13 Visualization of 3D Scalar Fields Using Ray Casting

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ABSTRACT
In this paper a high-quality rendering technique for the visualization of 3D scalar fields in an "aquarium model" is presented. This technique is based on ray casting. The model consists of scalar values defined on a grid, supplemented with glass walls and a bottom. Using trilinear interpolation within the grid is an option. The implementation has been divided into two stages; ray casting, and colour binding using transfer functions are implemented as separate processes. This enables the user to generate different pictures from the same viewpoint, experimenting with different parameters. The method has been applied to data obtained from simulations computing concentrations in sea water.

13.1 Introduction
In recent years, interest has grown in computer-generated visualization of 3D data obtained from measurements and numerical computations[4]. The enormous increase in power and availability of computing resources has stimulated the development of numerical models of ever growing scale and complexity. Manual interpretation of numerical data, always a tedious task, has become virtually impossible. For the further development of measurement and analysis techniques, there is an urgent need to exploit the high bandwidth of human visual perception in grasping the spatial structure of complex phenomena. Therefore, new visual data presentation techniques are being developed. Especially in the case of 3D simulations, traditional 2D visualization often fails to provide the necessary insight, especially when an overall view of spatial structure is desired.

In visualization of 3D data, the aim is to promote a primarily qualitative understanding of the global spatial structure. 3D data from numerical simulations or measurements are often represented as scalar or vector fields, defined by scalar or vector values on a regular 3D grid. Visualization of these fields can be supported by showing 3D objects or shapes representing the context, and 2D sectioning or slicing is provided for closer study in selected planes. With 2D visualization techniques, data are then shown in one or more projections or cross sections, using contour lines, flow lines, and similar aids to allow a more quantitative view of the data.

This paper describes a visualization technique for 3D univariate scalar fields, intended to show the spatial distribution of a diffuse field in a transparent medium. The applicability of the method is demonstrated in the study of the distribution of concentrations of silt or chemicals in sea water. Data for this were supplied by Rijkswaterstaat, the Dutch State Agency for Public Works. The data were computed concentrations, obtained from 3D numerical flow simulations, and represented as 3D scalar values on a regular rectangular grid, supplemented by depth measurement data.

The method uses ray casting to generate images of a so-called aquarium model (see figure 13.1). The region to be studied is represented as a rectangular tank, bounded by transparent glass walls, and an opaque surface for the sea bottom or the coast. The distribution of the scalar field of concentration values is shown as coloured diffuse clouds inside the aquarium. The data of the scalar field over the 3D volume is conveniently represented as a 3D array of samples. The spatial extent of the volume elements, located...
inside the aquarium model, is referred to as the data model.

The method is related to other volume visualization techniques based on ray casting, such as those described by Upson and Keeler[7] and Sabella[5]. Because of the transparent medium, in which the scalar field is visualized by a gradual decrease of transparency, a front-to-back volume rendering technique is generally preferable to the simpler back-to-front rendering techniques[3].

Upson and Keeler[7] describe two rendering techniques that use volumes as the basic geometric primitives. These techniques use a linear approximation of the scalar field within each volume element, called a computational cell. The first technique is based on ray casting, and processes the cells encountered by a ray emanating from the viewpoint. The second technique, called cell-by-cell processing, is a cell-oriented front-to-back method. A cell is projected onto the pixels of the screen starting with those on the plane closest to the viewpoint. The contribution of each cell is accumulated for each pixel.

Sabella[5] also uses ray casting to generate images showing certain properties of a scalar field, e.g., the distance to the peak value along a ray, or its center of gravity. These properties are mapped to HSV colour space to produce an image.

The method described here is based on the first method described by Upson and Keeler, adapted for application with the aquarium model; we have extended it using flexible methods for assigning colours to the field values, and we have implemented it as a two-stage process, allowing the user to experiment with several colour variations.

We first describe our ray casting technique, and then the final assignment of colours to the scalar field values. Next, the implementation as a two-stage process is described, and we give some results and pictorial examples. We end the paper with a brief discussion and directions for further development.

13.2 Ray casting

Ray tracing is a widely used technique in computer graphics to generate high-quality images incorporating optical effects such as reflection, transparency and shadows. In conventional ray tracing, rays are sent from the viewpoint through each pixel of the screen into model space, and intersections are calculated with surfaces hit by the rays. From the