3D Interactive Information Visualization:
Guidelines from experience and analysis of applications

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1. EXPERT KNOWLEDGE

Effective design of GUI interfaces is aided through the development and use of guidelines. Similarly, the effectiveness of 3D information visualizations will be aided through the development, testing and application of guidelines. The guidelines presented here are the direct result of the expert knowledge accumulated over the development of 50+ information visualizations since 1993. Various techniques have been tried for communicating information in 3D visual representations drawing from knowledge in the fields of graphic design, user interface guidelines, end-user consultation, psychology and neurophysiology.

2. SIGNIFICANT EXTENSIONS to GUIDELINES

No comprehensive set of guidelines exist for the field of 3D information visualization. These guidelines serve as a starting point for 3D information visualization builders and researchers. These guidelines go beyond case studies in graphic design or user interface guidelines to contradict intuitive extensions of 2D guidelines.

3. ITERATIVE METHODOLOGY

Most of these visualizations have been developed for specific clients to solve specific business needs. During the development process the applications were re-evaluated with clients and modified. Additionally, some visualizations have been constructed to be generalized re-usable frameworks, or as small test applications. Over time, similarities between successful visualizations have been noted as well as recurring difficulties. These observations have led to these guidelines.

4. GUIDELINES for INTERACTION and VISUALIZATION

The following guidelines can be used to create better visualizations. These guidelines not complete - and will continue to change as more research is done on information visualization. Also, as guidelines, they are not a guarantee to an effective visualization - poor quality data, poor mapping between data and visual attributes, or inappropriateness of visualization to the user’s requirements, will all result in an unsuccessful visualization which no guideline can rescure. Further, some goals may be better solved by breaking one or more of the guidelines - the actual circumstances surrounding the goal to be solved must be addressed first.

4.1 Know the goal

Before an effective information visualization can be created using any of the guidelines below, a real goal must exist. This means:

- a problem has been identified
- quality data exists which supports the problem

- there exists a correlation between the supporting data and the goal
- the goal can be found by human interpretation of the information

Without a clear identification of the goal, it is easy to create an interesting visualization with little value It is also easier to create a successful visualization with a clearly identified specific goal than a weak or general goal.

4.2. Interaction

Interaction is a key differentiator between a chart and a visualization. Interaction permits the user to manipulate the visualization to find and identify patterns visually while a chart is merely a static mapping of data to a representation.

4.2.1 Do not rely on interaction:

Visualizations which rely on interaction to be comprehended cannot be printed out, published, etc. Dependence on interaction limits the audience to a small subset who can execute the interaction. Information visualization often needs to be disseminated to a wide audience - even if the application was orginally designed for a few select select users. Thus, any information visualization should not rely on interaction.

A 3D scatterplot requires rotation of the scene so that a user can differentiate between points which are near and far. As a result, any printout of a 3D scatterplot is of limited value. We have tried various other cues (brightness, color, size) to illustrate depth, but in general we have found 3D scatterplots ineffective (for other reasons as well).

4.2.2. Interaction is required to make an effective visualization:

Interaction permits the user to work with a much larger data set than can be presented on the screen at once. By drilling-down, animating, changing axes or adjusting the data model, the user can explore a data space orders of magnitude larger than can be assembled into a singular 3D scene.

Interaction also permits the user to remove data from the display. By slicing, filtering, zooming and querying the data the user can quickly narrow a search through the information.

((((((A well designed visualization will permit these interactions and will also sufficiently describe itself so as not to violate the previous point. This is not contradictory with the previous point!))))))

4.2.3. The user must be able to adjust the viewpoint of the 3D scene:

Changing the viewpoint permits the user to:

a. see around occlusions

b. disambiguate uncertainties in the scene, such as an alignment of two different lines, or two objects of the same shading overlapping from a particular view.

4.2.4. User navigation model must be simple to use:

Many 3D systems (and most VRML browsers) suffer from poor 3D scene navigation. An information visualization navigation model should:

a. keep the scene always on screen. It should never let the user manipulate the scene so that the user is looking at empty space.

b. use a steady-cam model. It should not permit the scene to roll - i.e. the horizon should remain horizontal. Most people do not experience roll for most tasks. Thus, flight simulator interfaces are inappropriate.

c. provide consistent interaction. Virtual trackball interfaces (e.g. OpenInventor and many VRML browsers) rotate the scene differently depending on the initial location of the mouse.
d. provide fast feedback. A user can more quickly orient a scene if provided with a subset or proxy for the scene than if the user must wait until the entire scene redraws.

4.2.5. User must be able to drill-down to underlying data:

Since an information visualization presents data as a visual representation, many users require pieces of the underlying data at key points during the interaction. This is typically used for either identification or for verification. For identification, the user needs to see the data in its original format (numeric, text, image, etc). For verification, the user can validate the correctness of the data and verify his/her cognitive mapping of the data to the visualization.

For example, brushing the cursor across a visual object which then displays the data for that object provides immediate data and reinforces the mapping between data and visual representation.

e.g. brushing, slicing

4.2.6. Interaction aids interpretation:

Interaction such as drill-down and slicing permit the user to verify or modify his/her understanding of the information. This interaction can be a learning device. Brushing as described above is a good example.

4.2.7 Interaction permits unforeseen combinations and permutations:

Data used in information visualizations is often multivariate: interaction permits various queries across multiple dimensions in the data simultaneously. The data can often be analyzed in many ways (e.g. summaries, differences, averages, ratios, distributions). The data may have various different states - for example, a real-time visualization for stocks requires different representations during trading hours vs. after trading hours - or may have wide variance in any given state - for example, a slow stock trading day where stocks change less than a half percent vs. a day when most stocks lose 10 % of their value.

4.3 Visualization

4.3.1. Use an organizational device the user already knows:

The data representation could look like anything - an extruded map, a star field, blobs, etc. A representation which maps closely to how the user already thinks of the data results in a visualization which is more easily accepted than one which is not. For example, a number of our visualizations include “organizational charts” to represent hierarchical data - most corporate users are familiar with organizational charts. We have often used maps, grids, time series and rooms to organize information.

Richard Saul Wurman[1] describes 5 graphical organization devices:
a. Location - for example, maps, rooms, floor plans, etc.
b. Alphabet - that is, arbitrary sorted orderings based on some key
c. Time - for example, line graphs with 1 independent variable (such as time) and 1 or more dependent variable (the measurement, such as temperature or pressure)
d. Categorization - that is, arbitrary classification scheme to collect objects

e. Hierarchy - that is, multiple levels of summarization, potentially used on any of the above.

In addition, we also use:

f. Graph - that is, a set of objects (vertices) and relationships between them (edges), for example, a network.

h. Scatterplot - that is, objects located based on a measure within a given data dimenion.

We often use more than one of these within the same visualization. For example, we might use a room with 2 walls and a floor with an orgchart on one wall to select and display the information subset, a map on the floor to select and display information based on geographic region and time-series charts on the other wall.

4.3.2 Use small multiples:

From Edward Tufte[2], small multiples result in many tiny graphical objects which can be analyzed individually or compared across each other as a group. For example, a single small time series chart could represent sales at a store, and many of these charts could be located on a map. The user can look at one time series in detail zoomed in close, or compare the trend across many time series simultaneously when zoomed out.

4.3.3. Include legend, scale and annotation:

Visualizations require learning. Legends, scales and annotations provide an immediate graphical reference which can be used in context to understand the information represented. Without these, printouts are not useable by someone unfamiliar with the visualization, and the visualization requires more effort in training.

4.3.4. Provide a reference context:

Objects floating in space are difficult to locate. However, if all these objects refer to a common reference, such as a ground plane, then the location of each object relative to each other is possible.

4.3.5. Use different visual dimensions differently:

Use different visual dimensions (e.g. size, location, orientation, form, color, transparency, motion) for different types of data (e.g. enumerated, text, continuous, discrete). Color does not map well to an enumerated data type where there are more than ~ 10 enumerations - for example, 20 unique categories do not map effectively to 20 unique colors (Can you name 20 unique colors?) but can map to 20 unique locations. Some data measures may cognitively map well to visual attributes, for example a data measure “size” maps well to scale, or the measure “time” maps well to motion and animation.

4.3.6. Watch out for dis-information:

Perspective, computer graphics hardware, etc, can create artifacts which can be mis-interpretted as significant. Two common examples are:

a. Moire: many parallel lines or parallel long thin bars in 3D can create moire patterns on computer graphic screens. Moire distracts the user to the artifact not the information. Interactions such as filtering or scaling can overcome moire.

b. Alignment and overlap: objects can align or overlap when viewed from a particular viewpoint and confuse the user into seeing a single object instead of 2 unique smaller objects. Using objects with borders or depth creates visual boundaries for each object.

4.3.7. Redundancy is good:

A minimalist visualization (where one data attribute maps to only one visual attribute) may be difficult to comprehend. It may result in overlap (described above); or it may not map the data measure to an appropriate cognitive measure. Thus a mapping which contains some redundant or extra geometry may result in an easier to use visualization.

4.3.8. Visualization complexity:

The complexity and density of the information in the visualization is dependent on:

a. User: executives who will use a visualization 10 minutes every day need a simple, less dense visualization than an analyst who may use the same visualization for a week.

b. Data Type: homogenous data can be more densely represented than highly multidimensional loosely correlated data.

Typically information visualizations range from a lower bound of 500 data points displayed simultaneously to 100,000 data points displayed simultaneously.

5. CONCLUSIONS

Information visualization permits users to interactively explore large amounts of data. Poorly designed information visualizations will not reveal insight. Effective visualizations will. Guidelines will aid developers to make effective visualizations. These guidelines serve as a starting point for designing visualizations and as a starting point for further research.