Interactive Color Perspective for 3D Graphics Applications: Enhancing Depth Perception and the Understanding of Object Relations

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Abstract. Perceiving depth and spatial relations between objects in virtual environments is challenging and can be facilitated by the rendering process in 3D graphics applications. Often the perspective projection is not sufficient to visualize all necessary information because the projected image can lead to position and orientation ambiguity. Therefore, additional indicators are needed to improve the visualization of information about spatial relationships and the structure of the scene. For this purpose, we introduce a toolbox that applies color as an interactive design tool. Within this toolbox, six algorithms can be used to dynamically modulate the coloring of single objects or the scene as a whole. For evaluation, we report a study that tested whether object coloring as implemented in the toolbox can change apparent depth.

Keywords: Painting-like rendering, Non-Photorealistic Rendering, Drawing, Real-time Graphics.

1 Introduction

In computer graphics, perspective projection is used to determine spatial depth and the relations between objects, with the goal of providing a correct and natural representation of a scene. However, this projection has considerable shortcomings with regard to its visual appearance. In contrast, in the visual arts there is more to images than projection rules alone: beginning in the Renaissance, artists have developed various techniques to solve the problems associated with projecting a three-dimensional scene onto a two-dimensional surface. However, in order to communicate complex information effectively, other forms of visual abstraction are required. They should assist the viewer in directly perceiving which objects are relevant in the current context and in what relation they stand to other objects in the scene. As an overall goal, images need to be self-explanatory. A central technique is the manipulation of coloring to improve the quality of visualizations by creating depth in an image or directing the viewer to an area of interest. This paper proposes six algorithms that affect the coloring of objects based on the scene configuration and user interaction.

C. Stephanidis (Ed.): Posters, Part I, HCII 2013, CCIS 373, pp. 483–487, 2013.

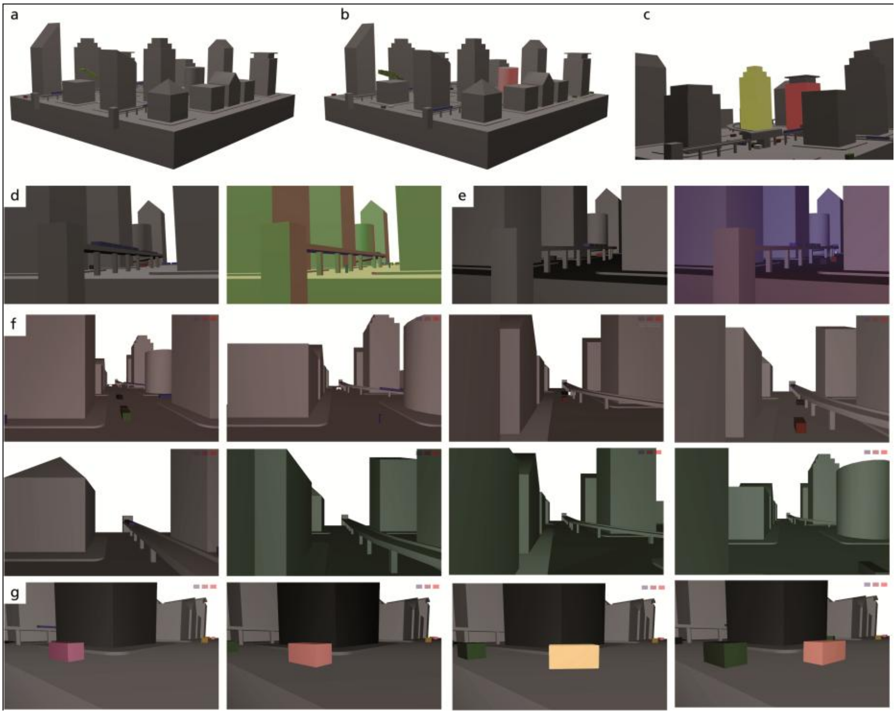

Fig. 1. Visualization results: (a) Reference scene (b) Object Identity (c) Object Interaction (d) Object Orientation (e) Spatial Depth (f) Camera Movement (g) Object Movement

2 Related Work

Two crucial aspects of the visual quality of 3D scenes are their ability to convey depth information and enable the user to understand spatial and semantic relations between scene objects. Humans consistently underestimate spatial distances in virtual environments [7]. Therefore, accurately conveying depth information poses a considerable challenge in 3D computer graphics. Beyond photorealistic imaging, artistic techniques provide other approaches to intensifying the perception of depth in a computer rendered scene [5]. For instance, Meier illustrates in [8] that depth can be implied by varying brush size. Such means for creating a depth impression are tightly coupled to the process of painting itself and thus less straightforward to apply in computer graphics. However, art provides another cue which has a high potential to inform 3D visualizations of depth: color. Until the mid 1990s computer graphics concerned with the depiction of 3D objects had widely neglected color as a depth cue [10]. Shannon argues that virtual reality is situated between science and arts, and promotes algorithmic solutions in the domain of color perspective. Empirical studies have supported the important role of color as a monocular depth cue: When judging the depth of differently colored line drawings [6], textures [3] or even 3D models of realistic objects [1], red objects are perceived to be closer than blue objects. Variations of color can serve other functions in image perception than enhancing the impression of depth. Coconu et al. [2] demonstrate that NPR is particularly efficient in conveying and transmitting selected visual information. Using Non-Photorealistic Rendering (NPR) techniques enables meaningful simplification for efficient stylization of silhouettes and realtime hatching of objects. A very effective use of color and NPR is presented by Mitchell et al. [9]. The presented methods are related to the technical illustration technique in [4] to indicate surface orientation relative to a given light source.

3 Interactive Color Perspective

Our toolbox contains six algorithms, which exploit coloring and shading in a three-dimensional scene. The properties of each algorithm can be characterized according to their global or local implementation, their application for depth perception or object relations, and their dependence on user interaction to trigger dynamic color change. With regard to user interaction, there are algorithms that vary color depending on the way the user navigates through the scene or performs explicit mouse actions. In contrast, other algorithms work independently of the user: the color overlay is fixed or dynamically changes according to the objects' own movements. Our reference scene Minitropolis depicts an abstract model of a virtual city, consisting of various buildings and moving objects like trams, cars, an airplane, and people (see Figure 1a). Despite such abstract models, further application areas are manufacturing engineering and automation or in facility and layout planning.

Object Identity. In some contexts it is necessary to highlight specific objects and distinguish them from other less relevant objects in the scene. For completeness, we provide the obvious facility of applying an individual color overlay for selected scene objects. The color overlay is achieved by adjusting the ambient material color in combination with scene related shading and illumination. Furthermore, the diffuse color component can be adjusted. Lowering the diffuse ratio reduces all lighting and shading effects, which makes it even more easy to visually extract an object from the scene context (see Figure 1b).

Object Interaction. Some tasks require an understanding of the user's actions in relation to objects in the scene. Therefore, the Object Interaction color perspective features four interaction types which can be associated with color-related effects. For instance, approach colors extract objects located on the path the user has chosen to take through the scene, while touch color is used to tag already visited objects. Hence, Object Interaction can be used to depict the navigational path through a virtual scene (see Figure 1c). Clicking arbitrary objects can result in coloring which visually extracts them from the scene context. Further interaction with objects is conceivable and can be color coded as well. For instance, introducing multi-touch interaction with objects might require additional colors. Besides a touch color, the highlighting of an object could change after a dwell time to enable hold gestures that open menus.

Object Movement. Moving objects readily attract the user's attention. However, when several objects are moving concurrently, it can be hard to distinguish relevant objects from others and overcome distraction induced by irrelevant movement. The Object Movement algorithm can be used to visually group scene objects by applying a color overlay. This overlay can be configured with colors for slow and fast movements as determined by a user defined speed threshold. Hence, a change in color emphasizes the change in speed of an object (see Figure 1g). Additionally, defining a color for Object Movement helps to distinguish it from Camera Movement.

Camera Movement. Further disambiguation of scene movement and the users' own movements is achieved by the Camera Movement algorithm. Color overlays can be defined to highlight movements of the camera (which are either induced by the user navigating through the scene or animations triggered by the system). Conversely, in achromatic mode camera movements do not lead to increased coloring but a reduction of colors in the scene by graying out pixels at the border of the screen. The achromatic approach helps to reduce color overload in a scene while still maintaining a specific coloring effect which can guide the user's perception.

Spatial Depth. As outlined before, depth information can be difficult to visually extract from virtual environments and should be emphasized. The Spatial Depth algorithm allows the definition of a differential color overlay for close-up and distant parts of the scene, respectively (see Figure 1e). Depth within the scene is calculated both in absolute and relative terms. Relative scene depth takes the position of objects relative to the camera into account, which results in a dynamic color change as the viewer navigates through the scene. In contrast, absolute scene depth is defined by the user by setting a near and far distance value, depending on the scene context. Such absolute criteria prevent undesired changes in coloring due to position changes.

Object Orientation. Based on the experiences of interior design, color can be used to influence the appearance and mood of a room. Hence, users of 3D scenes should also be able to adjust the atmosphere and impression of virtual rooms. For that purpose, the Object Orientation color algorithm allows a selective manipulation of scene elements depending on their position, visibility and orientation in relation to the camera position. Our Object Orientation algorithm provides the user with the options to configure individual colors for ”walls”, ”ceilings”, ”floors” and ”fronts”. It then calculates the surface colors by analyzing the surface normals in relation to the viewing direction. The resulting effect is that of a consistently color-coded convex space, similar to the illusion of being inside a room.

4 Study

To evaluate the potential of our Spatial Depth algorithm to affect observers' depth perceptions, the present study applied gradual color changes to approaching objects (cp. Figure 1g). If blue makes objects appear to be further away and red makes then seem closer, the application of a congruent color perspective (blue-to-red change) should result in the perception of a faster approach. Twenty-nine participants (13 females) aged 24-55 years (M = 31.9) viewed 58 scenes of approaching spheres with a fixed or distance-dependent color overlay. Eight of them were presented in color perspective (change from blue to red with decreasing distance), eight in inverse color perspective (red to blue) and three times eight in a constant color (red, blue and grey, respectively). After each trial, participants indicated whether they had seen a constant speed, an acceleration or a deceleration. Eighteen trials contained actual speed changes and 40 did not. Only the latter were used in the analyses.

We compared the two types of errors (misperception of acceleration and deceleration) between the five color conditions. Rating frequencies for each participant were subjected to one-way repeated measures analyses of variance (ANOVAs), which revealed an effect of color for both acceleration errors, $F(4, 108) = 36.00$, $p < .001$, and deceleration errors, $F(4, 108) = 29.04$, $p < .001$ (see Figure 12). Participants wrongly perceived an acceleration more often during color perspective trials than in all other conditions (48.7 vs. < 21 %), all $p < .001$, and decelerations were perceived most often for inverse color perspective (33.6 vs. < 13 %). The results indicate that dynamic color overlays can affect speed perception in 3D scenes, presumably via their effect on perceived depth. These results are far from trivial when considering that color is a relatively weak depth cue. The fact that it nevertheless influenced the acceleration ratings clearly demonstrates its usefulness in virtual 3D scenes.

Acknowledgments. The authors received funding by the German Federal Ministry of Education and Research (Project Number: VIP 18).

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