Abstract

This paper describes some visual phenomena of human perception in the context of computer based illustration. Some of these phenomena of the human visual system will be used to introduce an illustrative rendering style for three-dimensional line drawings with enhanced depth cuing to visualize spatial properties of three-dimensional objects. The additional purpose of this paper is to inspire the study of human perception more deeply to derive new non-photorealistic rendering methods that can enhance the visualization of complex spatial concepts and its three-dimensional characteristics.

Keywords: Perception, Non-Photorealistic Rendering, Illustration, Depth Cuing.

1. Introduction and Motivation

After the success in creating photorealistic computer images – a scientific field that had inspired and motivated scientists for many decades – recent developments in the field of non-photorealistic rendering (NPR) methods have created a wide interest in the simulation of traditional drawing, sketching and painting methods used by artists or technical illustrators with their skilled hands and eyes to generate visualizations of three-dimensional objects. Although there have been made attempts like in [STRO02] to categorize these new rendering styles into sub-fields the main term “non-photorealistic” indicates only a lack of theory and application of these rendering methods as just being described as an oppositional term. However, some techniques that have been used mostly for technical or scientific illustrations demonstrate a principle advantage over photorealistic techniques. The main ideas of these NPR methods are to emphasize certain shape or material characteristics that are important to explain certain properties of an object.

Additionally the emerging availability of commercial NPR, mostly marketed as cartoon shaders, shows the need for more illustrative rendering techniques for example in the field of architectural design. This was an interesting discovery, as photorealistic rendering methods are widely used in architectural visualizations by commercial programs on the market. Traditionally architectural renderings are created after some design of a building has been finished and the three-dimensional model has been exported from a CAAD program into a three-dimensional visualization package. At this stage the design of the building is already completed and photorealistic renderings of the modelled shapes can be created using libraries of pre-defined materials and light-sources. But usually in the early phases of design either sketches done by hand or very simple rendering techniques are used. One reason for this is that in early design stages the use of materials and even more the placement of light sources is not decided yet. Furthermore also the pure formal design of the shape of a building should also possess a style of visualization that characterizes this stage of intermediate design, where several design characteristics are not fully decided yet.

2. Some Phenomena of Human Perception

One fundamental fact of understanding visual phenomena of the human vision system is that our perception of how we “see” objects is not only determined by the light rays that reach our eyes, furthermore three-dimensional objects are constructed in our brains by performing some additional neural processing. Although the entire process of human perception is not yet fully understood, there exists a wide range of optical phenomena and experimental situations that create stimuli to our visual systems with possible different interpretations when perceived by the human visual system. This creates one
different approach in scientifically measuring the quality of NPR methods in comparison to the photorealistic methods. As the quality of photorealistic methods can be somehow measured with appropriate well defined experimental settings and comparing measured results of light parameters to similar virtual settings, other methods have to be chosen by evaluating NPR algorithms. The methods of evaluation for NPR systems can be partly derived from social sciences, by doing user surveys or asking expert users, but if NPR systems are used for artistic purposes – scientific evaluation becomes a very difficult task.

The approach of this paper will study first some of the visual phenomena of the human vision system, especially focused on three-dimensional perception of space, together with the application for architectural illustrations but with a broader and general usage in mind. Furthermore a computer based illustration method, which makes use of some of these visual phenomena, will be presented.

2.1 Ambiguous Three-Dimensional Objects

2.1.1 The Necker Cube

A very famous example of an ambiguous three-dimensional object is the Necker Cube, named after the Swiss naturalist Louis Albert Necker, who published this famous figure in 1832.

![Figure 1: Necker Cube](image)

This figure, although it appears flat is an ambiguous representation of two possible cubes, one with the vertex A in front and another one with the vertex B in front, let us call them cube A and cube B. Actually the human vision system is able to see both cubes, sometimes cube A, sometimes cube B, sometimes flipping between both cubes. A more detailed explanation of this phenomenon can be found in [HOFF98].

2.1.2 The Kopfermann Cubes

Another interesting example of ambiguous figures are the Kopfermann Cubes, named after the psychologist Hertha Kopfermann, who discovered 1930 that it can be difficult sometimes to construct three-dimensional objects from line drawings.

![Figure 2: Kopfermann Cubes and Necker Cube (middle)](image)

In the figure above, the left and the right drawings are the cubes of Kopfermann, which can be compared to the Necker Cube, situated in the middle. Although it is obvious that both Kopfermann Cubes are possible projections of cubes, they usually appear as flat figures and it takes considerable more time and effort to view them as cubes in comparison to the Necker Cube.
Donald D. Hoffmann [HOFF98] describes several visual rules that are used to construct a three-dimensional object.

**RULE1:** Always interpret a straight line in an image as a straight line in 3D.

**RULE2:** If the tips of two lines coincide in an image, then always interpret them as coinciding in 3D.

If the two visual rules are applied to the drawings above, a reasonable explanation can be found why the left drawing is difficult to view as a cube, while the right drawing allows an easy construction of a three-dimensional object. Additional visual rules together with more examples how the human visual system constructs objects can be found in [HOFF98].

### 2.2 Two-Dimensional Objects creating Perception of Depth

The following section will describe some visual phenomena of two-dimensional objects that will create a certain impression of depth associated with them. These examples were used in a work about graphic design [3] that focuses also on visual perception.

#### 2.2.1 Depth through Brightness

On the figure above the rectangle with the darker shade of grey appears to be nearer to the observer. This effect can be inverted by using a black background, as demonstrated below.
Although the shades of grey are the same, the perception of depth is changed on a black background, now the lighter rectangle seems to be nearer to the observer.

![Figure 6: the brighter rectangle in front of the darker one](image)

If the black background is used and the lighter rectangle is drawn above the darker rectangle, partly overlapping it, the relationship between the rectangles indicates a quite large distance in depth between these rectangles.

![Figure 7: the darker rectangle in front of the brighter one](image)

If the shades of grey are swapped between the two rectangles, so that the darker rectangle is overlapping the lighter one, the impression of a much shorter distance between these rectangles appears.

### 2.2.2 Depth through Colour

A similar effect can be experienced if different hue values are chosen, hereby it seems that the so called warm colours appear nearer than the so called cold hue values.

![Figure 8: rectangle with cold (blue) and warm (orange) colour](image)
The rectangle drawn with the warmer colour (orange) appears to be nearer than the rectangle with the colder colour (blue).

![Figure 9: the orange rectangle in front of the blue one](image)

If the orange rectangle is drawn in front of the blue one, the perceived distance in depth appears rather large.

![Figure 10: the blue rectangle in front of the orange one](image)

If the colour of the rectangles is swapped, the blue rectangle now appears much closer to the orange rectangle in the back.

2.2.3 Depth through Occlusion

As already indicated in the chapters before, occlusion is an essential indicator of correct depth perception. As this is a well-known fact, it is not necessary to give further explanations. Although the correct order of graphical elements that visualize a three-dimensional object is a necessary requirement, the perception of depth cannot be derived from the order of these elements alone.

![Figure 11: occlusion between rectangles](image)
2.2.4 Depth through Scale

Objects with different scale also indicate a depth relationship between them, where larger objects indicate a shorter distance than smaller objects.

![Figure 12: rectangles with different size indicate depth](image)

Although these rectangles do not overlap the decreasing scale of objects indicates an increase in distance to the observer. Of course the perspective distortion of three-dimensional objects can be also considered to be done with scaling operations.

2.2.5 Depth through Object Blur

An optical effect also known from photographic images is the depth-blur effect that usually puts the object in front into sharp focus, while displaying objects with increasing distance with an increasing amount of blurriness.

![Figure 13: rectangles blurred with different amount to indicate depth](image)

3. Perception based Illustrations

In this section several methods of enhancing the three-dimensional illustrative display of objects will be demonstrated. Hereby the focus of the presented rendering method was to display the complete object as a three-dimensional volume, also revealing inner or hidden structures. At most of the traditional rendering methods, hidden surfaces are removed to create a more realistic appearance of the shape. The complete shape, displaying also hidden parts can only be perceived as a wire-frame drawing, drawn usually with a very simple line representation, that will very often create an image that is difficult to analyse visually. This paper will present several depth cuing methods to enhance point and line representations of three-dimensional objects.

The reference object for the following example is an “oiltank” object – a cylinder with spherical upper and lower parts.
The point and line illustrations have been implemented as an export plugin for the software Cinema 4D. Thereby the rendering is done in 2D vector format as a SVG file [EISE02].

3.1 Depth Cuing by Scaling

Hereby the graphical element (point or line) that is used to draw a three-dimensional object is scaled according to the distance to the observer. The same depth cuing approach together with several other methods to enhance line drawings of objects is described in [STRO02].
The scaling of points implies that they have to be rendered as 2D-disks with varying radii according to the depth.

Lines are scaled with changing width according to the distance to the observer, hereby the line-width for the starting point and the end point are calculated separately resulting in a 4 point 2d-polygon. For visual enhancement also circular line-caps are rendered. Although scaling generates a better perception of depth, visual dense areas might be difficult to interpret.

### 3.2 Depth Cuing by Brightness

Hereby the Brightness of a point or line is calculated according to the distance to the observer as a scaling factor for the RGB-colour of the objects material.
In the line-rendering implementation, lines are drawn as polygons using a directed gradient fill in the direction of the line-vector, whereby the starting and end colour is calculated at the corresponding points of the line. This method enhances the depth perception quite well and allows a good visualization of the spatial structure. Changing of the brightness is an already well-known depth cuing method, as described for example in [FOLE92].

### 3.3 Depth Cuing by Blurring

With this depth-cuing method a blur-factor (standard deviation for Gaussian blur) is calculated according to the observers distance. The implementation was done with a post processing filter as described in the SVG definition [EISE02].
For the line-rendering method a constant blur factor for the line was chosen, averaging the calculated values for the end points.

Depth blurring without any additional visual enhancements can lead to misleading interpretations. As the human eye is able to focus at different distances also objects that are nearer than other objects can be blurred more. Especially at small or thin objects – as it is the case with points and lines – the blurring of these graphical entities leads to the display of larger graphical elements that might introduce the opposite visual clue – as larger objects should be nearer than smaller ones.

### 3.4 Combination of Visual Effects

In this section all three depth cuing methods have been combined to test if better visual results can be achieved.
If the scaling of graphical elements is combined with the change of brightness, very strong depth perception can be realised, by leading the focus of attention to elements near the observer, whereby distant elements can be perceived at the same time.
The combination of scaling and blurring does not create the contradictory effects as using blurring alone, especially when the increase of size due to scaling is larger than the increase due to blurring, although the depth perception is much weaker than at the combination of scaling and change of brightness.

Figure 26: depth by change of brightness and blur amount

Combining change of brightness and depth blurring creates quite acceptable depth perception, which might be considered better than by the combination of scaling and blurring, but still lacks the visual quality of combining scaling with change of brightness.

Figure 27: depth by change of brightness and blur amount

Figure 28: depth by change of size, brightness and blur amount
If all three effects are combined good depth perception can be achieved, although it might be difficult to perceive distant graphical elements.

4. Conclusion

Several methods of visual enhancements for three-dimensional illustrative rendering methods have been introduced. These include the effect of scaling, change of brightness and blurring of graphical elements as depth cuing methods, which are calculated in dependence of the distance to the observer. Also combinations of these singular methods have been evaluated. These visual experiments have been tested and discussed with user groups mainly from architecture, more extensive testing should be performed also with other users. The possible use might be to apply perception based illustration methods in three-dimensional design tasks in replacement of traditional wire-frame display methods. Furthermore they can be used as a separate stylistic illustration method. Future research will try to use these algorithms in combination with contour rendering and other abstraction methods.

There is still a need for more sophisticated computer based illustration and visualisation systems, which can be used for enhancing the display of shape characteristics as well as visualizing complex spatial concepts. Furthermore the process of design requires several conceptual and abstract visualization methods that also include ambiguity, uncertainty and incompleteness of visual properties of objects in an intermediate state of design.
The three-dimensional model of the Colosseum was taken from [DEES02].

5. References

[DEES02] DeEspona. 500 3D Objects. Taschen GmbH 2002