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Perceptual 3D rendering based on principles of analytical cubism ☆

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ABSTRACT

Cubism, pioneered by Pablo Picasso and Georges Braque, was a breakthrough in art, influencing artists to abandon existing traditions. In this paper, we present a novel approach for cubist rendering of 3D synthetic environments. Rather than merely imitating cubist paintings, we apply the main principles of analytical cubism to 3D graphics rendering. In this respect, we develop a new cubist camera providing an extended view, and a perceptually based spatial imprecision technique that keeps the important regions of the scene within a certain area of the output. Additionally, several methods to provide a painterly style are applied. We demonstrate the effectiveness of our extending view method by comparing the visible face counts in the images rendered by the cubist camera model and the traditional perspective camera. Besides, we give an overall discussion of final results and apply user tests in which users compare our results very well with analytical cubist paintings but not synthetic cubist paintings.

1. Introduction

Establishing a sense of realism in computer graphics has, until recently, been the main concern. With the realism goal nearly achieved, however, non-photorealistic and artistic rendering techniques [1–3] have started to garner more attention.

Cubism, pioneered by Pablo Picasso and Georges Braque, was a breakthrough in art, influencing artists to abandon existing traditions. It led to the emergence of modern art during a period of crisis that "the modern artist was heir to a tradition that had come to identify an object with its pictorial projection" [4]. In cubist paintings, we can perceive a multi-perspective projection of objects which creates ambiguity for overall composition. Differently than traditional one point perspective, artists show essential information of the content as much as possible by using multiple viewpoints. Cubism has its own evolution between 1906 and 1919. Although philosophy behind remains the same, its style has changed through these years. Two main periods of cubism are *Analytical Cubism* and *Synthetic Cubism*. Analytical Cubism covers the work of Picasso and Braque from 1908 until 1912 and mostly deals with the geometry of this new multi-view projection technique. On the other hand, during Synthetic Cubism period artists worked on new materials and combined them on canvas.

The philosophy and technique of cubism influenced not only artists, but also scholars and scientists from different disciplines. For example, various multi-perspective camera approaches have been introduced in the computer graphics field. Most of proposed methods provide a larger view of the scene than traditional perspective view using one camera or multiple camera models. Although radical spatial imprecision, clearly exhibited in all cubist paintings, has been addressed by several image based methods; for 3D, a comprehensive model giving solution for both multi-perspective view and spatial imprecision has not been proposed. In this paper, we describe a rendering method that uses principles of analytical cubism when generating images from synthetic 3D content (Fig. 1) by defining a flexible camera model ensuring expanded views with applied spatial imprecision. We also present a discussion of final outputs together with user evaluation results to validate the effectiveness of our approach.

The contributions of this paper are as follows:

- *A cubist camera model to render synthetic 3D scenes.* The proposed camera model enables multiple viewpoints with cubist-style faceting technique on a large and flexible camera surface. All viewpoints adjust their view angle (i.e. each facet adjusts its view-orientation) automatically to render important parts of the scene.
- *A perceptually based spatial imprecision technique.* Perceptually important parts of the 3D content are kept visible on the rendered image with this technique. The usage of perception techniques empowers artistic rendering approaches to bring artist's insight to the output.
- *Several methods to provide a painterly effect.* A border enhancement method, gradient mapping, and color transferring techniques are used to enhance artistic quality.

The paper is organized as follows: First, in Section 2, we discuss previous studies related to cubism, multi-perspective imaging, and artistic rendering. Then, we briefly explain cubism and its principles in Section 3, before giving the details of our approach in

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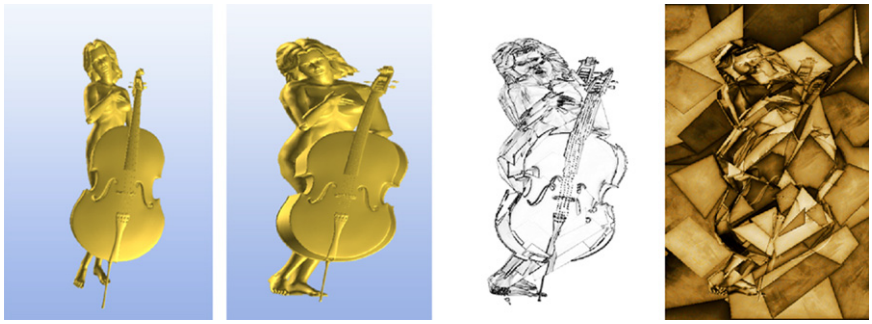

Fig. 1. Left: perspective view; Middle-left: cylindrical cubist camera view without perceptual spatial imprecision; Middle-right: line map of applied spatial imprecision; Right: final output of our result with applied perceptual spatial imprecision and artistic effects.

Section 4. Section 5 presents a detailed discussion of final outputs, and Section 6 concludes the paper.

2. Related work

Cubism as a movement breaking down traditional methods in art has inspired several works in computer graphics and imaging. Much of that has sought ways to introduce the principles used in cubist paintings, such as multi-perspective to computer rendering.

Multi-perspective rendering and non-linear projection. Inspired by cubism's multiple-viewpoints approach, several multi-perspective techniques have been proposed [5]. Most of these methods deal with a single camera combining multiple viewpoints. Glassner [6,7] introduced an approach suited to ray tracing, in which rays are defined with NURBS surfaces. Löffelmann and Gröller [8] suggested an extended camera model that produces artistic effects by retaining the overall scene with ray tracing.

The general linear camera (GLC) model described by Yu and McMillan [9] generalizes linear cameras defined by a four dimensional ray space imposed by two planes, offering ray modeling flexibility. A camera model is constructed with three given rays, which allows implementing multi-perspective and non-pinhole camera models [10]. Another non-pinhole camera model, proposed by Popescu et al. [11], integrates several regions of interest in a 3D scene to render a single layer in a feed-forward fashion. Taguchi et al. [12] presented geometric modeling of multi-perspective images captured using axial-cone cameras. These approaches involve multi-perspective cameras with different viewpoints and ray groups.

A flexible projection framework with a single camera, proposed by Brosz et al. [13], can model nonlinear projections with parametric representation of the viewing volume.

The multi-perspective approach has also been widely used for designing algorithms for panoramas. Wood et al. [14] proposed a background panorama construction technique for the usage in traditional cel animations. Similarly, Rademacher and Bishop [15] presented a method to create a single image from multiple projection points.

More recently, interest has shifted to composite projections generated by the results of two or more cameras [13]. The main difficulty of composite projections is the occlusion of multiple projections from different view angles. Agrawala et al. [16] developed an interactive system attaching local cameras to a three dimensional space to generate multiprojection images of the scene by blending the results of the different angles. Likewise, Coleman and Singh [17] described a framework for the interactive authoring of projections obtained from linear perspective cameras.

A number of studies have addressed the multi-perspective approach in image space. Among these, Collomosse and Hall [18] and Agarwala et al. [19] proposed algorithms to combine the images rendered from different camera positions in various styles.

Cubism and artistic rendering. Apart from the works using cubist principles to develop new camera models, a number of studies aspire to render cubist-style paintings. In a prior work, Klein et al. [20] presented a method to create outputs evoking cubist and futurist paintings by using a space-time data cube from video. Along with using different view angles for the same content, their method also considers imprecision of object parts and a painterly style to enhance the similarity of their outputs to cubist paintings. Later, they generalized their methods to a set of NPR tools for video processing [21].

Collomosse and Hall [18] proposed a method to generate cubist-style outputs from images. As with video cubes, they use a series of images of the content as input to produce angular geometry in cubist art. The images are segmented with image-saliency maps, and segments from different viewpoints are combined. The final composition is rendered with color and brush effects. However, Collomosse and Hall's work is image based and application of view-independent projection principle of cubism is dependent on the manually provided input images.

Influenced by the artistic styles of Kandinsky and Matisse, Song et al. [22] automatically produce highly abstract images using geometric shapes. A source image is segmented in different level of sizes and a variety of simple shapes are fitted to each segment. With a classifier, they automatically choose the segments which best represents the source image. The whole process creates an abstract form of the source image.

3. Analytical cubism and properties to create cubist imagery

In order to develop an accurate computational model representing analytical cubism and its rules, it is necessary to understand its concepts. To that end, we analyzed the works of Pablo Picasso and Georges Braque, given their pioneering role in Analytical Cubism. Although their paintings look like compositions of random shapes, the facets are ambiguous pieces of the content viewed from different angles, allowing a perspective that is not possible in a traditional projection. The main motivation behind cubist paintings is the desire to show that originality does not necessarily mean pictorial quality with a realistic perspective and unity [23]. Unconventional dimensions in the view and disharmony between object parts follow two major principles applied in cubist paintings:

- *View-independent projection*: In cubist paintings, radical discontinuities are emphasized through the manipulation of perspective, and artists exhibit a remarkable freedom from the point of view-dependency [24]. Instead of using a single viewpoint, multiple projections of a scene from different viewpoints are combined in a single projection. Thus, viewers can see more features of the content than in a linear perspective view. This multi-perspective approach has influenced