A Review of Dynamic and Static Visual Display Techniques

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In recent years there has been considerable interest in developing instructional techniques that enhance the visual perception skills of students taking engineering graphics courses. One of the techniques often mentioned is animation: the dynamic display of visual information. This paper examines computer-based dynamic display techniques that assist in the perception of three dimensional form. Also examined are a number of complementary static display techniques. The dynamic and static display techniques are critiqued based on a review of current research in visual perception and existing software applications.

Introduction

Animation of computer graphics has been a topic of considerable interest among computer users. With the ever improving price/performance ratio of computer equipment, the dynamic display of graphic information using traditional animation techniques has become affordable to a broad range of computer users.

In the engineering community an area of obvious application has been in kinematics. Dynamic display techniques can be used to represent the temporal dimension of complex mechanisms [Muir 85]. Application of dynamic display techniques have also been realized as a potentially powerful tool for assisting students in developing their visualization skills [McCuistion 91, Wiley 90a].

An important skill taught to engineering students is the interpretation of standard multiview drawings. The mental synthesis of orthographic views into a three-dimensional form can be a difficult skill to learn. One approach to teaching students how to perform this synthesis would be to start with a 3-D form, choose a stationary viewpoint, and rotate it in small increments between the standard orthographic views. This demonstration can not only be done with a real object, but also with a dynamic sequence of images on a computer. If we generalize this process, we can see how using computer animation techniques can be used to help develop visualization techniques to describe how objects undergo all types of changes over time: in location and orientation and also in shape and size [Zsombor-Murray 90].

As mentioned earlier, computers are now just as capable of producing the dynamic images of an animation as they are of creating static images. The question is then, are dynamic or static image presentation techniques more appropriate for teaching various visualization skills? Though visualization skills are the ultimate goal, these skills are developed through a process of perception and cognition [Wiley 90b]. A better understanding of these psychological principles will allow us to critique what type of imaging technique is most appropriate for developing particular visualization skills.

Since the graphics are computer-generated, a review of both psychological and Human-Computer Interface (HCI) literature is the most logical approach for evaluating imaging techniques.

Cognition and Visual Perception Theories

One way that HCI researchers look at the human mind is by using the metaphor of information processing [Baecker 87]. Though most people consider visual perception and cognition as different processes, visual perception is an active process that involves cognition. As an active process, resources are needed to receive and process visual information. When these critical resources are limited, our ability to make use of visual information degrades. Though there is a point of diminishing return, if more resources are made available, performance will be enhanced. If no more resources are available, another way to increase performance would be to improve the quality of information being received so not as much processing has to be done. Yet another way to improve performance is to be able to rely on "previous experience" to assist in the processing of the information. The efficiency in which this information can be retrieved from long-term memory will influence how much use it is in processing information currently being received.

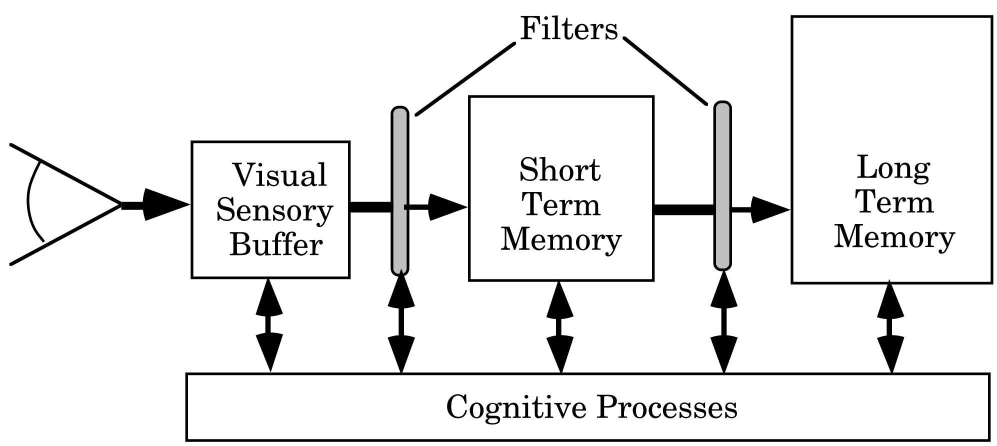


Figure 1.

Another aspect of the information processing model is the division of information storage into sensory, short-term, and long-term memories (Fig. 1) [Majchrzak 87]. Once the visual information impinges on the eye, the information is stored in a raw, holistic form in a visual sensory buffer. This information in the buffer decays rapidly because the senses are being bombarded with new information constantly and there is a limited capacity. Determinations are continuously made as to which pieces of information are passed from the sensory buffer to short-term memory. Short-term memory can be thought of as working memory where cognitive processing of both sensory information and information from long-term memory can occur. Since short-term memory is also very limited as to how much information it can retain. The raw information in the visual sensory buffer is filtered, allowing only a small percentage through to short-term memory for cognitive processing.

Not only are there limits as to how much received information can be processed, the cognitive processes only have access to a fraction of all of the information that occurs in the environment. The visual system that receives the raw information has only a limited bandwidth. This system can be thought of as an active, low-pass, spatio-temporal filter [Monk 84]. At the transmitting end, the computer is also limiting the information flow. Compared with real three-dimensional objects, the computer display is an impoverished representation, displaying low resolution, 2-D projections of 3-D objects.

Another important theory of human cognition is mental models [Norman 83]. People's abilities to perform tasks (such as synthesizing a 3-D form from orthographic views) are heavily dependent on the conceptualizations they bring to the task. People form internal mental models of themselves and the things with which they are interacting. These models, in turn, provide powerful explanatory capability for understanding the interaction. Few people can efficiently synthesize a mental 3-D image from a multiview drawing without prior experience. The first experiences with this task are usually guided by a teacher, and these experiences will form the mental model used for future executions of the task. The quality of the mental model formed will, in turn, influence how well they will perform the task. As mentioned earlier, a task is approached with only a limited number of resources available. More appropriate mental models will ease the load on the perceptual resources and allow for quicker, more accurate interpretation of complex graphics.

It is important to reiterate that perception is an active process. The visual system attempts to interpret and organize all information that it receives [Haber 82]. Since the perceptual stores only retain information for a limited amount of time, cognitive decisions are made as to what will be passed onto short-term memory and what will be discarded. The more the information is presented in a form that exploits the strengths of the human perceptual system and is already organized in ways that relates to familiar global schemas, the more likely the information will be retained and not forgotten.

Arguments for dynamic imaging

Many researchers have come out in favor of the use of animation as a tool for spatial problem-solving. For instance, empirical studies by Barfield have shown that animations created by the rotation of the subject's viewpoint improved the accuracy in describing the spatial relationship between two bodies [Barfield 90]. Others have directly tied animation to the positive effects it has on the development of mental models [Augustine 91]. McCuistion argues that enhanced spatial schema skills should be measurable through mental rotation tests [McCuistion 91]. His studies show that computer-assisted instructional material containing dynamic imaging improved performance on mental rotation tests relative to similar instructional material containing only static images. He also notes that a similar relationship was not found in performance tests developed specifically around engineering graphics concepts. This is an example of the difficulty in uncovering the relationships between visualization skills and engineering graphics.

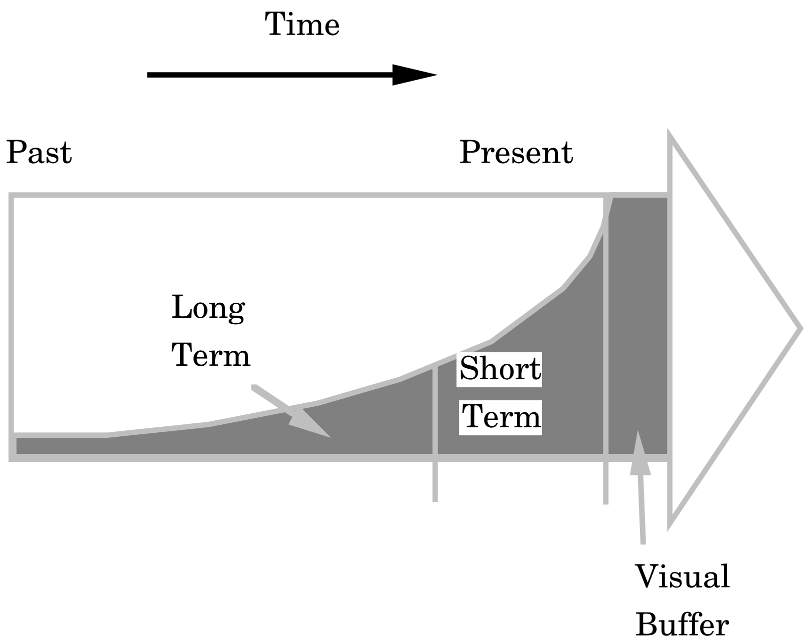
The value of dynamic imaging rests to some degree with the basic approach one takes in explaining visual perception. James Gibson argues that we normally perceive the world dynamically and that this dynamism removes ambiguity in our perception of three dimensional form [Kaiser 89]. Even more specifically, others have argued that the motion parallax induced through dynamic imaging improves depth perception [Wiley 90a]. In situations in which the subject is stationary, this dynamism can be created on the computer screen by simulating the movement of the object or the point of view of the observer.

Arguments for static imaging

Probably one of the strongest arguments for static imaging and against dynamic imaging is the loss of context of spatial relationships. As a subject views a sequence of dynamic images, the unstructured visual information is received in the visual buffer. This storage is called a buffer in part because what has been seen is retained for some length of time. This memory trace allows us to compare the current frame of the animation to the ones seen in the near past, giving context to the animation. Though the visual buffer allows for context to some past visual information received, the time span is very short. The information in this buffer decays exponentially: by 1/3 every 100-150 msec [Norman 82].

Some of the information in the animation may be retained by being passed on to short-term memory. There is a severe limit to how many "chunks" of unrelated material can be held in short term memory. These chunks in turn have a short life-span and will only be passed on to long-term memory if the information can be organized. Because of the nature of long term memory, the information stored there is filtered and incomplete and can be hard to recall relative to short-term memory and the visual buffer.

These suppositions of how human memory functions argues against flexibility in making mental comparisons between what is currently being displayed in an animation and what was displayed at some time beyond the near-past (Fig. 2). If you are a trained observer and know what you are looking for when viewing an animation, you can use your already developed mental model to organize the information being viewed and store it in short and long-term memory. When you are an untrained observer, such as a student, the situation is different. There arises the Catch-22 situation where the student is attempting to use an animation to help develop their mental model of visualization. Yet, they can't effectively process relevant information from the animation without a well-developed mental model.



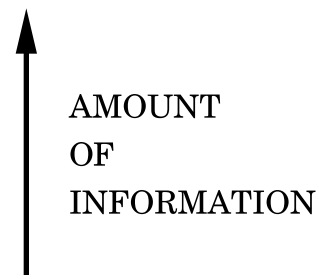


Fig. 2

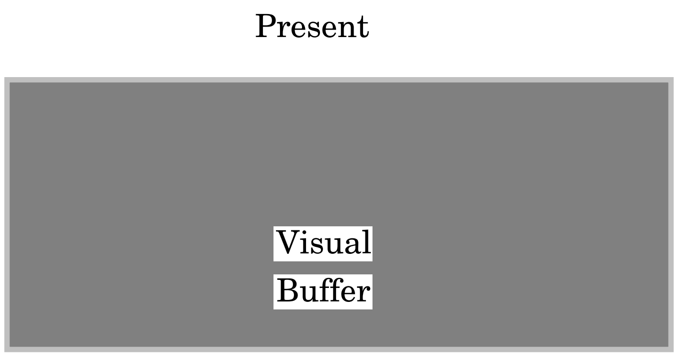


Fig. 3

These problems of context can be solved in part by using static images (Fig. 3). Because the information in the visual buffer is complete and unfiltered, as long as the viewer has the ability to focus attention on an image, he has a free reign as to how to order and compare information in the static image. The same spatio-temporal change depicted in the sequence of dynamic images can instead be organized into a single static image. This now turns control back over to the observer as to how the process the information depicted in a group of sub-images within a larger static image.

A potential problem is the clutter that arises from displaying too much information in one image. This problem can be especially bad for the student if they don't have the skills to sift through the information for what is most relevant. Again, if the student does not process the appropriate information, the likelihood of developing a sound mental model that will assist in developing their visualization skills is decreased. One solution is to visually organize the information on the screen by employing graphic techniques that exploit basic perceptual principles. This relieves the load on the viewer — skilled or unskilled — from some of the organizing and filtering of raw information.

Graphic Techniques for Organizing Information

Numerous researchers have proposed employing spatial organization techniques in order to relieve the perceptual and cognitive load on the viewer. In some cases the suggested spatial organization is based on an understanding of cognitive structure [Haber 82], whereas in other cases historic principles of aesthetics and graphic design are employed [Tufte 90, Morse 79].

One recommended approach — refered to as 'small multiples by Tufte — is to organize graphic information based on a Cartesian grid, much as in a spreadsheet. This differs from a spreadsheet because instead of holding only a single numerical value, each node of the grid contains a unique graphic image. Though the graphic information contained within a node of this grid may not be highly structured, the organization of the overall image on the screen is. This arrangement allows for scanning large quantities of information with little effort. Since all of the nodes are displayed as a static image, the viewer can scan at will, conjecturing and testing visual relationships at a pace suitable for learning.

In addition to spatial organization, another technique that exploits the qualities of human perception is rendering techniques. The visual attributes of 3-D objects being depicted on the screen can be altered using the ever-increasing computer graphics capabilities of computers. The way the objects are depicted can be used in direct support of the visualization learning process [Wiley 90c]. It is important to note that not only can these rendering techniques be used to represent the virtual objects on the computer screen as more "realistic", but also to enhance more abstract concepts.

Color has been found to be a very powerful tool for coding information on the computer screen [Truckenbrod 81, Salomon 90]. One way that color can be used is to highlight critical information. In an instructional setting, the teacher can use color to highlight information of particular importance for the students to see. Color is another element that has to be processed by the perceptual system. Since the goal of designing the visual display is to reduce the perceptual/cognitive load, the number of colors should be kept to a minimum. In doing this, focus can be kept on information that is of most importance. It is also important to choose perceptually distinct colors. Color choice on the computer often is reduced to selection of numerical values of primary colors. Large changes in these values does not guarantee a large shift in color perception. Instead perceptually-based color charts should be used to choose colors.

Another rendering tool that can be used is transparency. Though transparency does not have the same degrees of freedom that color does, it can be used in conjunction with other rendering techniques to depict a single variable such as time. It can also be used, like color, as a means to focusing attention. The more transparent an object is, the less attention it will draw relative to those objects that are more opaque.

The use of photorealism in rendering 3-D objects has been explored extensively as a method of increasing visual understanding of the object. Among the most common techniques explored are shading surfaces of the object to simulate a light source and hidden line removal. Research has not, however, come to a definitive conclusion as to whether these techniques improve the viewer's judgement of spatial relationships or performance on fundamental cognitive tasks such as mental rotation [Barfield 90, Sanford 87, McWhorter 90].

Specific Examples of Static and Dynamic Displays

There are a number of ways that static and dynamic display techniques can work together. One way of remedying the problem of lack of context in an animated sequence of images is to record each of the images in a computer file. This history file provides a quick reference to past images seen on the screen. Used like a video recorder, the animated sequence could be played backwards or forwards at any speed and stopped for inspection at any point. Unlike the information stored in short or long-term memory, this historical record on the computer would consist of an unfiltered, complete record of past images seen. Though only one image would be seen at a time, the viewer would have a high degree of control over the speed and sequence of images. This should allow for flexibility in making visual comparisons with holistic information. One of the disadvantages to this technique is the tremendous amount of computer disk space that can be taken up with these history files. This problem is exacerbated when the resolution and number of supported colors is increased to make more realistic images.

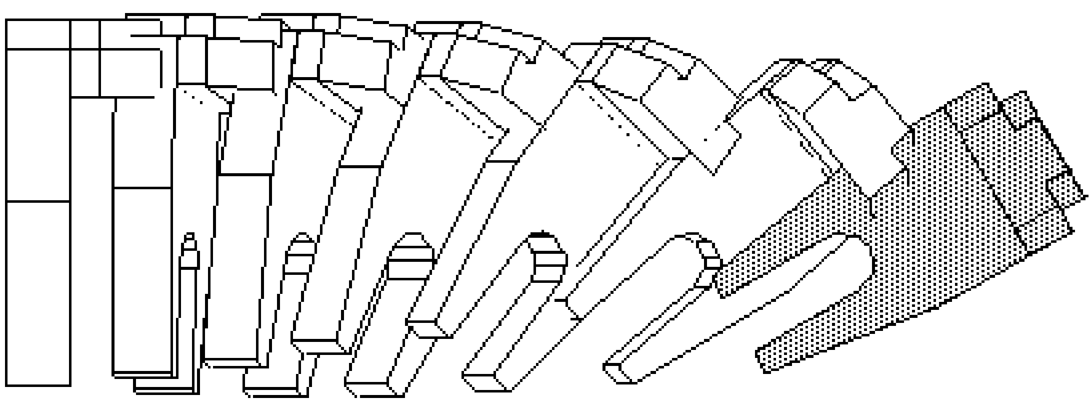


Figure 4.

A modification to the history file technique is leaving all or some of the frames of an animation on the screen. The trail of images on the screen provides for a tracing of the transformation that the object has gone through (Fig. 4). Each of the individual images in the trail has a specific time associated with it. That is, the image is part of a sequence with some images being drawn before and/or after it. This time dimension, in turn, can be represented by a degree of opacity. The most current image could be completely opaque with the older images being progressively more transparent, giving the effect of the images fading over time. The most current image could be further highlighted by using a color contrasting with the rest of the images. This technique could be used while a dynamic image sequence is being played or to create static images seen by themselves. In many ways this technique mimics the way the visual buffer is thought to work. The difference is that the temporal control of the visual information on the computer screen. For instance, the viewer can control the number of frames to remain on the screen, the speed of the decay, and time spacing between frames.

Though the tracer technique by and large avoids the computer storage problems of the history file, it still has weaknesses. By its very nature, the images in each frame reside on the screen unchanged in their location from where they would be in the animation. This is needed because the change in relative locations and orientations between frames is the primary information being conveyed by the overall image. The visual structure of the overall image is dependent exclusively on the dynamics of the object being observed. If the object undergoes very little displacement across the computer screen, the images may become bunched to a degree that features of individual frames become illegible. This same problem can arise if too many images are displayed at one time on the screen. Too many images can be the result of too small a time increment between displayed frames and/or too many separate objects being represented in the image sequence.

One solution to the cluttering is to impose an overt ordering to the individual frames of the image sequence. This can be done by organizing the frames into a one or two-dimensional grid or matrix using the small multiples concept. Though the absolute location of the object to some global or screen coordinate system is lost, the absolute coordinate system can be used to represent specific variables and to order the visual information in a way that is easily scanned. Students have had many years of training in reading information on a Cartesian grid. This skill can now be put to work at interpreting spatial information and improving visualization skills.

For example, with a 1-D matrix, the axis can represent the time dimension creating a history timeline. Each node of the grid can represent the change in the spatial relationship between two objects. With a 2-D matrix, each axis could represent rotation of the object about orthogonally opposed axes (Fig. 5). A matrix such as this could incorporate a traditional multiview drawing by highlighting the nodes in the matrix that represent standard orthographic views in a different color.

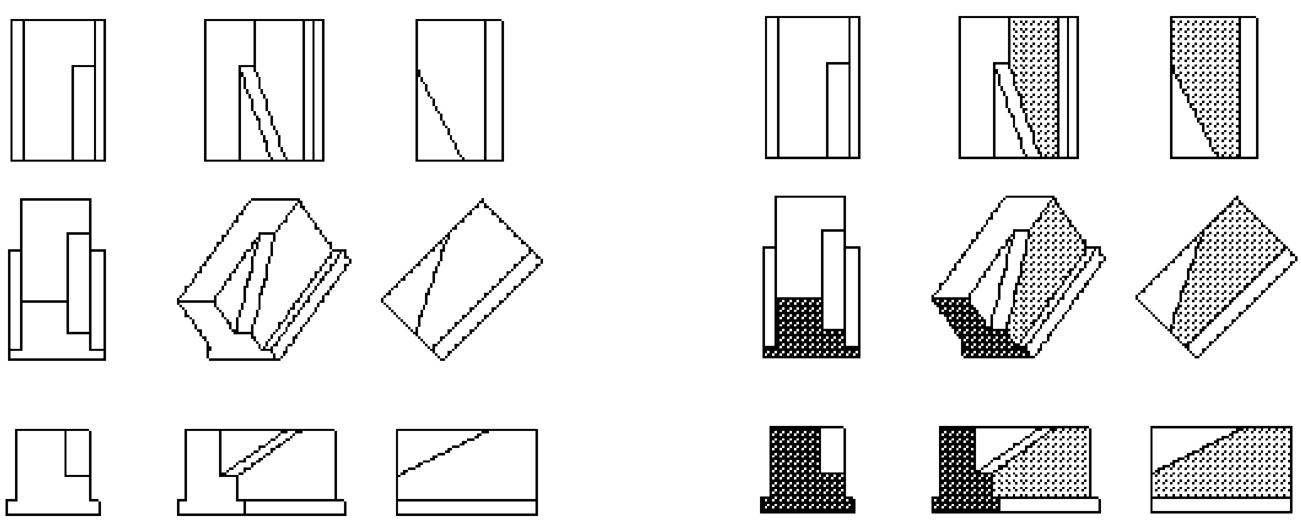


Figure 5.

Figure 6.

Another possibility for the use of color coding in the matrices is in highlighting particular edges or faces of the object and tracing their foreshortening as they undergo rotations relative to the viewer (Fig. 6). Length coding, like color coding, is a powerful perceptual cue [Morse 79]. Though length is a poor way of representing an absolute value, it is quite useful at showing relative change. A student can scan a matrix of an object undergoing rotation and perceive the change in length of the same edge highlighted in all of the nodes.

One of the real powers of a static display of a 2-D matrix is in the holistic nature of the information displayed. Not only does each node of the matrix represent a self-contained image, but the combination of all of the nodes and the relative visual difference of each node form an overall image revealing information different from what is contained at any single node. One type of holistic perception possible from viewing the entire matrix is that of texture. If each node is thought of as an element in a pattern, then the subtle shifts between each node can set up a perceivable pattern. Research has shown that pattern perception can be sensed without cognitive analysis [Pickett 88]. Exploiting pattern perception can become yet another tool for relieving cognitive load on the viewer.

Conclusion

In order to develop the best tools for developing visualization skills in students, perceptual and cognitive principles must be researched and applied. If the goal is to develop a sound mental model for understanding spatial relations, it makes sense that visual display techniques would be used in that development. Using the computer, a wide range of imaging techniques are available, both static and dynamic. Based on these principles, this paper outlined some of the strengths and weaknesses of both kinds of imaging. There is always a tendency to want to exploit the latest technological capabilities of computer systems. Though dynamic imaging techniques have a lot to offer as a teaching tool, there is also a place for static imaging techniques. With both styles of imaging, the increased rendering capabilities of computers offers tools that provide further perceptual interpretation enhancements to the images being displayed.

Not only does further research need to be performed on individual rendering techniques, but also on displays that integrate multiple graphic techniques. Many of the proposed spatial organization schemes seen in literature have not undergone any kind of empirical review. Methodology developed by psychology and human factors researchers could be applied to proposed displays such as the one and two-dimensional matrices outlined in this article.

Bibliography

Augustine, Matthew & Coovert, Michael (1991), "Simulation and Information Order as Influences in the Development of Mental Models", SIGCHI Bulletin, Vol. 23, No. 1, pp 33-35.

Baecker, Ronald M. & Buxton, William A. S. (eds.) (1987), Readings in Human-Computer Interaction: A Multidisciplinary Approach, Morgan Kaufmann, Los Altos, CA, pp 207-218.

Barfield, Woodrow, Lim, Rafael, & Rosenberg, Craig (1990), "Visual Enhancements and Geometric Field of View as Factors in the Design of a Three-Dimensional Perspective Display", Proceeding of the Human Factors Society - 34th Annual Meeting, pp1470-1473.

Haber, Ralph N. & Wilkenson, Leland (1982), "Perceptual Components of Computer Displays", IEEE Computer Graphics & Applications, Vol. 2, No. 3, pp 23-35.

Kaiser, Mary K. & Proffitt, Dennis R. (1989), "Perceptual Issues in Scientific Visualization", SPIE Vol. 1083, Three-Dimensional Visualization and Display Technologies, pp 205-211.

Majchrzak, Ann, et al. (1987), Human Aspects of Computer-aided Design, Taylor & Francis, Philadelphia, pp122-150.

McCuistion, P. J. (1991) "Static vs. Dynamic Visuals in Computer-Assisted Instruction", Engineering Design Graphics Journal, Vol. 55, No. 2.

McWhorter, S. W., et al. (1990), "Evaluation of 3-D Display Techniques for Engineering Design Visualization", Proceedings of the ASEE Engineering Design Graphics Division Mid-Year Meeting, Tempe, AZ, pp 121-129.

Monk, Andrew (ed.) (1984), Fundamentals of Human-Computer Interaction, Academic Press, London, pp 1-29.

Morse, Alan (1979), "Some Principles for the Effective Display of Data", (ACM) Computer Graphics, Vol. 13, No. 2, pp 94-101.

Muir, David W. (1985), "Computer Animation in Engineering", in Kunii, T. L. (ed.), Computer Graphics: Technology and Art, Springer-Verlag, NY, pp 299-307.

Norman, Donald A. (1982), Learning and Memory, W. H. Freeman, San Francisco, CA.

Norman, Donald A. (1983), “Some Observations on Mental Models”, in Gentner, Dedre & Stevens, A. L. (eds.), Mental Models, Lawrence Erlbaum Assoc., Hillsdale, NJ, pp7-14.

Pickett, Ronald M. & Grinstein, George G. (1988), "Icongraphic Displays for Visualizing Multidimensional Data", Proceedings of the 1988 IEEE Conference on Systems, Man, and Cybernetics, pp 514-519.

Salomon, Gitta (1990), "New Uses for Color", in Laurel, Brenda (ed.), The Art of Human-Computer Interface Design, Addison-Wesley Publishing, Reading, MA, pp269-278.

Sanford, James, Barfield, W., & Foley, J. (1987), "Empirical Studies of Interactive Computer Graphics: Perceptual and Cognitive Issues", Proceedings of the Human Factors Society - 31st Annual Meeting , pp519-523.

Truckenbrod, Joan R. (1981), "Effective Use of Color in Computer Graphics", (ACM) Computer Graphics, Vol. 15, No. 3, pp 83-90.

Tufte, Edward R. (1990), Envisioning Information, Graphic Press, Cheshire, CN.

Wiley, Scott E. (1990a), "Computer Graphics and the Development of Visual Perception in Engineering Graphics Curricula", Engineering Design Graphics Journal, Vol. 54, No. 2.

Wiley, Scott E. (1990b), "A Hierarchy of Visual Learning", Engineering Design Graphics Journal, Vol. 54, No. 3.

Wiley, Scott E. (1990c), "The Importance of Visualization Cues in Learning and Design in Engineering Graphics", Proceedings of the ASEE Engineering Design Graphics Division Mid-Year Meeting, Tempe, AZ, pp 103-112.

Zsombor-Murray, P. J. (1990), “2-D and 3-D CAD: Complements to Visualization”, Engineering Design Graphics Journal, Vol. 54, No. 3, pp 17-29.