Computers and visualisation of design Ideas: possibilities and promises

J. Landsdown
System Simulation Ltd and St. Martins School of Art (United Kingdom)

Drawing in all its various forms, from freehand sketching to detailed technical layout, is a type of modelling that designers find indispensible. In many cases, indeed, drawing is the only form of external modelling a designer uses. It has two basic functions: to assist in the *externalisation* and development of mental concepts and to help in the *presentation* of these concepts to others.

The current thrust of work in computer graphics - although valuable - tends to concentrate almost exclusively on the presentation aspects and it is now possible to create images almost resembling photographs of real objects as well as production drawings of great accuracy and consistency. This paper summarises some of this presentation work as well as developments which might go further in assisting the activities and processes of design.

'Realistic' images

Making pictorial images by computer graphics entails performing four tasks:

1. **Modelling** the objects to be depicted (in terms of their geometry and visual characteristics);
2. **Transforming** them (by means of the mathematical techniques of translation, rotation, scaling and projective viewing) so that they are set in the positions, orientations and sizes required;
3. **Clipping** the transformed objects so that only those parts which can actually be seen are sent to the drawing device;
4. **Displaying** the clipped objects including rendering them in their correct colours or tones and showing highlights and shadows if necessary.

Although much more work has yet to be done on developing appropriate modelling techniques, the major effort in current work in computer graphics is in the area of rendering the images. Transformation and dipping techniques are now sufficiently developed for the processes involved to be incorporated into silicon, thus obviating the need for programming them - with concomitant increases in speed and efficiency (Clark 1985).

Objects made up of plane, matt surfaces can be rendered at high speed using elementary techniques, and even curved objects can be approximated by planar ones rendered using an interpolation technique known as *Gouraud shading* (Gouraud 1971). Both these forms of shading are simple enough to be built into silicon but they cannot cope with objects having shiny surfaces. Such objects have highlights and these can be rendered using another interpolation method called *Phong shading* (Phong 1973). This form of shading, whilst more convincing, is however computationally expensive and can take more than ten times longer to execute than Gouraud shading. In its current form, too, it is difficult to embody in silicon. A recent development of the method by Bishop and Weimer (1986) and called fast *Phong shading is,* however, in a form which could be put into firmware. Even in its software form, their method appears to take only twice as long to execute as Gouraud shading.

Ray tracing

To make pictorial images containing transparent or translucent objects with reflections and shadows entails employing a somewhat brute-force rendering technique known as 'ray tracing'. The method potentially involves following the notional path of every lightray as it passes through or bounces off objects in a scene and then recording the ones that actually meet the eye. As this would be impossible in practice, it is assumed that the rays start at the eye, pass through the picture plane represented by the display surface and encounter objects on their way, splitting into son and daughter rays, reflecting and bending in the process.

One ray is passed from the eye out through every pixel in the screen and its progress and that of any of its progeny is recorded until it either disappears into the background or meets a light source. At this point its brightness and colour can be determined (Rogers 1985).

For a screen of 1024 by 1024 pixels (fairly normal by current standards), over a million parent rays have to be cast and son and daughter rays can often double this figure - so the process is slow and computationally intensive. There are, of course, many pragmatic short cuts available which speed-up the process by factors of three or four but, essentially, ray-traced scenes are slow to produce (some taking from many minutes to hours on quite large computers).

Radiosity

Another technique, radiosity, can cope with some rendering problems not covered by ray tracing (back-lighting, for instance), and can render scenes without transparent objects at a faster rate than ray tracing techniques (Immel, Cohen and Greenberg 1986), The major advantage of radiosity is that those illumination effects which are independent of viewer position can be calculated once and for all in a given scene. When multiple views need to be presented, this pre-computation can result in major time-savings (Greenberg 1987). Kajiya (1986) has succeeded in summarising all the properties of illumination models in a single equation which promises to increase the scope of rendering methods enormously.

Some other developments

For designers, it is not clear that the sort of photorealism achievable by ray tracing and radiosity is necessary but, if it is, there are a number of developments on the near horizon which promise to improve the speed and cost-effectiveness of rendering. These, together with the continued work on faster and more appropriate algorithms, will ultimately make it possible for designers in even the smallest practices to contemplate using computing as their primary means of visual presentation if they wish.

The foremost developments are those of incorporating rendering methods in hardware thus increasing speed of execution, reducing cost and time, and minimising the need for specialised programming. By their very nature, too, many rendering techniques - especially ray tracing - lend themselves to parallel processing and a number of systems are being devised to exploit this fact. Theoretically it would be possible to allocate one processor to each pixel in the image and allow all the ray calculations to proceed in parallel - making the computation effectively instantaneous. However, there a no systems having such a plethora of processing elements but systems having 64 or more Inmos Transputers - each devoted to some part of the scene - are already available. Parallelism in some form or another is likely to be the major thrust of hardware developments in rendering techniques over the next few years.

An interesting approach to the time/ computation trade-off being taken by R & D workers at the University of North Carolina, Chapel Hill, is what they call *adaptive refinement* (Bergman et al 1986). In this they assume that what the viewers need first of all - and quickly - is some sort of line-only view which illustrates the overall scene. Whilst this is being displayed, further developments of the scene are being presented, showing more and more rendered detail as time progresses. Each successive development is based on the last so that, in general, only those areas of the scene which need special treatment are rendered in the most detailed form. Thus Gouraud or polygonal shading might be used for most of the scene and Phong shading only for appropriate areas. At any time the process can be interrupted by the user or it can be allowed to develop to completion. This approach seems especially applicable to interactive designing where a fully rendered picture would only be needed if time permitted its presentation.

Why stop at drawing?

Although techniques for rendering images of designed objects are quite well developed, it is not now necessary to confine ourselves to drawings as the only means of displaying computer graphics output. For example, by using a desktop mechanical device made by the Roland Company and costing about as much as the personal computer necessary to control it, we can automatically cut a 3-D model out of plastic directly from the same information necessary to draw a conventional perspective view of it. Models of up to about 300mm on a side can be carved by this device and it is especially good for complex curved forms such as product and packaging designers might need - and which often take a long time to render on small computers.

On a more distant time horizon are computer-produced holograms and three-dimensional presentation devices based on the head-up helmet displays used by fighter pilots. The Media Lab at MIT have succeeded in computing a hologram of an architectural scene - in fact, Frank Lloyd Wright's Robie House -but a great deal more work needs to be done before their technique becomes a practical design tool. Their method comprises calculating eighty separate views which are synthesised into a single image: this is not the same as computing the interference patterns of the image directly which is the approach of some workers. The holographic work of Yatagai (1976) and Tsujiuchi (1982) is also worthy of note. When we can persuade one of the companies engaged in the military sector to make available their now very sophisticated head-up display devices for pilots, presentation possibilities emerge such as those envisaged long ago by Sutherland (1968). IBM seems, however, to have some interest in the head-mounted display field (Young 1983).

Sensing a possible market for other forms of stereoscopic displays, Tektronix have recently introduced their 4126 device whose images, when seen through polarising spectacles, show convincing 3-D views. No special programming efforts are needed to present stereoscopic pictures on this device - a normal solid modelling approach is all that is necessary. Experiments are proceeding in a number of centres to develop 3-D displays which do not require their viewers to wear special spectacles. These rely on exploiting the effects of parallax by presenting the user with two or more slightly different views of the scene in rapid succession. The eye/brain perceptual system should then fuse these images into one coherent 3-D view. Surprisingly, it is reported that the best results are not obtained with the expected side-by-side views (Hodges and McAlister 1985). It is too early to say what the outcome will be of these investigations but initial results do not seem too promising. It should also be noted that 10% of the population cannot see stereoscopically even though they have otherwise perfect vision.

The designed artifact in its setting

One special form of assistance that computer graphics imaging techniques can give to designers is that of helping them visualise their designs in context. Architects, for instance, need to relate their buildings sympathetically to the surroundings; packaging designers need to see their designs en masse on supermarket shelves related to those of competing products; planners need to visualise the appearance of electricity pylons and similar items in place in the landscape. This often hard to do in practice and designers sometimes mislead themselves and others in the process of visualising these things. Computer graphics techniques relating synthetic images to real ones - akin to photomontaging in both still and movie form - are now available and promise to eliminate many of the practical problems (Mayer, Steam and Sussock 1986)

Hardcopy

Except in the case of production drawing and similar systems outputting to pen plotters, raster electrostatic plotters or monochrome laser printers, it is very difficult to match the quality of screen displays in hardcopy and this sometimes has a disincentive effect in using computer graphics for presentations. Screen copiers giving 35mm transparencies produce the closest match but paper copies only allow very approximate renditions. Colour ink jet printers are continually improving in quality but *their c*olours and resolutions can rarely be tuned to resemble those on the display. Thermal transfer printers - as typified by the Mitsubishi Electric G series - can deliver seven colour pictures at a resolution of 300 dots per inch and give close approximations to some displayed pictures. (The effects of more than seven colours are achieved by dithering' methods - where different colour dots are placed side by side - but this reduces apparent resolution.) Thermal transfer printers seem to present the most likely development path for high quality output - although, of course, there are optical and colour considerations which make it unlikely that the subtractive colour techniques used in paper printing can ever do more than approximate the appearance of the additive colour techniques used in displays.

Other forms of visualisation

Much of a designer's time is devoted to visualising the appearance of artifacts in the process of being transformed from their initial partly-conceived state to their final finished form. But, in addition, a lot of time is also devoted to visualising and externalising more abstract concepts such as relationships, characteristics and attributes as well as the consequences of certain planning actions. Sketching and diagrammatic formalism are often the designer's media here too.

Some existing computer techniques could be useful in this area: spread sheets, for example, encourage investigation in a 'what if?' mode. The physical analogy of spread sheets to pencil and paper figuring make them relatively painless to use. Simulation techniques also aid in understanding consequences of different courses of action. These can be used to look at discrete events, such as people arriving at lifts (Barney and Dos Santos 1977) or continuous events such as flow of energy through building surfaces (Clarke 1982).

Some of the *hypertext* and *hypermedia* systems that are available for personal computers: GuideTM, perhaps, or FilevisionTM, also promise to change the way designers relate to information processing. Hypermedia programs allow the presentation and manipulation of information in new mixed text and graphics ways which can be tailored to suit the personal and often idiosyncratic needs of designers. Lansdown (1983) and Lansdown and Roast (1987) outline the sort of information needs that designers have. In the 1987 paper Design Knowledge Manipulation Environments (DKMEs) are proposed in which both computer data of a conventional sort and visual databases on videodisc are brought together with computation modules to assist designers in navigating their way through the complex information mazes that inevitably have to be set up. Undoubtedly the work of Negroponte and his colleagues at MIT as described at this conference by Patrick Purcell will do much to make these DKMEs a practical proposition.

Summary

Designers need tools to help them visualise:

Abstractions, such as relationships and connections;
Behaviour, that is performance and attributes of artefacts and systems;
Movement, both discrete and continuous;
Appearance, of artefacts and their environments.

Over the next few years, six developments are likely to assist in fulfilling these needs:

1. Photorealistic systems are likely to become cheaper and faster.
2. Systems able to interpret designers sketches of both artefacts and abstractions

will become available.

3. Despite being the least 'realistic' of all imagery, computer production of holograms will become commonplace.
4. Hypermedia systems allowing mixture of text, sketches, photographs, drawings, voice and other media will arrive to enable more responsive Design Knowledge Manipulation Environments to be created.
5. Full stereoscopic imaging systems will be usual.
6. Idiosyncratic systems able to be tuned to the specific design models of users will become generally available.

The techniques of photorealism are likely to continue developing apace but it should be noted that we do not judge 'reality' by seeing snapshots of views - but by experiencing it. We interpret snapshots by bringing to them all the understanding this experience gives us. Thus photorealistic views may not be the best way of presenting *future* realities to designers or their clients. Other techniques might be more powerful and expressive. These need to be examined in parallel with photorealism.

References

Barney CC and Dos Santos SM (1977) Lift *Traffic Analysis Design and Control,* Peter Pereginus Ltd, Stevenage

Bergman L, Fuchs H, Grant E and Spach S (1986) Image Rendering by Adaptive Refinement, *Computer Graphics* (20) 4 pp29-37

Bishop G and Weimer DM (1986) Fast Phong Shading, *Computer Graphics* (20) 4 Pp lO3-1O6

Clark JA (1985) Graphics Software Standards and their Evolution with Hardware Algorithms, In: Earnshaw RA, *Fundamental Algorithms for Computer Graphics,* Springer-Verlag, Berlin pp 6l9-631

Clarke JA (1982) *ESP (Multi-Zone) User Manual,* ABACUS, University of Strathclyde, Scotland

Gouraud H (1971) Continuous Shading of Curved Surfaces, *IEEE Transactions on Computers,* (C-20) 6 pp 623-628

Greenberg DP (1987) Computer Graphics and Visualisation, In: Pipes A, *Computer-Aided Architectural Design Futures,* Butterworths, Sevenoaks pp 63-67

Hodges LF and McAlister DF (1985) Stereo and Alternating-Pair Techniques for Display of Computer-Generated Images, *IEEE Computer Graphics and Applications* (5) 9 pp 38-45

Immel DS, Cohen MF and Greenberg DP (1986) A Radiosity Method of Three-Dimensional Objects, *Computer Graphics* (20) 4 pp 133-142

Kayija JT (1986) The Rendering Equation, *Computer Graphics* (20) 4 pp 143-150

Lansdown J (1983) *Knowledge and Information in the Design Office of the Future,* Working Paper, System Simulation Ltd, London

Lansdown J and Roast C (1987) The Possibilities and Problems of Knowledge-Based Systems for Design, *Environment and Planning B: Planning and Design* (14), (to be published)

Mayer TW, Stearn D and Sussock H (1986) Visual Impact Analysis: The Application of Computer Graphics to Architecture and Planning, *Proceedings of Eurographics* UK, Glasgow

(Bui-Tong) Phong (1975) Illumination of Computer Generated Pictures, *Communications of the ACM,* (18) 6 pp 311-317

Rogers DF (1985) *Procedural Elements for Computer Graphics,* McGraw-Hill, New York

Sutherland IE (1968) A Head-Mounted Three-Dimensional Display, Proceedings: Fall Joint Computer Conference, Thompson Books, Washington DC pp 757-764

Tsujiuchi J (1982) Three-Dimensional Image Display using Holography, *Journal Institute of Electronic and Communication Engineers of Japan* (65) 12 pp 1296-1302

Yatagai T (1976) Stereoscopic Approach to 3-D Display using Computer-Generated Holograms, *Applied Optics,* (15) 11 pp 2722-2729

Young JER (1983) Head Mounted Display, *IBM Technical Disclosure Bulletin* (25) 12 p6373