A survey of some perceptual features for computer graphics and visualization

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Abstract

Some high level and some low level features of perception related to computer graphics and visualization are discussed in this survey paper. The need for perception in computer graphics and visualization will be important for the future of the area.

CR Categories: A1 [Survey], I.3.m [Computer Graphics miscellaneous]

Keywords: perception, computer graphics, visualization

1 Background

Computer graphics and visualization often have had a focus on speed and memory. The pictorial result has been accepted or rejected after a quick review by the author. During the last few years more interest has been oriented towards the quality of the image and how the methods can be adjusted in order to obtain a good or better result without unnecessary sacrifice of calculation efforts. In some applications one may accept lower quality in order to achieve speed. The limitations of the human visual system are used as a guide. We need knowledge on how scenes and visual information can be displayed so that its use is optimized for the observer. Details that can't be perceived by the observer should not be calculated and displayed.
From the beginning of computer graphics and visualization there has always been an influence from perception. One example of this is the experimental way of working that has been used. Fast visual inspection is in fact a way of using perceptual evaluation to see what methods that work.
From a low level hardware point of view perception has also been used. Integration features in the human visual system are used in CRT displays. Phosphor dots on the screen are fused when viewed on some distance from the screen. Another example is given by temporal variation (animation) of intensity on a screen, where integration in the human visual system makes the viewer perceive a stable image.

Investigation of perception and its relation to the physical world is much older than computer graphics. New is that we are able to manipulate the objects and the data in a much more flexible way than before which also means that we need to know more details on what effects we get by adding and removing different features in an image.

The diagram in figure 1 is confusing to many viewers. This is due to the choice of camera position, which most viewers would expect to be from above. A comment that the camera position is from below clarifies the presentation.

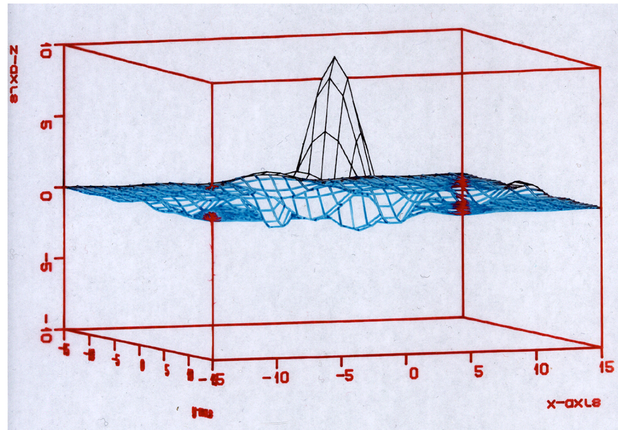

Figure 1: Graphical presentation of a mathematical function

The interest for perception in graphics and visualization has during recent years been manifested by articles in magazines, special issues of journals, tutorials at conferences etc. Two examples are the short presentation by Mahoney [2001] and the SIGGRAPH tutorial on experimental studies for computer graphics given by Ferwerda et.al. [2002].

The area of visual perception for computer graphics and visualization is interdisciplinary in its nature. Visual perception is important and related knowledge can be collected from people from many disciplines, e.g. perception researchers using psychophysical methods, neuroscientists, artificial network researchers, vision researchers, graphics and visualization researchers, graphics designers, artists and last but not least from application oriented persons.

Perceptual results are often given by psychophysical experimental studies. These results often have a quantitative character. Much research are more oriented towards qualitative investigations which is needed to understand fundamental mechanisms and performances in human-computer interaction. This would imply that perception is less interesting. According to our view, investigations and experimental studies on visual perception have a goal of achieving a pattern of understanding which is a qualitative result although a single experiment seems to be quantitative in nature.

2 Reasons for using perception

There are several different reasons for taking into account the perceptual aspects in graphics and visualization. Below is a list of questions where perception may contribute to an answer. For some questions some hints are included.
• how can we adjust rendering calculations to make the images more realistic?
• how can we present information and data in a way that make patterns in the data easier to detect?
Healey et al. [1996, 1998, 1999, 2002] discuss these questions.

• how can we avoid mistakes in the human understanding of an image?
Figure 1 gives an example of a possible misunderstanding.
• how can we emphasize the important parts of an image and how can we suppress the less important parts?
• how can we adjust the presentation/image to be more pleasing to the user?
• how can we avoid bad colour choices and colour combinations in images and presentations?
• how can we in scientific visualization find a good mapping between data dimensions and visual dimensions?
• how can we adjust our algorithms to avoid making unnecessary calculations of features that the human visual system will not perceive?
• how can limitations in hardware be taken care of?
Antialiasing and tone mapping are used here.

3 Application domain

The application and the task that you are working with apparently influence the visual features that should be used. Low level tasks include target detection, boundary detection, counting and estimation. High level tasks include modeling, image presentation, scientific visualization and computer graphics.

Application oriented issues include:
• modeling: how can you help the user to see the patterns needed to reveal the 3D structure and the relations between objects in the 3D environment?
• image presentation: how much can we manipulate a picture and still comprehend the picture as being identical to the original?
• data visualization: how can you help the user to recognize or detect patterns, outstanding objects etc?
• human computer interaction: what role does the graphical presentation have for interaction?
• compression: how much can we remove and still comprehend what we need?

Different categories of researchers and practitioners are interested in perceptual aspects of pictures - they use different methods to find out about knowledge related to images. Healey and Enns [2002] discuss common features for visualizations and professional artistic paintings showing in an experiment that people judge some kind of visualization pictures as comparable to patintings. Non photorealistic rendering relies on artistic values for the quality.
[Horton 95] gives a list of possible blunders by designers. The possible blunders may deal with for instance cultural differences, i.e. we interpret images differently depending on our background related to gestures, icons and colour. Other examples deal with resolution and integrated organization of text and images.
Artists use different effects to enforce impressions and to transfer information to the viewer (user). For instance the Egypts drew important persons bigger than the unimportant ones.

Categories of researchers/users that are interested in perceptual aspects of images include:
• perception researchers using psychophysical methods
• neuroscientist
• artificial network researchers
• vision researchers
• graphics and visualization researchers
• graphics designers
• artists
• photographers

4 The human visual system

The eye is the registrating part of the visual system and it is therefore important to have some fundamental knowledge about the eye. Here we will point out some pertinent properties of the eye that may be used in graphics/visualization systems.
The resolution of the eye is often measured in cycles per degree (c/deg) and is dependent on contrast but has a limit of about 60 c/deg, when it drops to zero [Reddy 2001]. For special objects the resolution may however be somewhat better. Hyperacuity makes it possible for us to perceive certain stimuli that are 10 times smaller than the size of the cones. The reason for the extra resolution is probably due to differences between integration of signals from many receptors in the eye.

There are two different kinds of photoreceptors in the eye, i.e. the cones (located mainly in the neighborhood of the fovea) and the rods located outside the fovea. The rods have a spectral sensitivity maximum at 500 nm, while the cones are of three kinds with different maxima, 450 nm ("blue" or S for short wave length), 525 nm ("green" or M for medium wave length) and 555 nm ("red" or L for long wave length). There are approximately 120 million rods, and 6 million cones. The 120 million receptors transmit their signals to layers of cells in the retina that can e.g. perform primitive detection of circular areas based on illumination as well as movements.
The S cones seems to be a little different from the M and L cones [Mollon 2000]. The S cones are more rare, only 8% of the cones are of S type. The S cones also combine their signals through a special cell (bipolar cell) with 2-3 cones for each bipolar cell, which means that the S signals yield a poor spatial resolution.
The last cell layer in the eye consist of the ganglion cells delivering their signals to the optical nerve containing about one million fibers. The optical nerve from the two eyes then cross each other before entering the visual cortex of the brain.

It should be observed that some people have deficiency in detecting differences between red and green. There is a relation between this deficiency and a property of the x cromosone. As a result of this more men (approximately 8%) than women (approximately 0.4%) have problems to detect pattern variations in red/green. Stilling [1877] was the first person to design pseudoisochromatic plates for detecting colour deficiency where the dots in the pattern randomly vary in size and lightness. These test pictures are similar to the way fruit and berries appear in nature. Mammals might actually have developed colour vision to detect fruit and berries in nature [Mollon 2000].

The signals from the three cone types are combined to three new types before they are sent through the optic nerve. Red (L) and green (M) are combined to luminance, red and green are combined to a ratio between those two colours and finally blue (S) and luminance are combined to a ratio between yellow and blue. The luminance signal is used later in the visual system for detecting edges etc which means that borders using only blue are hard to detect clearly. A problem with the yellow-blue signal is also that the number of blue cones are scarce in the central fovea making it hard to detect fine details in blue.

An important aspect of how we use the human visual system is the focus of the attention, which can be bottom-up/stimulus driven or top-down/goal directed.
The bottom-up features are also called preattentive features and are processed in parallel in the visual system in only about 200 ms. The top-down features usually include a linear search through the data which may make this feature substantially more time consuming and dependent of the number of data items. It should be observed that the visual system often cannot integrate multiple features preattentively and that the preattentive features may be dependent of the focus and interest of the observer. The preattentive features includes colour, shape, direction, texture etc. However also some more high-level features may be processed preattentively as for instance three-dimensional shape and orientation.

Research indicates that processing of visual information in the brain takes place in at least three different "pathways" [Rheingans, Landreth 95]:
• "blob-thin-stripe-V4", processes spatial distribution of colours
• "parvo-interblob-pale-stripe-V4", processes high-resolution shape information
• "magno-4B-thick-stripe", processes movement and stereoscopic depth.
This indicates for instance that continuous presentations are quite different from discrete presentations. Continuous presentations make the viewer focus on global aspects while discrete presentations make the viewer focus on shape details.

5 Investigation methods

Investigation methods for the use of images include methods from different fields. We discuss a few of these methods here and use colour as an example.
Colour is usually the single most important surface property. Colour can be categorized in different ways. [McCann 2000] discusses four different levels:

Problem	Discipline	Model
scene	physics	colourimetry
appearance	psychophysics	sensation
recognition	AI	perception
aesthetics	fine arts	visualization

The first category models the response of the cones and rods at the retina of the eye and has physics as a base for the building of the concepts. The second category models responses but at the same time taking into account the human perceptual response. This discipline is called psychophysics and has a focus on how colours appear. The third category models the recognition of colour. It is related to our earlier experience. The forth category models emotion and is related to what artists and designers are doing.

Methods for evaluation of perceptual efficiency/quality often rely on some image quality metric. The construction of these metrics depend on what information the images are intended to communicate. An overview of image quality metrics is given in [Chalmers et al. 2000].

Most image metrics deal with low level features oriented towards photorealism. In [Shacked and Kischinski 2001] six "target" terms are given to control the quality of the image. The last of these terms is regarded as optional. It constraints the light coming from above and is as a matter of fact important for the interpretation of the shape, which can be seen in the examples in the paper.

Different kind of measures have been developed:
• comparison of actual photo and computer generated image
• comparison between several images such as in an iterative sequence of synthetic generated images
• user evaluation of the image
• evaluation of several images (gallery)
• some kind of expert evaluation of the image, by an artist, a designer, an application oriented person or some other person.

6 High level features

Our vision can be divided into different levels of perception. Low level perception deals with for instance how small details we can actually see (usually related to features computed in the eye). High level perception deals more with our understanding of the concepts in the scenes presented to us (usually related to features computed in the visual cortex of the brain). High level concepts use our experience of how the world usually is built and presented to us. Examples of properties that the human may use:
• rooms usually have 90 degree corners
• light comes from above
• objects of limited size are usually observed from above (the Ecker cube is often resolved using this observation similar to the example in the beginning of this paper).

There is sometimes an interaction between low level features and high level features. Goldstone [1995] showed that shape categories of objects influenced the perceived colour of an object.

The interpretation also depends on the experience of the viewer. An architect may use his knowledge to interpret drawings in a better way than an ordinary novice.

May [2000] gives some background to high level perception in relation to computer graphics. We should be aware how the viewer understands the concepts in the scene. Walker et al [1994] give an example:the emotion in a facial expression presented at the screen may influence the answers of a questionnaire.

One part of high level visual perception was formulated by Gestalt psychologists more than 100 years ago. They use concepts for visual perception such as proximity, similarity, continuity, closure, figure ground etcetera
The Gestalt laws are usually used for geometrical objects but may also be used for object attributes such as colours with a particular hue, saturation or lightness.

7 Cue theory

Already in the 1700s cues for perception of 3D were developed [Wanger et al. 1992]. Those cues were divided into primary cues, such as convergence and binocular disparity, and into pictorial cues, such as perspective, texture, shading, shadowing and motion. In addition to this, reference pictures (match boxes etc) are also important for determining size and distance.

Visual variables have been discussed by for instance Bertin [1983]. Those variables include things such as shape, size, orientation, intensity, colour and texture. Other visual variables are elevation, shadows, projection, motion, shape, and depth

Combination of features in images is used by humans to interprete the image and extract properties. In vision research this problem is usually referred to as the cue combination problem.
A study made by Wanger et al. [1992] performed three experiments studying the six cues: elevation, object texture, ground texture, shadow, projection and motion. The three experiments were set up for three different tasks, i.e. positioning, rotation and scaling respectively.
It turned out that a substantial positive effect for positioning was given by the cues shadow and perspective. For orientation some positive effect was given by motion and a substantial negative effect was given by perspective projection. For scaling (size) a substantial effect was give by shadow and some effect was given by motion. A negative effect for scaling was given by elevation.

8 Colour

Colour is one of the most important features in a visual presentation.

Perceived size and depth depend on the colour of the object:
• the perceived size of an object is influenced by its colour [Rheingans, Landreth 95]
• the perceived depth of an object is influenced by its colour [Rheingans, Landreth 95]
Experiments show that object appears larger/closer according to:
`green - blue - yellow - orange - red`
where red is largest and closest.
Part of the explanation may be due to different refraction of the different wave lengths of the light in the eye. Experimental results also indicates that the effects are diminished by decreasing saturation.

The perceived colour of an object is influenced by the colour of the surroundings referred to as colour interaction, colour induction, or colour assimilation.

Healey et al. [1999] discuss three features important for fast and preattentive detection of targets in a display. The features are colour distance, linear separation and colour category. We discuss them in u*v*-space (designed to be approximately perceptual uniform):
• perceived colour distance, DE* = sqrt((DL*)2 + (Du*)2 + (Dv*)2)
where D is delta (difference) and L* is luminance
• linear separation regards whether the target can be separated from the non-targets by a line in the u*v*-space.
• colour category specifies the categories such as blue, purple and red.

There are two categories of colour coding, nominal coding and ordinal coding.
The nominal coding use colours that are not intended to be ordered in any way. They are only used for identification. Usually a number of five to seven colours are suitable for error free identification.
Ordinal coding use an ordered sequence of colours, which we here call colour scales. Colour hues are not naturally sorted in the same way as lightness and saturation. Nevertheless there are examples of natural colour scales. The hues of the rainbow constitute the spectrum colour scale. A heated radiating body generate subsequent colours as the temperature increase, which constitute the heated-object colour scale (black - red - yellow - white - blue). Other scales are intensity scale and colour saturation scale, where lightness or saturation are varied along the scale.
[Levkowitz and Herman 1992] and [Rogowitz and Treinich 2003] has investigated colour scales.
The rainbow scale may give artifacts such as perceived contours without any discrete transition in the data whereas other transitions may be hard to detect and colours with a high lightness such as yellow may attract attention which is not intended.

There are many possibilities to combine the basic colour scales. Those combinations may be used either to reinforce the same information and hence make it easier for the observer to perceive or to increase the information content of the presentation. Below we give a list of possible combinations. Many of these combinations have been used for a long time in disciplines like geographical maps.
• an elevation map of a region showing heights with shadows can be combined with a usual colour scale showing some non elevation variable.
• double ended colour scales (e.g. based on a scale with intervals of interesting values, uninteresting values, interesting values)
• striped colour scales, discussed in [Rheingans, Landreth 95]
• multiple scales (using several of the parameters above, e.g. both intensity and saturation at the same time), e.g. Levkowitz's optimal colour scale using brightness+hue is linearlized in just noticeable differences [Levkowitz 92].
Further colour scales are discussed in [Rheingans, Landreth 95] and [Ware 98].

9 Texture

Texture is one important feature to visualize a surface. Textures have been studied by researchers in computer graphics, computer vision and cognitive psychology. Sometimes the term pexel is used for perceptual texture to emphasize the perceptual aspects of textures.
Textures can be categorized by several dimensions. Examples of such dimensions are orientation, size, density, contrast, regularity and complexity. Some of these dimensions may be related. For instance we may have
size = constant/density. Density and height are used as separate variables in a study by [Healey et al. 99]. Both variables are detected preattentively.

Ware and Knight [92] discussed the OSC texture space with the purpose of using a three dimensional space for texture properties in similar way as HSV or RGB is used for colour. The three variables for texture would include orientation (O), size (S) and contrast (C). Texture(x,y) is a function with three values:
• orientation (O), the angle of the texture at (x,y) given in the range (0,p)
• size (S), the width of the texture at (x,y). It is the inverse of the density. It can also be described as 1/frequency.
• contrast (C), amplitude of intensity
The authors performed experiments to determine a uniform texture space.

10 Shading

Atherton and Caporael [1985] made a study of judgments by 30 participants. The subjects evaluated spheres rendered with different shading techniques (flat shading, Gouraud shading and Phong shading) and with different number of polygons. The result show just a minor difference between Gouraud shading and Phong shading for the task given to the participants.
Another similar study was set up by Barfield et al. [1988]. The participants were asked to decide whether two objects with different orientations had the same shape.

More advanced computer graphics techniques such as the radiosity methods have been compared in experiments intended to reveal if there is a difference between a radiosity image and a photograph [Meyer et al. 1986]. They used very simple scenes with block like objects. The subjects were unable to distinguish between the radiosity image and the photograph.

New algorithms use the knowledge of perception in order to improve the quality of the images, to prevent calculating things that are invisible and to determine what is most important to calculate if the resources are limited. Prevention of unnessesary calculations may use limitations in frequency, intensity and contrast in the human visual system. A survey is given by McNamara [1999].

11 Levels of realism

Ferwerda [2003] has given three levels of realism in computer graphics:
• physical realism (physical signal is correct)
• photo-realism (physical respons is correct)
• functional realism (the same information is given)

There are more possible levels or categories of realism in computer graphics. A categorization can be made with a point of departure in the different features discussed earlier in this paper. Such categories could include 3D realism, surface (texture) realism, colour realism and illumination realism.

A categorization can also be based on the experience or feelings of the user (viewer). Such experiences could be characterized by the level of e.g. presence, excitement, comfort, recognition and detection.

12 Recommendations and guidelines

Below we give a few examples of advice regarding good pictures in computer graphics and visualization. Guidelines are not always true in the specific case. Sometimes they have to be broken. Guidelines in a limited application as for instance diagram drawing can be more precise while guidelines for images where specific content has not been given is more general. Sources for compiling guidelines include [MacDonald 1999], [Foley et al. 1990] and [Tufte 2001].

Examples of general guidelines for visualization of data:
• have a properly chosen format and design
• use words, numbers, and drawings together
• display an accessible complexity of detail
• often have a narrative quality, a story to tell about the data
• avoid content-free decoration, including chartjunk

Examples of more specific guidelines, here on the use of colours:
• be restrictive in the use of colours. There are many possible mistakes so it might be better to avoid colour if it is not necessary to for the application.
• many people (in the order of 8% of the male population and 0.5% of the female population) have deficient colour perception. Use redundancy for information encoding and presentation.
• equipment will display colours differently dependent of display and printer technology - some kinds of equipment are black and white. Use redundancy for information encoding and presentation.
• the eye and the brain needs intensity differences to distinguish edges. This means that colour hue differences should not be used as the only way of presenting edges. Use intensity differences, saturation differences and/or border lines.
• strong colours, i.e. colours with high saturation, may give afterimages if they are viewed for longer time interval. This means that images with high saturation colours should be avoided for many applications. They can be used to grab attention though.
• perceived hue and intensity are influenced by surrounding coloured areas. This effect can be corrected by adjusting the colours to compensate for this effect (which is hard). It is also possible to use surrounding colours with less saturation.
• colours don't have a natural order from a perceptual point of view. Intensity and saturation have a more natural order. This means that colour scales with only hue differences should be avoided if an ordered relation is presented. Hue differences are better for classification.

13 Conclusions

There are many challenges for computer graphics in the future. Researchers will strive for creating better pictures. An important aspect is to determine if the features created can be seen or are necessary for the viewer. This will require knowledge of perception and related areas.

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