Should the Elements of Diagrams Be Rendered in 3D?

Pourang Irani
Visual Interfaces Laboratory
University of New Brunswick
Box 4400 Fredericton, NB
Canada E3B 2A3
(506) 453-4566
s71h@unb.ca

Colin Ware
Data Visualization Research Lab
Center for Coastal and Ocean Mapping
University of New Hampshire
Durham, NH 03824
(603) 862-1138
cware@omg.unb.ca

Abstract

To some extent the utility of a diagram depends on how effectively the information can be perceived. We have applied the structural object recognition theory of Biederman to the problem of constructing node-link diagrams. According to geon theory, as objects are perceived they are decomposed into 3D primitives called geons, together with the skeleton structure connecting them. This work evaluates diagrams using geon-like primitives. Results of two experiments are reported. These show that diagrams constructed of 3D components can be visually analyzed more rapidly, with fewer errors, and can be remembered better in comparison with equivalent 2D silhouette diagrams.

Keywords
Diagramming, geon theory, object recognition, perception, recognition-by-components, visual display.

1. Introduction

In this paper we report on ongoing work to develop a set of diagramming conventions based on structural object recognition theory. According to this theory, as objects are perceived, they are decomposed into a set of 3D primitives called "geons", together with the skeleton structure connecting them.

Diagrams can act as cognitive "externalizations" enhancing cognition by mapping problem elements to a visual display in such a way that solutions become evident [5][7]. The diagram thus becomes part of a larger cognitive process involving perceptual pattern finding and cognitive symbolic operations. To be effective in this way it is important that the mapping from a problem to its representation is such that meaningful patterns can easily be perceived in the diagram. Thus a diagram's effectiveness, to some extent, depends on how well it is designed as an input to the perceptual system [2][6]. In previous work we have shown that diagrams based on geons are more easily remembered and analyzed than equivalent diagrams drawn using the conventions of the unified modeling language (UML). In the present paper we report on a more rigorous experiment to test whether it is really the 3D aspect of our geon-based diagrams that makes them more effective.

2. Geon theory

Marr and Nishihara were the first to develop a reasonably complete structure-based approach to object recognition [4]. In their theory an object can be decomposed into axes of generalized cones depending on the nature of detail required. Thus for example, to differentiate between a horse and a giraffe, the decomposition would result in an arrangement of axes of differing lengths representing generalized cones which in turn approximate the head, tail, neck, limbs and body of the object. The axes of the objects are derived mainly from the occluding contour or silhouette of the image.

We have taken as our main source of information the more recent and elaborate structural object recognition theory of Biederman and his co-workers [1]. Their theory proposes a hierarchical set of processing stages, leading to object recognition. In the first two stages, images of objects are decomposed into edges, then into component axes, oriented blobs, and vertices. Following this, three-dimensional primitives such as cones, cylinders and boxes are identified. A central concept in Biederman's approach is that a set of generalized cones or "geons" (short for geometrical ions) are 3D perceptual primitives. A family of 36 geons is defined by image properties of the silhouette contours in the 2D plane, by co-linearity, symmetry, parallelism, curvature, and co-termination (the contours meet at a point, eg. a cone).

The next stage extracts the structure that specifies how the geon components interconnect. The decomposition of an object results in a geon structural description (GSD), consisting of geons, their attributes, and their relations with adjacent geons. It is this structural description that contributes to viewpoint invariance, i.e. if two views of an object result in a similar GSD, then they should be treated as equivalent by the object recognition system. Finally, object recognition is achieved. Figure 1 illustrates a subset of geons and some simple objects constructed with geons.

According to geon theory, color and texture are surface properties of geons that play a secondary role in object classification. These properties may aid in the recognition process, but do not constitute the defining characteristics.

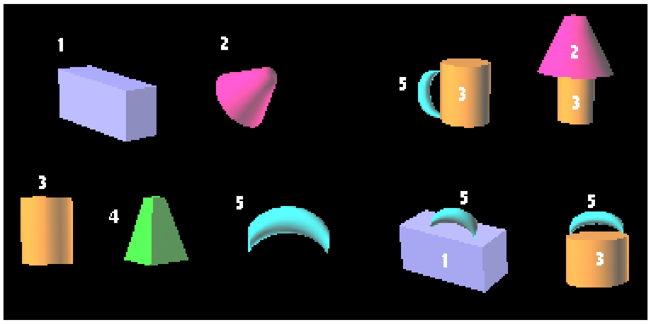


Figure 1 - Geons and objects constructed using them. Note that the relation between geons is important to distinguish objects; two different arrangements of geon #5 with geon #3 produces two different objects.

In previous work we compared geon-based diagrams with equivalent UML diagrams. To do this we implemented a toolkit using the OpenGL 3D graphics standard. The toolkit facilitates the creation of diagrams from a set of 24 geons and enables the mapping of color, texture, shading and transparency to geon components

Our experiments showed that users identify geon sub-structures more quickly than identically structured UML diagrams (twice as fast in identifying the geon sub-structure) [3]. The geon diagrams were also easier to remember than UML diagrams (18% error rate for the geon diagrams vs. 39% for the UML diagrams). We also found users were able to memorize better the structure of the diagrams constructed using geon primitives without color and texture when compared to unlabeled UML equivalents (error rate of 22.5% for recalling the geon diagrams and 42% for recalling the equivalent 2D UML diagrams). This however still does not allow us to make the generalization that diagrams made with 3D components are more effective. There were many other differences between the 3D geon-based diagrams and 2D UML diagrams, in particular the outline shapes of the elements used.

Here we provide the first report of two experiments that specifically address the issue of whether 3D diagram components are more effective than 2D diagram components. Our experiments were designed to test the hypothesis that geon diagrams are easier to visually interpret and remember than diagrams that had elements with the same 2D outlined shapes. The one-to-one mapping between geons and 2D outlines of the shapes used for the experiments is shown in Figure 2.

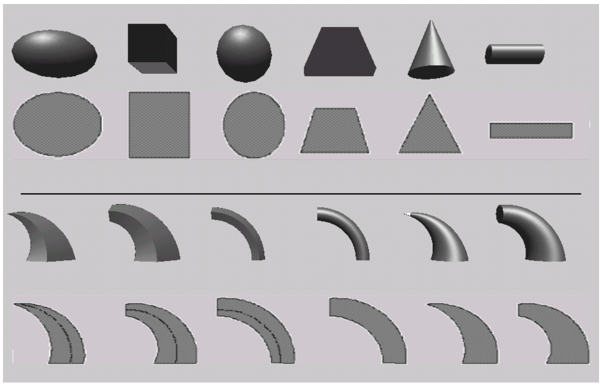


Figure 2 - One-to-one mapping between geon primitives and 2D silhouettes used in the experiments

The first experiment is designed to test our ability to interpret these kinds of diagrams. To do this we measure the amount of time it takes a subject to identify a sub-structure in a diagram. We also measure the accuracy with which the user identifies the sub-structure. The second experiment investigates the accuracy of recalling geon diagrams in comparison with 2D equivalents.

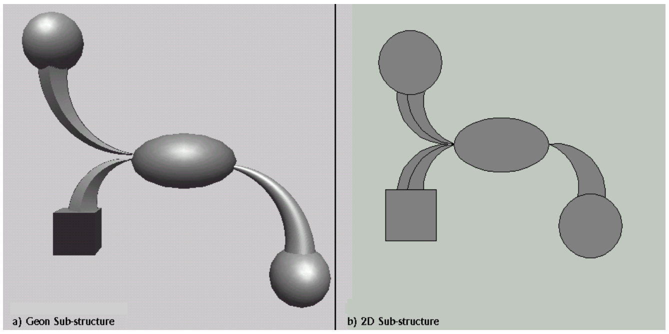
3. Experiment 1: Sub-structure identification with geon diagrams versus 2D-silhouette diagrams

The purpose of the first experiment was to determine the ease with which people can identify sub-structures in geon diagrams in comparison with equivalent 2D-silhouette diagrams. We measured the time and error rate for a subject to recognize a sub-structure of a diagram. We hypothesized that it should be possible to identify sub-structures faster and more accurately with geon diagrams.

3.1 Method for experiment 1

Diagrams. Two sets of ten 2D-silhouette diagrams were drawn using Adobe Photshop^{TM} and equivalent sets of geon diagrams were constructed using the geon toolkit. For each set a sub-structure diagram was constructed; the sub-structure of the first set contained 3 components and that of the second set contained 7 components (Figure 3). This sub-structure was present only in half the diagrams. A diagram was defined as containing a sub-structure if the sub-structure's components and their connections were present. However, the layout could be different meaning that sub-structure recognition could not be performed by a template match (Figure 4).

The diagrams included a variety of combinations of the primitives in each case. Neither set of diagrams were equipped with surface attributes or labels because we wanted to look only at the 2D versus 3D issue. Diagrams were presented on a computer screen.


a) Geon Sub-structure

b) 2D Sub-structure

Figure 3 - Sub-structures to identify in experiment 1

Procedure. During each trial the subject was first shown the sub-structure for 15 seconds and then conducted a set of 3 practice trials. The program selected a diagram randomly from the set of 10 diagrams and presented it to the user. The user would press the 'Y' key if the sub-structure was present or else press the 'N' key. The response time of the user was recorded along with the accuracy of the response.

To balance the task the order in which the sets were presented to the subjects was randomly selected as follows where G denotes a set of geon diagrams and 2D a set of 2D silhouettes: {G1,2D1,2D2,G2}, {2D1,G1,G2,2D2}, {2D1,G1,2D2,G2}, {G1,2D1,G2,2D2}. The 16 subjects all had previous exposure to using a computer and were volunteers for this task.

3.2 Results of experiment 1

Results are summarized in Table 1. These show that substructures were identified both faster and more accurately with the geon diagrams. From the 16 subjects, 9 subjects correctly identified the sub-structure in more geon than 2D silhouettes, 3 subjects identified the sub-structure equally often with the geon diagrams as with the 2D silhouettes, and the remaining 4 were more accurate with the 2D silhouettes. A sign test shows this to be significant ($p < 0.1$).

	Geon Diagram	2D Silhouette
Identification Time (s)	4.1	5.3
Error Rate	12.11%	19.24%

Table 1 - Summary of Results for Experiment 1.

On average the subjects took 4.1 seconds to identify (correctly or incorrectly) the presence of the sub-structure in the geon diagram and 5.3 seconds for the 2D silhouettes. Of the set of 16 subjects, 14 identified the geon sub-structure faster than the 2D sub-structure. A t-test on the average time for each subject shows this difference to be significant ($p < 0.05$).

These results support the hypothesis that geon diagrams are easier and faster to interpret than 2D silhouettes.

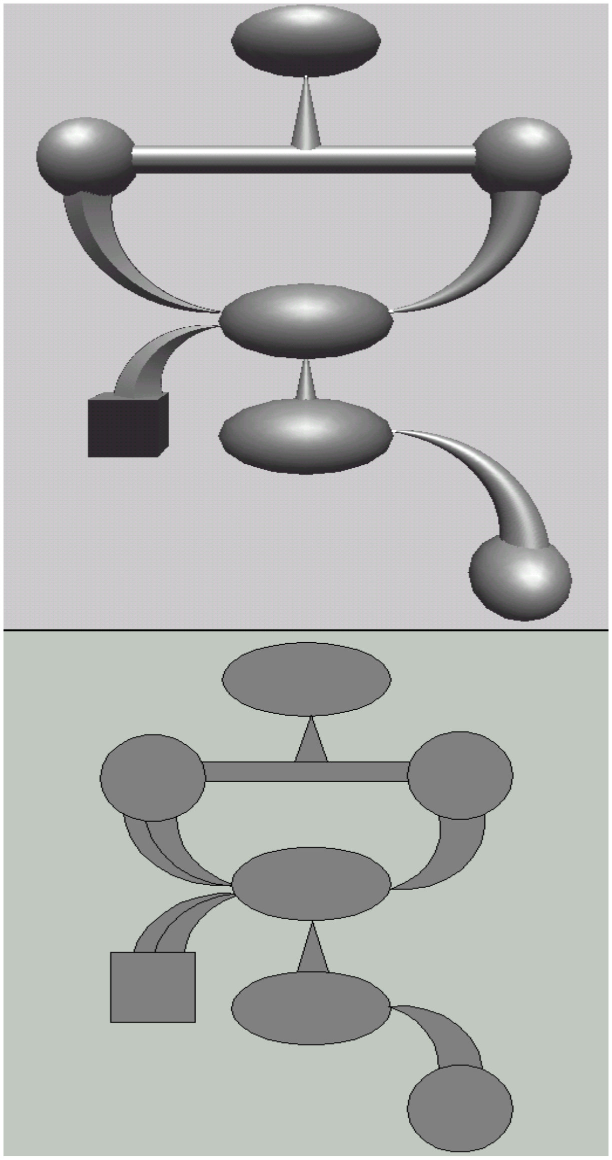


Figure 4 - Diagrams containing the sub-structures in figure 3

4. Experiment 2: recall of geon diagrams versus 2D-silhouette diagrams

The purpose of the second experiment was to determine whether geon diagrams can be remembered more easily than 2D-silhouette diagrams. We hypothesized that geon diagrams might be more accurately recalled after a brief exposure than comparable 2D diagrams.

4.1 Method for experiment 2

To determine whether a user can easily recall a recognized set of geon diagrams, this experiment was formulated to compare the accuracy of recalling geon diagrams versus equivalent 2D silhouettes.

Diagrams. Using our one-to-one mapping convention of geons to 2D shapes, a set of 14 geon diagrams was produced using the geon toolkit and a set of equivalent 2D silhouettes was drawn using Adobe Photoshop^{TM}. Both sets of diagrams were printed in black and white on 8.5 by 11" transparencies.

Procedure. The experiment was conducted using two groups of students in senior level courses. The experiment was performed in a classroom setting with a class of students who had not seen these diagrams before (if a student had performed a similar experiment in a previous lecture, he/she was asked to indicate that on the handout and the result was later discarded).

At the beginning of the lecture the students in the first group were shown half (seven) of the set of geon diagrams in random order for 15 seconds per diagram. After viewing the first half of the geon diagrams, they were then presented with seven 2D-silhouette diagrams at intervals of 15 seconds. At the end of the lecture, approximately fifty minutes later, the students were shown the full set of 14 geon diagrams, then 14 2D silhouettes. Each diagram was shown for 10 seconds and the subject would indicate on a printed sheet whether that diagram had been part of the initial set. To counterbalance the first set of results, the same procedure was applied to a second set of students with the 2D-silhouette diagrams being presented first and the geon diagrams second.

There were 15 students that participated in the classroom where the geon diagrams were presented first and 19 students that participated in the lecture with the 2D silhouettes presented first giving a total of 34 subjects.

4.2 Results of experiment 2

The results show that subjects made fewer errors in recalling geon diagrams than they did for the equivalent 2D silhouettes: there was a 21.7% error rate for the geon diagrams vs. 32% for the 2D silhouettes. From the 34 subjects, 25 recalled correctly more geon than 2D diagrams while 4 recalled the same number of geon diagrams as 2D-silhouette diagrams and 5 subjects recalled more 2D-silhouette diagrams. A sign test shows this difference to be significant ($p < 0.05$).

These results support the hypothesis that geon diagrams are easier to remember than their equivalent 2D-silhouette diagrams.

5. Conclusion

Node-link diagrams represent a broad class that includes software structure diagrams, state diagrams, data flow diagrams, flow charts, and various kinds of diagrams used in process modeling. Currently all of these diagrams are drawn using outline shapes to represent the nodes and lines to represent the links. In other words, conventional diagrams look much more like the 2D diagrams we used in our experiments than the 3D geon-based diagram.

A possible explanation for the improved performance with the geon primitives is that 3D components are easier to identify and remember than equivalent 2D primitives because they better stimulate the object identification mechanisms in the brain. However, although we have shown 3D diagrams to be superior in two respects we realize that there may be a penalty. Specifically, the difficulty of putting clear text on a 3D shape may make geons less desirable since text is an important part of all diagrams currently in use. Nevertheless, we feel that our results warrant continued investigation because diagrams with 3D components may provide greater ease of interpretation.

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