something has also been lost. Traditional graphics are generally applicable, the methods are simple and the tools can be used on the cheapest computers. Scientific visualization, on the other hand, is usually connected to supercomputers, highly sophisticated tools, visualization experts and special applications.

5. Modeling and modeling tools

At some point in the ideation process, sophisticated geometric modeling capabilities are usually required to perform operations on the geometric representations of the ideation objects. The modeling functions that are useful in this context are scaling, positioning, combining objects, addition of new objects, elimination of objects, substitution of objects and renderings such as, color, labels, shading, hiding, zooming and perspectives. Animation in terms of simulation is also a valuable tool to aid in the modeling process.

A model is a preliminary pattern that acts as a tentative description of a system or theory that accounts for known properties. Models may be continuous space-time, discrete space-continuous time or discrete space-discrete time. They may be iconic, analog or abstract. They may be conceptual, mathematical, geometric or models of natural phenomena. In any case, models serve to aid in making predictions, providing a framework for managing complexity, representing reality or guiding research.

The Information Visualizer, from Xerox Palo Alto Research Center (PARC), is an example of a highly sophisticated modeling system (Clarkson, 1991). Here, 3-D real time animation is used to help users to organize and retrieve data. This 3-D effect is achieved by standard rendering techniques, but it enables users to look at their data in a depth perspective. A “moving around” effect, enabling the user to view the 3-D displays from different angles is implemented by animation. Some of the same animation techniques are found in several other systems, some of which are commercially available (Donoho et al, 1988). These systems give the user the possibility of plotting and viewing data on several dimensions, as well as using rotation along user defined vectors to present different perspectives.

6. An alternative approach to visualization

As we have seen, there are a number of different strategies, techniques and tools for visualization. Each has their advantages and disadvantages. A summary of these are:

Traditional graphical methods:

- introduces the idea of visualizing data for explanation and communication
- are generally applicable across various application domains
- are based on simple methods, techniques and tools
- displays are static and are — most often — limited to two dimensions

Mapping systems:

- are based on data having an inherent (most often, real world) position
- presents data at a specified position
- makes use of layers of data overlaid on a base-map
- computerized mapping systems utilize a *visual data interface*

The field of scientific visualization:

- implements the concept of using graphics for exploration and ideation
- are characterized by the use of sophisticated display methods, sophisticated tools and powerful computers
- specialized applications, often applications where data has an inherent position

and together with modeling tools:

- utilizes the possibilities of powerful computer systems to run highly interactive and dynamic visualization applications

As seen, we lose the simplicity and generality when we move from traditional graphics to the more modern techniques of scientific visualization. It could therefore be interesting to study an alternative approach that may avoid many of the disadvantages. This approach should support the ideation and exploration paradigm of scientific visualization, but still be as simple and general as traditional graphical methods. That is, we are looking for a visualization method which can be characterized as:

a. general applicable
b. easy to learn, use and understand, no complicated set-up required
c. not resource demanding, can run on any computer
d. intuitive, displays can easily be understood by a person with knowledge of the data

e. dynamic, modeling capabilities should make it easy to view data from different perspectives
f. an interface to underlying data

a ensures applicability of the method, *b*&*c* that experimentation is practical. *d* and *e* support the ideation process and *f* the idea of a visual data interface.

As a first implementation of an alternative visualization system, we propose the VIBE (VIsualization By Example) system.

7. VIBE visualization methodology

VIBE (VIsualization By Example) is based on the idea of scatter diagrams and mapping systems, where data is presented as a position. However, while the traditional approach is to position data according to a set of axis, VIBE let the user define an information space consisting of a number of *points-of-interest* (POIs). Each POI, visually represented by a unique icon, describes *a (simplified) example or prototype object that is given an example or prototype position*. A POI will describe a concept or a characteristic attribute of the data objects. Icons for the data objects will then be positioned in this information space accordingly to the *influence* from each POI. For example, if a data object is influenced by only one POI it will be placed on top of this point, if it is influenced by two POIs it will be positioned between these, etc. A metaphor of this approach is the way we may position books on a shelf, e.g., the mathematic books to one side, the statistics to the other and mathematical statistics books in the middle of the shelf.

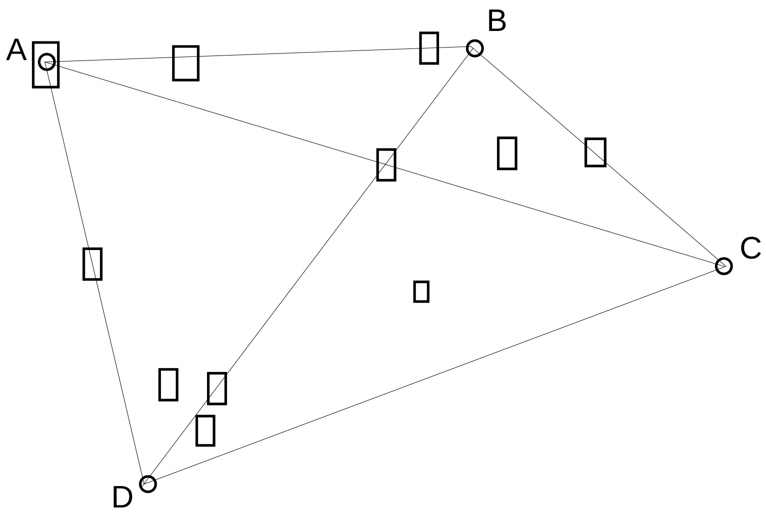

Figure 3. A VIBE diagram

Figure 3 shows an example with four POIs - A to D. A POI is visualized by a circle icon. It may represent a concept or an attribute of the data objects, in a similar manner as an axis in a Cartesian system. Data objects are visualized by rectangular icons. These are positioned according to the score they get on the POIs. This score may be the attribute value (usually normalized) or may be calculated from a set of attributes. For example, VIBE has been used on a "world database" where the standardized values for GNP/capita, infant mortality, etc., were used directly as POI scores. For visualizing a collection of journal references POIs were described through a set of key-words — then the frequency count for each POI (the sum of frequencies for the key-words included in the POI) determined the score (these examples are presented in more detail later).

The interpretation of a VIBE diagram is rather straightforward. Icons close to a POI must have a high relative influence from this POI. Icons positioned on top of a POI (such as the icon on POI A in figure 3) are influenced only by this POI. Icons that have got a score on two POIs, are positioned on the line between these POIs (e.g., the two icons on line AB). A middle position indicates equal influence (e.g., the icon on BC). Icons in an outer triangle must be influenced by the outer POI (e.g., icons in triangle ABC must be influenced by B).

The positions will indicate the relationship between score values rather than actual values. The actual positioning of an icon for a document *D* is performed by a positioning function.

$$(u,v) = \sum_{i=1}^{N} \alpha_i \, (u_i, v_i)$$

Input to this function is:

- the data object score vector α [α_1, α_2. ..., α_n], where n is the number of POIs. α_i represents the score for POI$_i$, normalizedover all POIs ($\sum\alpha_i = 1$).

- the POI position vector P [p_1, p_2, ..., p_n], where n is the number of POIs. p_i represents the display position (u_i, v_i) for POI$_i$.

This point-oriented location system ensures an alternative utilization of the display area than a traditional Cartesian-based system. There will be no theoretical limit to the number of POIs that can be used at any time. However, with more than three POIs the coincidence of two objects may be real — they are identical with regard to the POIs, or false — resulting from the projected superposition of distinct locations (see for example the icon positioned in the crossing point between the lines AC and BD in figure 3). However, by carefully positioning POIs, by moving POIs, coloring POIs, etc., this problem may be controlled (see the next section).

While relations between scores are visualized by position, the absolute value of the highest score is visualized by the size of the icon. The size of an icon is an indication of the "importance" of the object it represents and is derived from the scores that an object gets in relation to the specified POIs. For example, an object that gets a low score on all POIs will be displayed as a small icon. Likewise, an object that gets a high score on one or more POIs will be displayed as a larger icon. In practice, the objects shown as larger icons should be more closely related to one or more POIs than the smaller icons.

8. VIBE user interface

A dynamic, window-based user interface is used. POIs may be positioned anywhere on the display. By a "click" on a mouse button the user may move a POI to a new position, or tell VIBE that this POI is to be ignored, i.e., this POI will no longer influence data objects. Redisplays after such changes are performed immediately, based on a table of POI component data kept in memory.

VIBE implements the concept of a visual data interface. By clicking on a data object, VIBE will present all the information on the object that is available in the database. If more than one icon is positioned in the same position, VIBE will present the topmost object — moving through the object stack for each "button click". Such an overlay of icons is shown by lines under an icon, each line representing another data object.

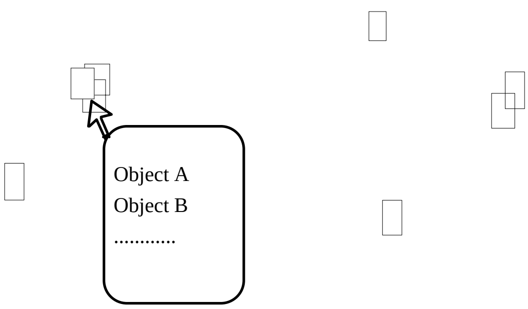

Figure 4. Lens-function.

A *lens*-function (figure 4) makes the process of obtaining more information from icons even simpler. By moving the cursor over the screen the lens will at any time include information on the objects (e.g., name of country, title of article) at the cursor position. The lens will act as a menu, giving the user the possibility of selecting a data object. Then all information on this object will be presented in a separate window.

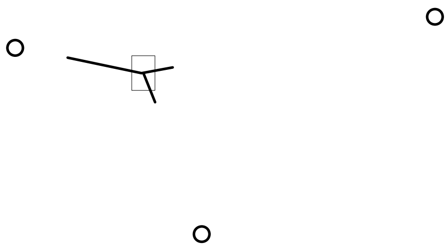

Figure 5. The star-option (visualizing POI scores)

The star-option allows for direct visualization of POI scores (Figure 5). The length of a line from the center of an icon towards each POI will show the strength of the score. This presentation will be shown by clicking on an icon, or may be combined with the lens-function.

Icons can characterize or describe the objects they represent in many different ways. The attributes of a VIBE icon include its size and its color. Size is automatically applied in all cases. Colors may be given to POIs, implying that all objects that are influenced by this POI will get this color. Several different colors may be used. However, if two colored POIs influence the same object a predefined “collision color” will be used. Therefore, the color option will be most practical for disjunct POIs, i.e., where data objects only get a score on one of these POIs. Colors may also be used to indicate new attributes, and may thus increase the dimensionality of a display.

Displays can be saved, retrieved individually or overlaid with other displays for comparison, or printed on a laser printer.

9. Ideation and Hypothesis Formulation with VIBE

A hypothesis is a statement that attempts to explain the relationship(s) among a set of data. The set of data can take many forms such as direct event observations, sample numerical values, written statements, spoken statements, images, documents, etc. In order to formulate a hypothesis, some means of observing the set of data is required before speculating about its meaning. Event observations can be recalled, numerical data can be eyeballed, written or spoken statements can be analyzed, documents can be read, images can be examined in order to speculate about relationships that may exist. Of course, prior knowledge and experience play a large role in how we interpret what we see in the data. If the set of data can be used to generate a visualization, relationships may be much easier to “see.”

The real advantage of using visualization is that many different hypotheses may be generated simply by viewing patterns in the data display. VIBE will provide the viewer with the capability to perform operations on the data objects so as to present different views of the same data. This may provide a stimulus for generating alternative hypotheses.

As an example of how visualization may be used in the ideation process we shall apply VIBE to a “world database.” However, one should note that a static presentation, as this, will not give full credit to a dynamic system. It could perhaps be compared to presenting a movie as a couple of slides. In addition, VIBE's capabilities as an interface will not be seen through this presentation.

Figure 6. World data

The world database consist of 102 countries, with data on *infant mortality*, *life expectancy*, *literacy,* and *GNP per capita* (source: The World Almanac, 1991). Figure 6 presents a VIBE diagram of these data — standardized by subtracting average values and dividing by standard deviations. Negative, or lower than average, values are represented as influence towards a low POI, positive values toward a high POI. We shall classify low infant mortality, high life expectancy and the high GNP/capita as “good” POIs, the others as “bad.”

As seen from figure 6, most of the countries fall into two categories:

1. A “first world” influenced by the “good” POIs.

2. A “third world” influenced by the “bad” POIs.

By giving a color to the high GNP/capita POI all objects that are influenced by this POI will get the same color. With such a display one would see that all countries, with higher than average GNP/capita, are in the “first world” category.

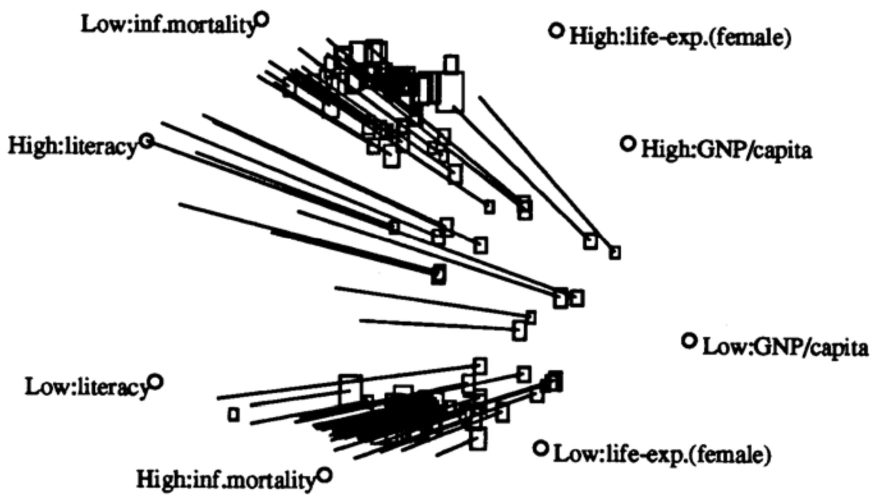

Figure 7. World data — displacement function.

We may use color to show the influence from the low GNP/capita POI as well, but in figure 7 an alternative display is presented. Here we have asked VIBE to visualize the displacement of icons, by drawing lines from the former position (no icon) to the new position (icon), when the low GNP/capita POI is introduced. As seen, nearly all the “third world” countries are influenced by this POI. In addition, about half of the “first world” countries have moved towards this POI, some significantly. We may retrieve the names of these countries (e.g., China, Albania, Colombia, Jordan) in addition to other information by “clicking” on the icons. The remaining “first world” countries are unaffected by introducing the low GNP/capita POI, since their score on this POI is zero, i.e., their GNP/capita is above the mean value.

From these few examples we may generate many questions about the world database, e.g.:

- Will the two distinct groups show up for other POIs (health care, education, transportation, defense…)?
- Why do countries as Mozambique, Chad, Angola and Namibia (the largest icons in the third world group) get such a high score on the negative POIs?
- Which poor countries, or categories of poor countries, get a score on the “good” POIs?

or hypotheses, e.g.:

- If a country obtains a higher than average score on one of the “good” POIs, it will also obtain a higher than average score on the other POIs in this category.
- If a country obtains a higher than average score on one of the “bad” POIs, it will also obtain a higher than average score on the other POIs in this category, except the low GNP/capita.
- A high GNP/capita is not necessary in order to obtain scores on the other “good” POIs.

This exploration and ideation process will be fed by VIBE, when we change POIs, reposition them or when we study individual objects on the display.

10. Hypothesis testing with VIBE

Visualization provides a “quick and dirty” method for testing hypotheses. A hypothesis about a set of data implies that a pattern or lack thereof is expected among the data. A visual display of the data can be used to quickly confirm or reject a hypothesis simply by viewing the resulting pattern. There may be instances where a hypothesis can not be clearly confirmed or rejected but requires additional views of the data.

As an example we shall use data from the Energy database of the Office of Scientific and Technical Information (OSTI), Department of Energy (DOE). VIBE has been used for a research project funded by DOE/OSTI. This research project investigated methods of extracting meta information from large scientific bibliographic databases that extends beyond the information that can be extracted using the traditional Boolean search mechanisms of such systems (Sochats et al, 1991). In this project, VIBE was used on a sample collection of documents from this database on a very specialized and constrained subject area — *inertial confinement*. Each document reference in this database consists of a full abstract and several indexing terms organized in a hierarchy, together with other information on documents (title, author names, country of origin, etc.). The indexing has been performed manually, by professional indexers.

We will present two simple examples of hypothesis testing on these document representations. In particular, we were interested in examining the following questions:

i. Do indexers assign a few major index terms to each document, or are the document representations over indexed by the introduction of several major index terms?

ii. Where terms are part of a hierarchical structure, do indexers use only the most detailed term and the term above this, or are all other terms in the structure included, as well?

Figure 8. DOE/OSTI diagram - major descriptor POIs

A VIBE diagram for question *i* is presented in figure 8. Note that overlaying icons are visualized by a line under the first icon, each line representing another document. As can be seen, most of the documents fall on top of one of the POIs, each describes one major term (indicated next to the POI icon in figure 8). At least with these terms, it seems that very few documents fall between POIs. Thus, it seems that indexers manage to limit the number of major terms assigned to each document.

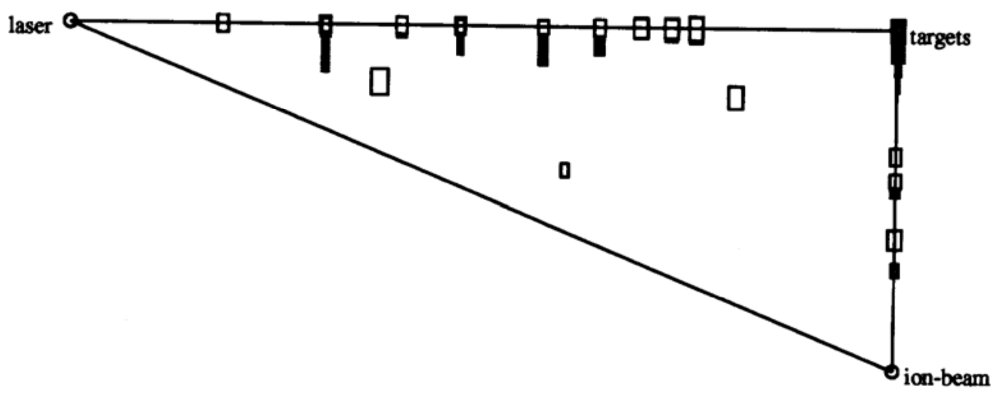

Figure 9. DOE/OSTI diagram — term hierarchy POIs

Figure 9 presents a VIBE diagram for question *ii*. As can be seen, all but three documents either fall on top of a POI or are on the line between two POIs in the hierarchy *laser*, *laser target* and *ion beam laser target*. The three documents that scored on all three POIs are general articles on the field. This diagram seems to confirm that indexers know the structure of this research area, and that they are careful when assigning terms to documents.

11. VIBE and modeling

One of the most important aspects of a modern visualization system is the ability to manipulate the data, to present different views and perspectives by the touch of a button. It is in this respect that visualization can be distinguished from the more traditional graphics metrologies. Some of the modeling capabilities of VIBE have been introduced earlier, such as introducing and ignoring POIs, moving POIs and visualizing the displacement of icons. However, in all of the previous figures the POIs seem to have received logical positions, close to related POIs. Positioning POIs is an important part of any session with VIBE. We shall therefore try to give an indication of how this process may proceed.

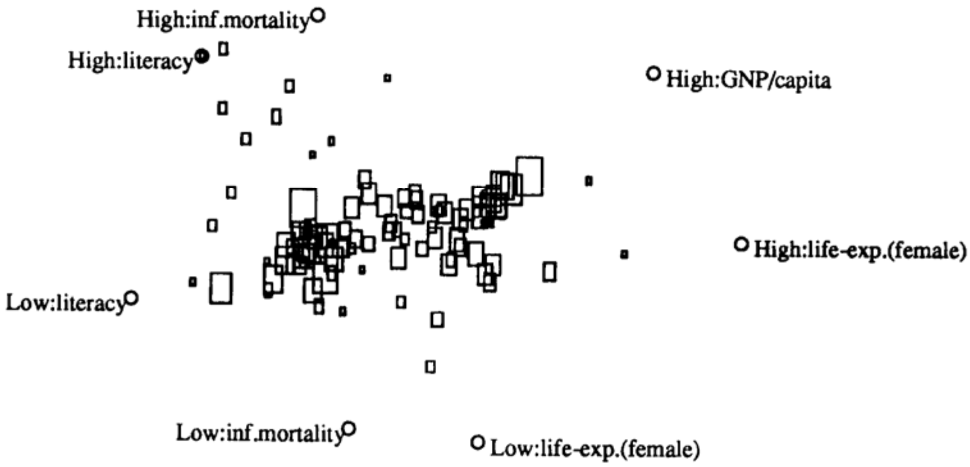

Figure 10. World data (random positioning of POIs)

Figure 10 presents a VIBE diagram generated from the world database. With a more or less random positioning of the POIs used here, none of the nice clusters that we obtained in the previous diagrams appear. We could use our knowledge of the data, intuition or a trial-and-error approach to find better POI positions. However, VIBE offers a simple option that may be of help. By drawing dashed lines from every icon to its POIs of influence (the degree of dashing determined by the score), the relations among POIs and objects become apparent.

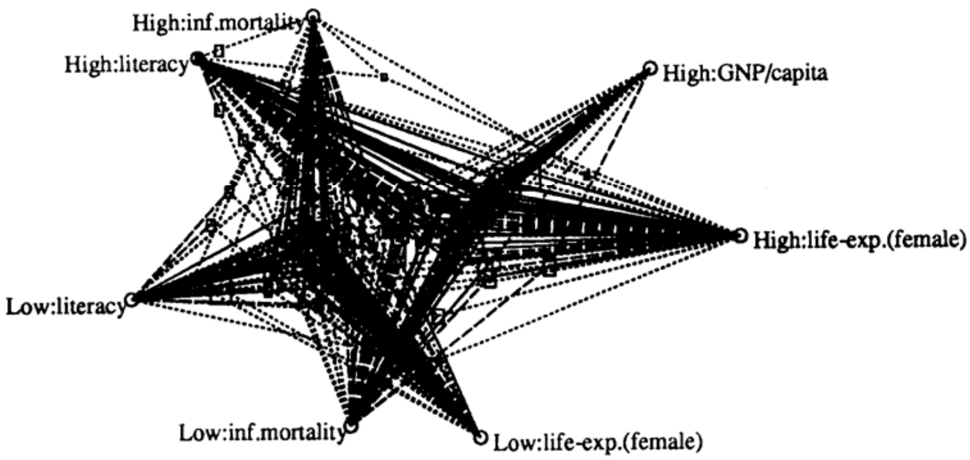

Figure 11. World data, with *lines*-option

This is seen in figure 11. Clearly, one may obtain a simpler diagram by moving the high infant mortality POI to the bottom of the diagram, the low infant mortality POI to the top. This option has proved to be very valuable for the initial positioning of POIs.

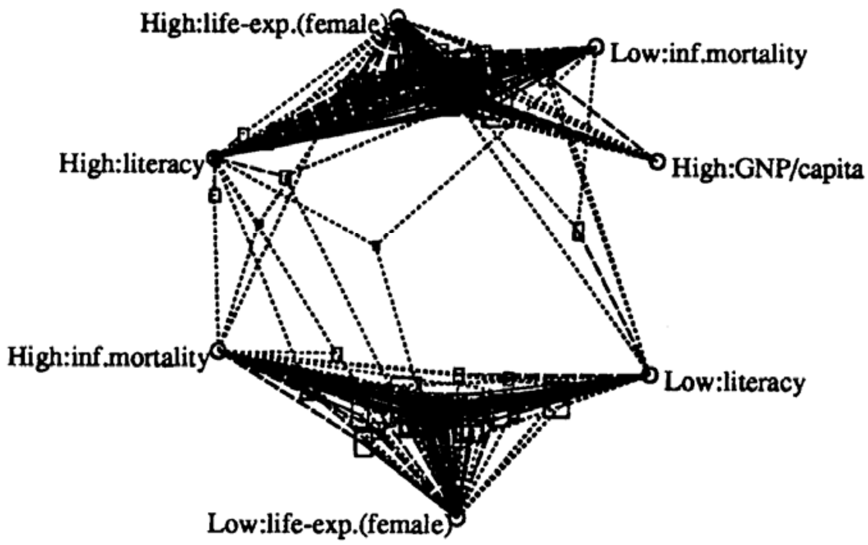

Figure 12. World data with lines-option, rearranged POIs

The result is seen in figure 12. Here the related POIs are positioned close together.

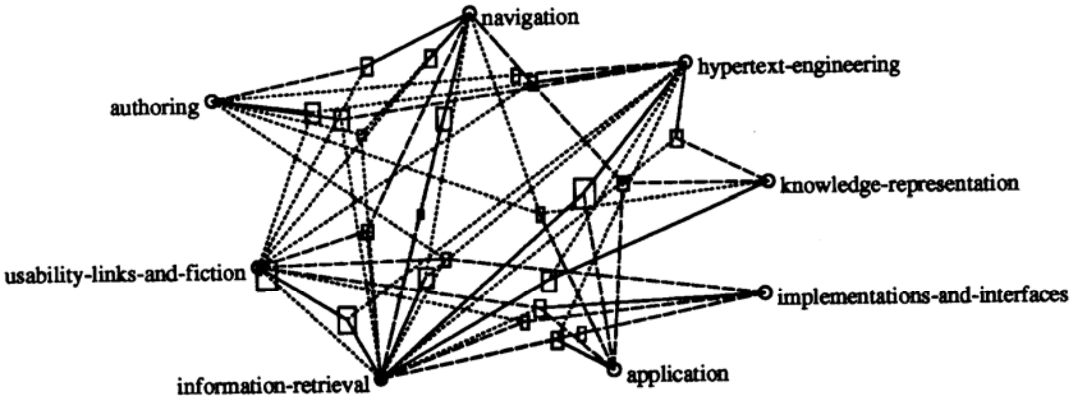

Figure 13. Document collection

A counter example is presented in figure 13, based on a document collection (Hypertext'89 conference papers, section headings as POIs). In this case, moving POIs leads to no clear patterns. We may draw the conclusion that these POI positions are as good as any, and perhaps that the POIs are not good discriminators for the document collection, or, that this collection of similar documents does not allow any further focusing.

12. Conclusion

Visualization offers a possibility of sending data from a computer system to a user with a bandwidth many times as high as with textual and numerical presentations. Through such a form of communication, the power of the computer can be used to manipulate large amounts of data. It is important to understand that visualization is not the process being automated, only humans can visualize. However, a visualization tool may aid the user to get an overview and an understanding of large data sets.

In this article a new approach to visualization has been presented through the VIBE system. Through a simple and general visualization methodology, this system seems to offer a method that can be used to provide such an understanding of the data sets involved. The system is general applicable, can be used by anyone and may, due to the simple display methodology, be used on most workstations and personal computers.

The VIBE system has been used over a range of data sets, from document representations to quantitative data. These experimental results have been promising. Our further efforts this direction will be directed towards investigating the requirements necessary for a visualization environment that will provide scientists, engineers and others with the capability to formulate problems as graphical depictions and animated sequences. In particular we are interesting in identifying potential applications for visualization. This work will be based on the VIBE display methodology.

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