Visualization Viewpoints

Editors: Theresa-Marie Rhyne and Lloyd Trinish

Minimal Graphics

Ivan Herman

CWI, Amsterdam

David Duke

University of Bath, UK

Thirty spokes share the wheel's hub;
It is the centre hole that makes it useful.
Shape clay into a vessel;
It is the space within that makes it useful.
Cut doors and windows for a room;
It is the holes that make it useful.
Therefore profit comes from that which is there;
Usefulness from what is not there.
—*Tao Te Ching, No. 11* by Lao Tse

Photorealistic rendering of graphical models continues to be a topic of considerable research effort in the computer graphics community. However, photorealism isn't the only criterion for judging an image's value. In visualization, where rendering is the conduit through which abstract, nonrealistic forms (such as isosurfaces or streamtubes) become perceivable to users, photorealism may neither be the most useful nor appropriate property. This article describes our long-term research vision in an area that, in our view, should gain a lot of importance in the future.

Courtesy of the WebMuseum

1 **Johannes Vermeer's *The Little Street*. The image source is http://www.ibiblio.org/wm/paint/auth/vermeer/vermeer.street-delft.jpg.**

Artistic traditions

Consider the paintings in Figures 1 and 2. Figure 1 is a reproduction of a painting by Johannes Vermeer, one of the outstanding Dutch painters of the 17th century. His *The Little Street* is a typical example of Dutch and classical European paintings. Figure 2 is a detail taken from a landscape painting by the Chinese artist Yun Ge, dated to the 17th century.

The artistic techniques used in the paintings are quite different. If we consider these paintings as forms of communication, then a natural concern is how the different representation styles affect that communication. A full account of these issues lies in the areas of art theory and visual perception. Here, we simply use the example as an analogy, to observe that computer graphics, which plays a major role in visualization and visual communication within today's information society, has focused on one particular approach to rendering information—so-called photorealistic rendering.

Vermeer tried to represent reality on the canvas by using all the intricate effects of lights, shadows, reflections, and so on. Such minute details as the texture of the brick walls or the people's garments are also represented with great care, although they're hardly noticeable to the naked eye. This attempt at realism was one of the main characteristics of European paintings up to the beginning of the 20th century. This approach to art is in sharp contrast to the art of China and Japan. Clearly, Yun Ge, like most traditional Chinese and Japanese painters, didn't try to reproduce nature. The picture conveys an impression of a landscape—it represents only parts of the contours and main lines of objects (such as the hills, trees, and so on). The whole of the picture is remarkably void of details. Nevertheless, the message—the information content—is there, and the aesthetic beauty of this painting is just as appealing as Vermeer's. (Note that, in this article, we used Far Eastern painting as a contrast. We could've also referred to various schools of modern European art or to cartoon and caricature drawings. Beyond issues of personal taste, a reason why Chinese and Japanese paintings might be an interesting point of departure are the traditions and philosophical background underlying the art, which may help in developing new methods of rendering.)

Some European artists (like Albert Dürer or Leonardo da Vinci) and Vermeer conducted life experiments to

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understand the propagation of light, human vision, the nature of shadow, and so on. In doing so, they became precursors of an early form of experimental mathematics. For example, modern projective geometry—the rules of perspective mappings—grew out of these experiments. This tradition of developing models of representation based on physical reality has continued into the 20th century and became the foundation of traditional rendering in computer graphics. However, in looking at other artistic traditions, we might want to ask deeper questions about how information is represented in an image. Apart from enriching our understanding of how we select and represent visualization data, these questions prompt us to reevaluate the principles of rendering with application to graphics.

Courtesy of the Kyoto National Museum, Japan

2 **Detail of Yun Ge's *Sunset at Huawu,* China, 17th century.**

Motivations

Why should information scientists be interested in artistic traditions? We can consider traditional computer graphics, as it has evolved over the past 15 to 20 years, a direct continuation of traditional European painting, at least up until the end of the 19th century. The goal is to reproduce nature through images generated by computer graphics. The ideal is photorealism, or its generalization into concepts of virtual reality, virtual humans, and so on. The goal of this article isn't to criticize these lines of research, which are stimulating, exciting, and full of challenging research problems. However, we shouldn't forget an essential issue. A significant goal of computer graphics is to help the human observer to understand information through pictorial means. In some cases (such as a virtual walk-through of a building), photorealism has a clear role, but particularly in visualization, we should realize that this isn't necessarily the case. The example of Chinese and Japanese paintings shows we can also convey information about our environment without striving for photorealism, but by choosing instead a level of graphical information that's enough to communicate the intended message. In addition, we can do this without losing the image's expressiveness and aesthetic beauty.

A form of visual simplicity underlies Chinese and Japanese art. Our objective is to find a new approach to rendering that incorporates this aesthetic. For a lack of a better name, we chose the term *minimal graphics* for the following research goal: Based on some model of information (which may be either a traditional geometric model of a full scene or something different), we should produce images that strive for a minimum level of complexity that should be as simple as possible but which should convey the intended information to a human observer. Furthermore, the generated images should be pleasing to the eye (although this is even more difficult to describe in algorithmic terms).

Although an intellectual challenge or aesthetic requirements can motivate research, computer graphics has always been driven by practical needs, too. Is minimal graphics of any practical interest? We think so for these three reasons:

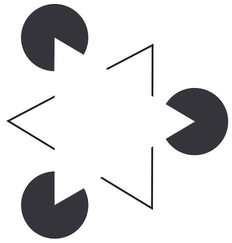
- Schuman et al.[1] have described how architects, when talking to their clients in the early phase of design, prefer to use sketches rather than photorealistic images. Sketches seem to have an affective quality that encourages interaction, as they convey a sense of only partial commitment to a design. Would minimal images be better at encouraging dialogue and interaction than photorealistic alternatives?
- Application development for mobile computing via devices such as mobile phones and personal digital assistants is constrained by the devices' limited displays. If images convey information within applications, the rendering processes will need to take the display limitations into account. The research goal of minimal graphics is essentially what's needed for using these devices more effectively.
- New kinds of input and output devices are becoming available to support human–computer interaction. Haptic devices are one example of this. Although these are still expensive and limited, they're becoming more widely accessible. Haptic rendering has significant timing constraints. Variants of minimal graphics might be more adaptable to this technology than algorithms derived from photorealistic approaches.

Nonphotorealism and minimal graphics

Artistic considerations have already influenced the development of new rendering methods in computer graphics (these considerations have also contributed to visualization.[2]) The majority of this work has concentrated on reproducing various artistic techniques and tools, such as pen and ink, pencil, brush, and paint effects. Researchers have also developed nonphotorealistic (NPR) techniques that use principles of human vision. However, the emphasis has been on low-level aspects of cognition, such as the use of textons, shading, and so on. Minimal graphics aims to use models of human information processing that encompass not just low-level vision but also structural recognition, interpretation, and affective properties of images to produce a general-purpose foundation for rendering graphical information.

Fundamentals of minimal graphics

Extracting minimal information from a model seems to be, at first glance, a geometric task. We could try extracting and using, for example, geodesic or other characteristic curves, using some sort of silhouette detection algorithm or special forms of dithering (for further examples, see our report on this topic[3]).



3 The Kanisza triangle. (Adapted from Shapely et al.[5])

4 The Duomo of Milan. (Photo by Ivan Herman.)

However, these approaches don't simplify the image, and the results lack the symbolic, abstract nature that minimal graphics seeks to achieve. Other techniques could complement these approaches. For example, we could use a smooth (not necessarily convex) hull of 3D objects for the final image. We also envisage that wavelet-like encoding—multiresolution methods in modeling objects—might help extract the "sweep" of a curve or surface.

Completing images

However, adapting existing techniques from graphics isn't sufficient. When trying to formulate the issues raised by minimal graphics, we soon realize that "abstract" and "minimal" aren't concepts that can be described in purely algorithmic terms. Rather, minimal means that the image is just rich enough for the human mind to complete the representation through cognitive processing. This might seem as if we're posing additional demands of completion on the human, thus incurring a usability deficit. However, perception isn't just a matter of completion. In practice, a great deal of irrelevant information, or noise, must be disposed of before completion of what remains—the signal—can take place. Researchers have described several optical illusions that exemplify how human cognition is capable of "completing" an image. (The book by Ninio[4] is one of the best collections of such illusions we know about.)

Figure 3, for example, shows the so-called Kanisza triangles: the three wedges in the black circles create an illusionary white triangle. To take another example, consider the image of the Duomo of Milan (Figure 4). The building's facade has a complicated edge, consisting of a complex pattern of stone carving. Nevertheless, the human mind clearly perceives a triangular facade, by "smoothing" the edges in the image. Looking at a cloud in the sky or the contours of a fractal image are examples of the same effect. Generalizing from these examples, it seems that the human cognitive process is somehow able to fill in some "emptiness" (the triangle in the middle of Figure 3 and the empty space at the edge of the Duomo). This duality between empty versus full seems to play an essential role in the way humans perceive their environment. This is why sketch images can show the Duomo of Milan as a simple triangle with some additional ornaments. Minimal graphics should be able to generate similar sketchy images automatically.

Although there's no simple, complete model that accounts for all aspects of visual illusion in terms of cognitive processes, existing theories explain significant aspects of the problem at particular levels of operational detail—for example, from neurological properties of the precognitive phase to cognitive effects grounded in the interplay between top-down and bottom-up processing. We can reduce the cathedral image in Figure 4 to a triangular outline by frequency filtering, and similar bottom-up processes may complete the occluding triangle in Figure 3. But these can't be the only processes in operation.

As we said before, perception isn't just a matter of completion. Minimal graphics can aid users by minimizing irrelevant information. The computational target is to find algorithms for identifying noise within graphical representations. We can only do this by identifying the original data's task-relevant attributes, coupled with an understanding of the ways in which cognitive processes map images to percepts. Therein lies, in our view, the greatest challenge in minimal graphics. Visual perception and psychophysics are some of the original parts of experimental psychology, and many different theoretical approaches deal with specific problems such as depth perception, motion perception, binocular fusion, object recognition, and so forth. Of course, minimal graphics doesn't aim to produce new cognitive theories but rather to draw on the existing knowledge of how such processes contribute to our understanding and interpretation of images; Strothotte contains interesting examples of this.[6]

We believe that an interesting analogy exists between the foundations of photorealistic graphics and minimal graphics. The principles of photorealistic graphics rest on an approximation of physical reality that's elegantly captured by Kajiya's rendering equation.[7] In contrast, minimal graphics doesn't necessarily seek to reproduce physical aspects of reality and requires instead a model of cognitive information processing. Kajiya's equation isn't in itself an algorithm for rendering images, but it provides the theoretical foundation for families of approaches (such as ray tracing and radiosity) that implement aspects of photorealism. Similarly, we don't expect or require that the cognitive theories underpinning minimal graphics will provide an explicit approach to rendering. Rather, we believe that such theories will provide the basis for defining a family of new rendering techniques that achieve a minimal approach.

Conclusions

In this article, we argued that the conventional view of rendering is one part of a much broader enterprise of graphics-based communication in which there's a need to consider different approaches to the rendering problem. To make progress, we need to understand perceptual and cognitive theories that explain how humans process and understand graphical information. What isn't simple to state, of course, is how we can address this new view of the rendering problem. Our comparisons have focused on nonphotorealistic rendering. There are, of course, other lines of work that deal with the issues of generating effective presentations, these include work on visual communication and, from an AI perspective, on presentation planning. We still need to explore the contribution of these areas to minimal graphics, and we're aware that this article only scratched the surface of a significant research effort. ■

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Readers may contact Herman at CWI, Kruislaan 413, 1098 SJ Amsterdam, The Netherlands, email ivan@cwi.nl.

Contact department editors Rhyne and Treinish by email at rhyne@siggraph.org and lloydt@us.ibm.com.