Interactive Inverted Perspective Rendering for Architectural Visualization

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Abstract: Inverted perspective is an illusion of depth perception characterized by the inversion of depth cues in the scene. Distant parts of the scene are shown larger and nearer parts shown smaller than they would appear in linear perspective to achieve the illusion. In this paper, we present a method to achieve this illusion in real-time for interactive applications. We also present a 3D modelling environment for conceptual design which makes use of this display method. Apart from the artistic and perceptual applications of inverted perspective rendering, our method is also very useful for creating an active viewport scene for 3D modelling of solid models with boundaries and complex interior structures. Effective and legible visualization of complex conceptual objects with different kind of layered structures is an important topic for design research. Our method also enables the user to easily create non-photorealistic renderings to understand both the interior and exterior structure of a spatial model from a single image.

1 INTRODUCTION

In this paper we present a three-dimensional polygonal modelling package that includes the ability to create inverted perspective renderings in real-time. Inverted perspective transforms the conventional understanding of digital space perception as well as adding another mode to space and boundary relationship from the user/designer's viewpoint. Our program provides an interactive viewer which can display an object using normal perspective as well as inverted perspective. The interactive nature of the viewer allows the user to pan and rotate the scene, greatly enhancing the effect of inverted perspective.

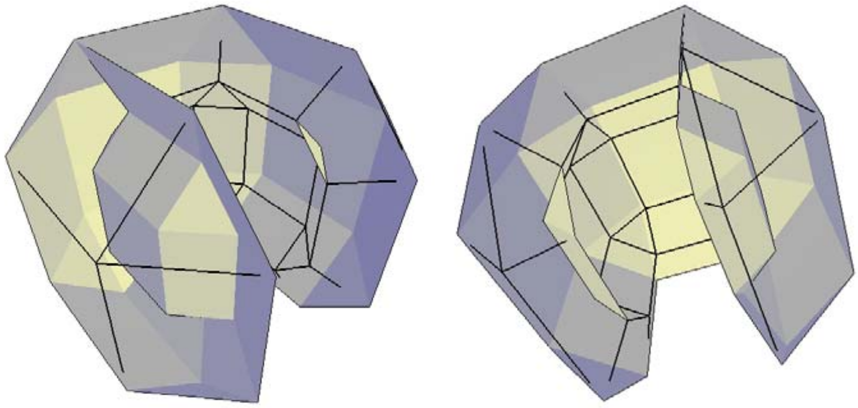

Figure 1 Two views of an inverted perspective rendering of a conceptual model

Building on the inverted perspective rendering method, we have also developed a new non-photorealistic display technique that can help the user visualize the interior structure and the external shape of an object simultaneously. Figure 1 shows two views of a conceptual model rendered using this new technique. We also introduce a new modelling approach, based on this non-photorealistic display technique that greatly simplifies the modelling of complex interior components.

2 BACKGROUND

In the real world, humans perceive distant objects as being smaller than objects which are closer. This characteristic of our visual experience is made use of in conventional two-dimensional artwork, when the artist wants to convey the three-dimensionality of objects or the scene. By manipulating the relative size and angle at which objects are drawn, the artist gives "depth" to the painting or sketch, adding a sense of realism to the artwork. This type of illustration is commonly referred to as linear perspective illustration.

Inverted perspective is an illusion of depth perception where the usual depth cues are reversed. In this perspective, distant parts of the scene are shown larger while nearer parts are shown smaller (Cook et al. 2002). A static two-dimensional image doesn't always convey the inverted perspective effect – we simply interpret the visual cues in a natural way and assume that smaller objects are far away and the larger ones are closer. However, if the viewer knows the relative positions of objects in the scene through other means, then even the static two-dimensional image achieves the illusory effect and at times confuses the viewer because the image is contrary to what the viewer expects to see. Inverted perspective also uses a linear projection but with a different centre of projection. To avoid confusion we will use the term "normal perspective" to refer to the normal linear perspective.

The effect of inverted perspective illustration becomes more pronounced when the viewer moves in front of the scene (Cook et al. 2002). Conversely, if the scene moves in front of a static viewer, the same effect is achieved. The changing angle of view causes the scene to change in a way that is contrary to what the viewer expects based on the depth cues present in the scene.

Artists have explored inverted perspective as far back as the 16th century. A prominent example from the Renaissance period is Dürer’s *Adoration of the Trinity*. More recent examples include the artwork of Patrick Hughes, who has focused on producing objects in a manner referred to as “reverse perspective” or “reverspective” (Wade and Hughes 1999, Slyce 1998).

Several theories have been proposed to explain the motivation and the reasoning behind such illustrations (Cook et al. 2002; Papathomas 2002; Cook, Neumann and Brugger 2003). In recent years, the phenomenon of inverted perspective has received increased attention from perceptual psychologists. Goodman was of the view that in some situations inverse perspective actually conveys more information that linear perspective (Goodman 1976). Arnheim had a similar viewpoint and noted that “the wish to combine frontality with a display of the side-faces favours the use of divergent shapes” (Arnheim 1972).

From an architectural point of view, the design process has many dimensions in cognition and perception but it is bounded to graphic representation. From renaissance to the digital age perspective projection principles have been widely used by architects. When we rethink perspective it is inevitable for an architect to analyze the proportional relations between space boundaries and objects, from the user’s or designer’s eye.

With the advent of computers, the ideas of perception and representation have undergone significant changes. The mathematical concepts of the perceptional illusion have made the production of complex perspectives possible in a digital medium. The static production approach is to imitate the natural phenomena of perception and physical concepts of vision. Many modelling packages are capable of producing this kind of perspective images. Although there have been significant advances in ray tracing and rendering, the basic principles of linear perspective projection remain the same.

Digital media has transformed the way architects and artists look at space and its representation. The flexibility of the digital medium has opened up new avenues for creative expression (Koutamanis 2000). Now we have the opportunity to experience the designed space in real time. It is possible to implement various kinds of projection methods to enhance the production and representation of conceptual spaces. Architects have begun to use this flexible medium to represent various kinds of designs, both conventional and non-conventional. With the increased usage of this medium, the need for new digital tools and techniques for advanced representation and design has also increased. Architects are looking at more advanced and non-conventional methods of representation to expand the limits of visualization. Inverted perspective is one such visualization technique, which, we believe, will be a significant addition to digital tools available to the architect.

The work of Vallance and Calder is worth mentioning in this context. They have developed a computer interface to facilitate multi-perspective rendering, which includes the ability to create reverse perspective renderings (Vallance and Calder 2001). However their implementation is too slow for interactive visualization and involves an entire application programming interface. More recently, they have presented a technique for rendering inward looking projections, in which the projections converge to a point in front of the image plane (Vallance and Calder 2003). Their results of their technique, which they call “anti-perspective projection”, are very similar to inverted perspective images. Zorin and Barr presented an approach to reduce perspective distortions in images (Zorin and Barr 1995). Schwartz also discusses computer algorithms for converting distorted perspective into linear perspective and the reverse (Schwartz 1998). The former has applications in remote sensing and imaging, where the need is to convert satellite imagery into a rectilinear format.

In this work, we are primarily interested in being able to create the inverted perspective effect in an interactive medium, namely the computer. We will thus restrict our focus to the implementation aspects and possible applications of inverted perspective display in architectural design and visualization. In the following sections, we describe a method to achieve the inverted perspective effect and its applications in conceptual modelling and visualization.

3 INTERACTIVE INVERTED PERSPECTIVE

We achieve the inverted perspective effect using a very simple computer graphics “trick.” In a typical three-dimensional graphics application, the user is able to see parts of the object that are pointing towards him or her. In terms of the mesh structure that is used to represent the object, this translates to displaying the faces of the mesh that point towards the viewer. Faces that point away from the viewer are not displayed. Naturally the front side of the object obscures or “hides” parts of the object which are behind it, even if they would otherwise be displayed. This makes use of the “depth” of an object in the scene, which is the distance of the object from the viewer. Thus objects which have a larger depth value can be obscured by objects which have smaller depth values. Typically faces which are obscured are not even drawn to reduce processing requirements. This technique is commonly referred to as “hidden surface removal.” Note that the set of faces which point towards the viewer can change as the viewer navigates through the scene or rotates the object. Thus when we refer to the “front” or “back” of the object it is with respect to the current viewpoint.

We achieve the inverted perspective effect by switching the faces of the mesh that are displayed. The faces that are pointing away from the viewer are shown and those that point towards the viewer are not drawn. As a result of this switch, the front side of the object is not visible, since the faces are pointing towards the viewer. More importantly, faces which comprise the back side of the mesh are now visible. Figure 2 illustrates this using a two dimensional cross sectional view.

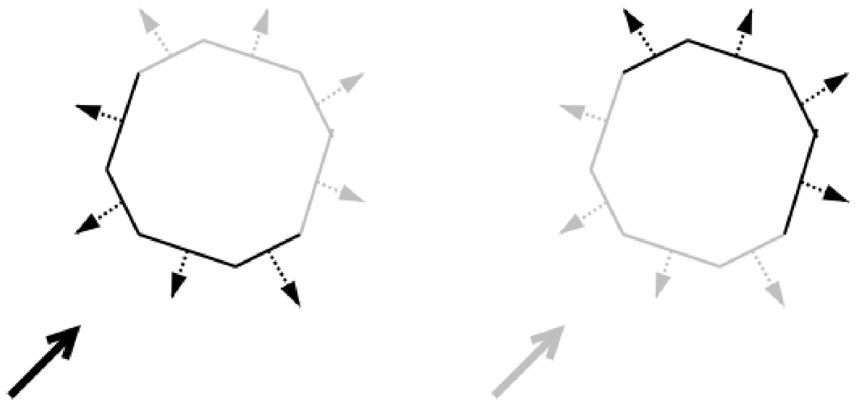

Figure 2 Normal (left) and inverted perspective (right) display modes. The long arrow indicates the viewing direction. Black edges represent faces which are drawn; grey edges represent faces which are not drawn

If the object has an associated texture map, the system flips the texture coordinates in inverted perspective display mode, so that the texture is visually oriented correctly in both modes.

Vallance and Calder use a similar approach to obtain their inward looking projections (Vallance and Calder 2003). In addition to changing the orientation of the faces in the object, they reverse the way the depth value is used and reverse the normals of the faces. The result of these changes produces an image in which we still see only the outer faces, but in an inverted perspective projection. However, for the design and visualization applications which we are exploring, being able to see the back of the object is important, and their technique is not directly applicable.

The inverted perspective rendering of a particular view of an object is obtained by switching the set of visible faces *and* rotating the object (or the scene) so that the user is effectively looking at the object from the opposite side. The user will thus be looking at the same set of faces as in the original view (assuming they are not obscured by other faces in the new view) but from the opposite side. In the absence of additional visual cues, the switch may not be readily apparent. Rotating the scene with respect to the new viewpoint provides the needed additional cues and the inverted perspective effect becomes visibly apparent.

4 INTERACTIVE NON-PHOTOREALISTIC DISPLAY

An important and useful aspect of visualization for conceptual design of complicated structures is the ability to see interior elements of the structure. Although a wireframe representation provides a fully transparent model view, it is not an effective method to understand spatial configuration and boundary structure, since it does not convey depth information effectively. Wireframe representation of models with a large number of faces can become very complicated, making them practically illegible as can be seen in Figure 3. The wireframe rendering is confusing and does not convey the details of the layout effectively.

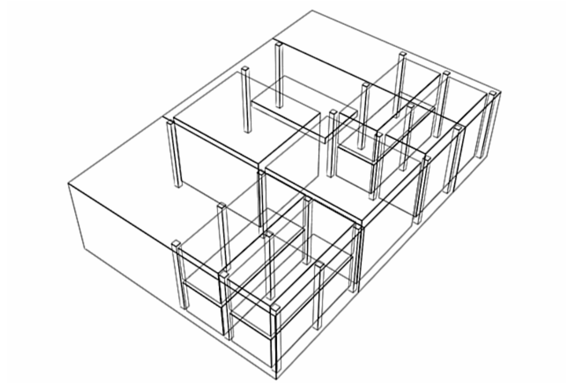

Figure 3 Wireframe rendering of a model

Other display methods which show interior layouts typically move the viewpoint inside the exterior surface. Moreover, one can either view the interior or the exterior in a single image, not both. We introduce a display method to show both the interior and the exterior simultaneously. Our method is based on the transformation used for inverted perspective display described in the previous section and extends the perception of conceptual models to include both the interior and the exterior.

The new rendering technique is an extension to the method used for inverted perspective rendering. In this technique, in addition to switching the set of faces that are displayed, we also draw a wireframe representation of the faces that are otherwise not drawn, namely the faces that point toward the viewer. This has the effect of overlaying a wireframe representation of the front side of the object on top of the visible backward pointing faces. Note that hidden surface removal will still be utilized. Thus if there is a face which is pointing towards the viewer, but which is obscured by other faces it will not be drawn at all.

The switch used for inverted perspective rendering exposes the interior portions of the structure, while the wireframe overlay gives a good idea of the exterior shape of the object without obstructing the interior structure. The flipping of the texture coordinates is also essential to convey the correct idea of the interior layout.

An example of this kind of rendering is shown in Figure 4. The image on the left shows the model in normal perspective mode and the image on the right shows the same model with the new display mode.

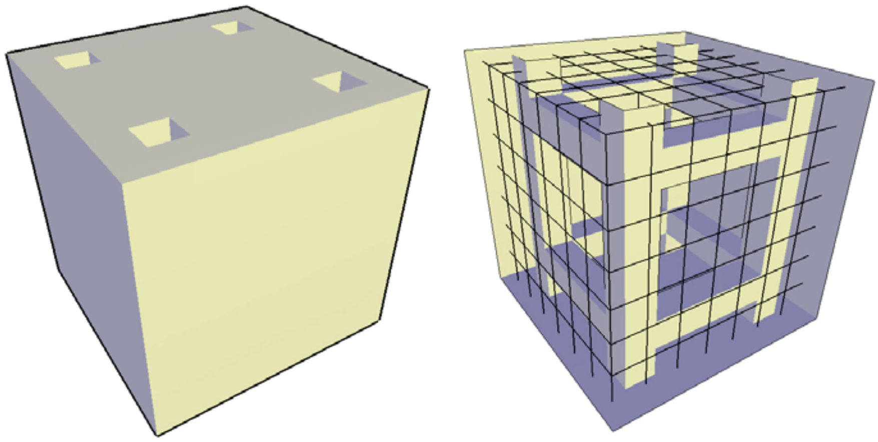

Figure 4 Non-photorealistic rendering (right) which shows the interior layout and the external shape simultaneously

Our method can be easily modified to handle complicated nested structures such as a building layout with interior walls. By suitably reversing the normals of the interior elements, such structures can be interactively viewed as shown in Figure 5. These images help us understand the layout much better than the wireframe rendering of the same object, shown earlier in Figure 3.

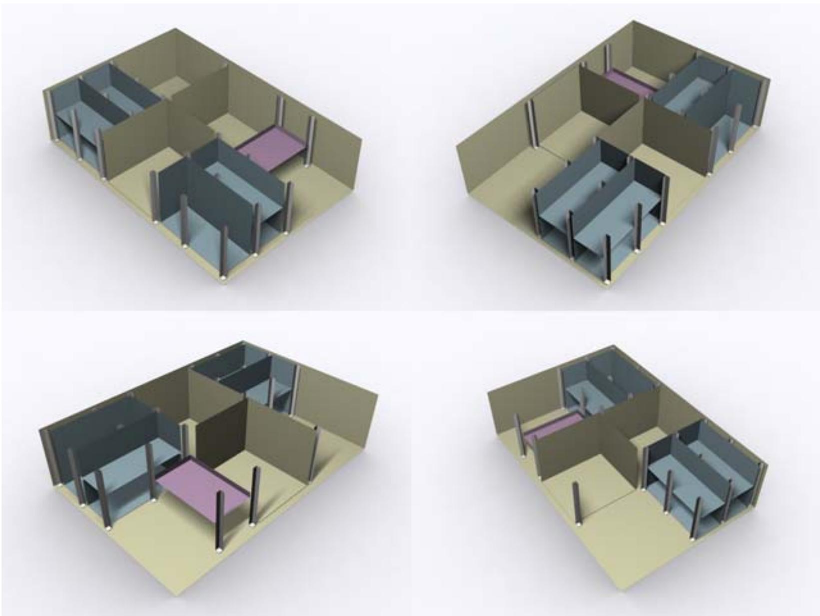

Figure 5 Four views of a model with nested structures

5 THREE-DIMENSIONAL MODELLING

The non-photorealistic rendering method introduced in the previous section also has applications in three-dimensional modelling of complex structures. Recall that the user is able to see the back surface (as regular filled polygons) and the front surface (as a wireframe). By making a slight modification and showing the wireframe for the entire mesh, we can facilitate modelling of structures that require connections between faces in the front surface and faces in the back surface.

It must be emphasized that this display mode is different from the one described in the previous section. Turning on the wireframe for the entire mesh would have been counter-productive for the effect we were trying to achieve earlier. However, the wireframe is essential for being able to select faces, edges and vertices, which are the foundation of all modelling operations.

An example of modelling an interior beam using the new interface is shown in Figure 6. We want to make a connection between the highlighted face in Figure 6A and the face which is exactly opposite to it on the other side. Typically this would require rotating the object and selecting the face on the other side. For complicated models with non-regular meshes or even with regular but dense meshes, selecting the correct face on the other side is not easy. However, using the new display mode, when we rotate the model to the other side, the user can continue to see the face that was selected (Figure 6B). It is now easy to select the correct face to make the connection as shown in Figure 6C. The result is shown in Figure 6D.

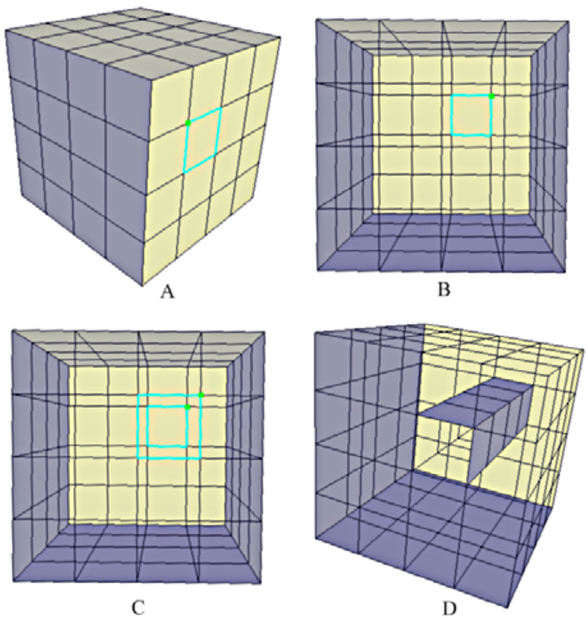

Figure 6 Screen capture of the mesh modelling system illustrating the use of the new display mode for modelling interior structures

6 IMPLEMENTATION

The rendering and modelling approaches described above have been incorporated into the topological mesh modelling system that we have developed. Our system also includes several other features that simplify the modelling of architectural structures with large number of beams, holes, and handles, besides providing basic modelling and interactive rendering capabilities.

The interactive inverted perspective display and the wireframe overlay can be toggled on or off using a single keystroke or mouse-click. The user-interface for these tools is minimal and essentially consists of menu and hotkey toggles for the various display modes and overlays. The mesh modelling system is written in C++ and uses OpenGL and the Fast Light Tool Kit (FLTK) for the graphics and the user-interface respectively.

7 CONCLUSIONS

Inverted perspective is an illustration technique that has been in use for several centuries. We have presented a system which allows the viewer to explore this interesting idea in an interactive manner, thus bringing an age-old idea to the digital age. The interactive nature of our system enhances the illusion of inverted perspective by allowing for relative motion between the viewer and the scene.

Our work on interactive inverted perspective has also led to the development of tools which have applicability in architectural modelling and visualization. One tool allows the user to visualize the interior layout of a structure and the exterior shape simultaneously in a single image. The other tool extends this new display method to simplify the modelling of interior structures with complex components.

Although we have used static images to illustrate the capabilities of our system, our contribution is essentially interactive in nature and is best experienced in real-time using our software. The display techniques presented here can be particularly helpful for virtual environments as well as for digital models of physical architecture.

Our preliminary observations, based on an informal survey amongst a small group of architects and computer scientists, indicate that the inverted perspective visualization, particularly in combination with the non-photorealistic rendering, is effective in the users understanding of the conceptual models. The 3D modelling technique was also found to be effective in modelling objects with fairly complicated interior structures. We plan to conduct a more rigorous survey to validate our observations, particularly with respect to the effectiveness of inverse perspective projection in comparison to normal projection.

Our work has opened up several new ideas for future research and development. It will be interesting to explore how the inverted perspective can be used in a virtual reality environment. By making inverted perspective illustrations easily accessible, our system allows this technique to be used for conducting experiments in perception and cognition, an area of interest to perceptual psychologists. In terms of technical aspects of our system it would be very useful to be able to apply the various display modes to selected surfaces rather than the whole scene.

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