Minimal Graphics

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Photorealistic rendering of graphical models continues to be a topic of considerable research effort in the computer graphics community. However, photorealism is not the only criterion for judging the value of an image. In visualization, where rendering is the conduit through which abstract, non-realistic forms (e.g. isosurfaces or streamtubes) are made perceivable to users, "photorealism" may be neither the most useful, nor indeed appropriate, property. This article describes the authors' long term research vision in an area which, in their view, should gain a lot of importance in the future. The direct inspiration for this line of work came when one of the authors (IH) visited an exhibition on Japanese prints in Amsterdam but, indirectly, the visit the authors made some years ago to the old imperial city of Kyoto had a great influence, too; the reader will soon understand why.

Consider the paintings in Figure 1 and Figure 2. The first is a reproduction of a painting of Johannes Vermeer, one of the outstanding Dutch painters of the 17*th* century. His "The Little Street" is a typical example of Dutch, but also of classical European painting. The second is a detail taken from a landscape painting by the Chinese artist Hsia Kuei, dated to the 12*th* century. The artistic techniques used in the paintings are quite different, as will be discussed shortly. If we consider these paintings as forms of communication, then a natural concern is how the different styles of representation 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 today plays a major role in visualization and visual communication within the information society, has concentrated much on one particular approach to rendering information, so called photorealistic rendering.

Figure 1. Johannes Vermeer, "The Little Street"

Vermeer tried to represent *reality* on the canvas, with all the intricate effects of lights, of shadows, of reflections, etc. Such minute details as the texture of the brick walls or the garment of people are also represented with great care, although they are hardly noticeable to the naked eye. This attempt for realism has been one of the main characteristics of European painting up to the beginning of the 20th century. This approach to art is in sharp contrast with the art of China and Japan. The contrast between the two paintings is striking. Clearly, Hsia Kuei, as most traditional Chinese and Japanese painters, did not try to *reproduce* nature. The picture conveys an *impression* of the landscape; only parts of the contours, of the main lines of objects (of the hills, the trees, etc.) are represented. The whole of the picture is remarkably void of details. Nevertheless, the "message", the "information content" is there, and the undeniable aesthetic beauty of this painting is just as appealing as the one of Vermeer's*.

Some European artists, like Dürer or Leonardo da Vinci, and indeed Vermeer himself, too, conducted life experiments to understand the propagation of light, human vision, the nature of shadow, etc. 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

* Note that, in this text, the example of Far Eastern painting is used as a contrast; one could also have referred to various schools of modern European art, or to cartoon and caricature drawings. Beyond issues of personal taste, a reason why Chinese/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.

Figure 2. Hsia Kuei: A Pure and Remote View of Rivers and Mountains.

of developing models of representation based on physical reality has continued into the twentieth century and became the foundation of traditional rendering in computer graphics, too. However, in looking at other artistic traditions, we might be encouraged to ask deeper questions, about *how* information is represented in an image. Apart from enriching our understanding of how we select and represent representations of visualization data, these questions prompt a re–evaluation of the principles of rendering with application to graphics in general.

Motivations

Why should artistic traditions be of interest to information scientists? Traditional computer graphics, as it developed in the past 15 to 20 years, may be considered as 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 generalisation into concepts of "virtual reality", "virtual humans", etc. It is not the goal of this paper to criticise these lines of research, which are stimulating, exciting, and full of challenging research problems. However, one should not 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 (e.g., a virtual walk–through of a building) photorealism has a clear role, but particularly in visualization one should realise that this is not necessarily the case. The example of Chinese/ Japanese painting shows that information about one's environment can also be conveyed *without* a strive for photorealism, judiciously choosing instead a level of graphical information which is enough to communicate the intended message. In addition, this can be done without losing the expressiveness and the aesthetic beauty of the image.

Underlying Chinese and Japanese art is an aesthetic of visual simplicity. Our objective is to find a new approach to rendering that incorporates this aesthetic. For a lack of a better name, the term "minimal graphics" has been chosen 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) one should *produce images which strive for a minimum level of complexity for a task*, i.e. which should be as simple as possible, but which should convey the intended information to a human observer. Furthermore, (although this is even more difficult to describe in algorithmic terms) the generated images should be "pleasing" to the human eye.

Although research could be motivated by a sheer intellectual challenge or aesthetic requirements, computer graphics has always been driven by practical needs, too. So is minimal graphics of any practical interest? Here are three reasons:

1) Schuman et al.[4] 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?
2) Application development for mobile computing via devices such as mobile phones and PDA–s is constrained by the limited displays of these devices. If images are to be used to convey information within applications, the rendering processes will need to take the display limitations into account. We suggest that the research goal of minimal graphics is essentially what is needed for more effective use of these devices.
3) New kinds of input and output device are becoming available to support human-computer interaction. Haptic devices are one example of

this. Although these are still expensive and limited, they are 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.

Non-photorealism and Minimal Graphics

Artistic considerations have already influenced the development of new rendering methods in computer graphics. The majority of this work has concentrated on the reproduction of various artistic techniques and tools, such as pen and ink, pencil, brush, and paint effects. Non–photorealistic (NPR) techniques have also been developed that utilise principles of human vision. However, the emphasis has been on low–level aspects of cognition, e.g., the use of textons, shading etc. The aim of minimal graphics is to use models of human information processing that encompass not just low–level vision, but also structural recognition, interpretation, and even affective properties of images to produce a general purpose foundation for rendering graphical information.

Artistic considerations have already made significant contributions to visualization. There is no place to give a detailed overview here, let us just refer to the paper of Laidlaw in the March/April issue of IEEE CG&A[2] as one example of the potential interaction.

Fundamentals of Minimal Graphics

The extraction of a minimalist information from a model seems to be, at first glance, a geometric task. One would try to extract and use, for example, geodesic or other characteristic curves, use some sort of silhouette detection algorithm, or special forms of dithering (see a more complete report on the topics[1] for further examples). However, these approaches do not "simplify" the image, and the results lack the "symbolic", abstract nature that minimal graphics is seeking to achieve. Other techniques could complement these approaches, for example the use of some sort of smooth (not necessary convex) hull of the 3D objects, which could be used for the final image. Wavelet–like encoding could be envisaged; multiresolution methods in modelling objects might help in extracting the "sweep" of a curve or a surface.

However, adapting existing techniques from graphics is not sufficient. When trying to formulate the issues raised by minimal graphics, one soon realises that "abstract" and "minimal" are not concepts that cannot 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 were posing additional demands of completion upon the human, so incurring a usability deficit. However, perception is not 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. A number of optical illusions have been described which exemplify how human cognition is capable of "completing" an image.* 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 façade of the building has a very complicated edge, consisting of a complex pattern of stone carving. Nevertheless, the human mind clearly perceives a triangular façade, by "smoothing" the edges in the image. Looking at a cloud in the sky, the contours of a fractal image: these are all examples of the same effect. Generalising from these examples, it seems that the human cognitive process is somehow able to fill in some "emptiness" (the "triangle" in the middle of the Kanisza figure, the empty space at the edge of the Duomo). This duality between "empty" vs. "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.

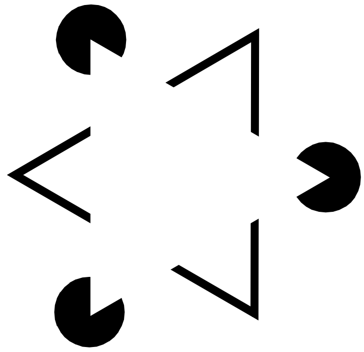

Figure 3. The Kanisza triangle

Although there is no simple, complete model that accounts for all aspects of visual illusion in terms of cognitive processes, there are theories that explain significant aspects of the problem at particular levels of operational detail, for example from neurological

Figure 4. The Duomo of Milan

* The book of Ninio[3] is one of the best collections of such illusions we know about. Although in French, it is quite enjoyable for non French readers, too

properties of the pre–cognitive phase, through to cognitive effects grounded in the interplay between top-down and bottom-up processing. The image of the cathedral may be reduced to a triangular outline by frequency filtering, and similar bottom–up processes may complete the occluding triangle in the Kanisza figure, but these cannot be the only processes that are in operation.

As said before, perception is not just a matter of completion. Minimal graphics could aid the user by minimising irrelevant information. The computational target is to find algorithms for identifying 'noise' within graphical representations. This can only be done by identifying the task relevant attributes of the original data, coupled with an understanding of the ways in which cognitive processes map images to percepts. In there lies, in our view, the greatest challenge in minimal graphics.

Visual perception and psychophysics are some of the original parts of experimental psychology, and there are many different theoretical approaches to specific problems such as depth perception, motion perception, binocular fusion, object recognition and so forth. It is of course not the goal of minimal graphics 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 doing this [5].

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

Conclusions

In this article we have argued that the conventional view of rendering, is but one part of a much broader enterprise of graphics–based communication in which there is a need to consider fundamentally different approaches to the rendering problem. To make progress on this enterprise, it is necessary to understand perceptual and cognitive theories that explain how graphical information is processed and understood by humans. What is not simple to state, of course, is how this new view of the rendering problem can be addressed. Our comparisons have focused on non–photorealistic rendering. There are, of course, other lines of work which deal with the issues of generating effective presentations, these include work on visual communication and, from an AI perspective, on presentation planning. The contribution of these areas to minimal graphics is still to be explored. We are well aware that this paper only scratched the surface of a significant research effort.

Let us close this note with a traditional Taoist poem which nicely symbolises some of the ideas that influenced us:

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.
— Lao Tse: Tao Te Ching, No. 11

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