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Technical section

Interactive out-of-core isosurface visualisation in time-varying data sets

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Abstract

We present a combination of techniques for interactive out-of-core visualisation of isosurfaces from large time-dependent data sets. We make use of an index tree, computed in a pre-processing stage, which effectively captures temporal coherence in the data set. This tree data structure enables fast extraction of all isovalue-spanning cells from any time step and for any isovalue. For very large time-dependent data sets, such as those resulting from CFD simulations, this data structure can easily become too large to fit in main memory. Therefore, we have adapted the generation of the data structure, as well as the data structure itself for out-of-core application. During generation, the data set is spatially divided into several regions, each resulting in a separate tree. For visualisation, the application uses all these trees simultaneously, but will use only part of each of the trees. Only a user-specified time window will be kept in main memory and other parts of the tree will be read and released on demand. Finally, to avoid time-consuming triangulation and surface reconstruction, we have used a hardware-assisted direct point rendering algorithm for displaying the isosurfaces. These combined techniques allow interactive exploration and visualisation of very large time-varying data sets on a normal PC.

Keywords: Scientific visualization; Large data handling; Isosurfaces; Out-of-core techniques; Time-dependent data

1. Introduction

One of the greatest challenges in visualisation today, is the interactive exploration of large, time-varying data sets. Especially in areas such as flow visualisation, time-dependent simulations are becoming common practice, and can produce high resolution grid data sets with many thousands of time steps. In spite of the huge size, scientists investigating these data sets need interactive visualisation techniques with which they can browse through the data in both space and time.

Flexible, general-purpose visualisation techniques such as particle tracing, volume rendering, or isosurface extraction are in general not fast enough for time-dependent exploration, or for interactive control of the visualisation parameters. For example, when using isosurface extraction for a time-varying data set, it is desirable to interactively change the isovalue, and watch the development of the surface shape over time. However, extracting and rendering a new isosurface for each time step is generally too slow for interactive exploration.

Our approach to this challenge is to use a specialised data structure allowing very fast access and data retrieval for answering a specific type of visualisation query. We used a number of criteria in choosing such a

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data structure. First, it should do fast isosurface extraction for any isovalue. Second, it should be suitable for time-dependent data sets. Combining these two, it should be possible to do time-dependent or "incremental" surface extraction, or to determine the differences between successive time steps. This means the data structure should exploit temporal coherence in the data. Of course, it should be much faster than straightforward isosurface extraction from every time step separately. Finally, the results of the extraction should be directly passed to a fast rendering algorithm for display.

We have employed a data structure for fast isosurface extraction from time-dependent data sets [1]. To make our system achieve interactive frame rates in browsing a data set, we have directly linked the output of our isosurface extraction with a fast, hardware-supported direct rendering algorithm [2], resulting in interactive isosurface extraction and visualisation from time-varying data sets. The direct rendering avoids the time-consuming construction of polygonal surfaces using a Marching Cubes-type of algorithm [3]. By combining these two methods, and capitalising on temporal coherence, the user can specify an arbitrary isovalue and time step, and the development of the isosurface can be dynamically visualised in forward or backward time direction (see Fig. 1).

However, the tree data structure used may become too large to fit in main memory. We have overcome the huge memory requirements for creation and use of this data structure. For this, we have adapted the data structure for out-of-core application. We designed and implemented an intelligent paging scheme to enable interactive out-of-core isosurface extraction and rendering on a regular pc.

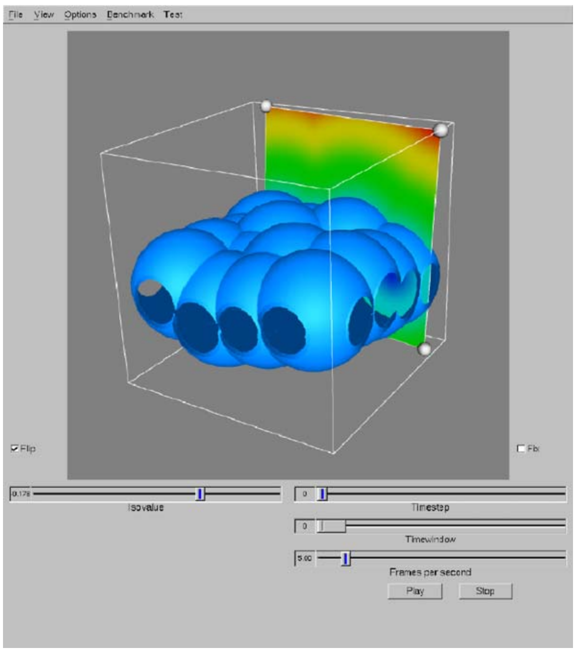

Fig. 1. A 256^3 data set of air bubbles rising in water.

This paper is organised as follows. In Section 2, we discuss related work in isosurface extraction techniques from time-dependent data, suitable rendering techniques to display the isosurface, and out-of-core techniques. Then we will briefly explain the data structures we have used in Section 3, together with the out-of-core algorithms and adaptations in Sections 4 and 5. The results will be discussed in Section 6, and we will give our conclusions and directions for future work in Section 7.

2. Related work

Many techniques for fast isosurface extraction are based on tree representations. Sutton and Hansen introduced the Temporal Branch-on-Need Tree (T-BON) [4]. This is an extension to the original Branch-on-Need Octree (BONO), described by Wilhelms and Gelder [5]. The T-BON is a version for time-dependent data sets, but it does not make use of temporal coherence. The data structure is suitable for fast isosurface extraction.

Shen presents an algorithm for fast volume rendering of time-varying data sets, using a new data structure, called the Time-Space Partition (TSP) Tree [6]. This structure could also be adapted for fast isosurface extraction. The TSP tree is capable of capturing both spatial and temporal coherence in a time-dependent field. Both the spatial and temporal domain are represented hierarchically in the TSP tree: each node of the octree representing space, contains a full bintree representing time. Although this allows multi-resolution access in any dimension, it involves a huge storage overhead.

Shen describes another data structure for isosurface extraction from time-varying fields, called the Temporal Hierarchical Index Tree [1]. The idea behind this structure is to store voxels that remain approximately constant throughout a certain time span only once for that entire time span. Within this data structure, two other data structures are used. First, the Span Space representation, as introduced by Livnat et al. [7], is used to store intervals in a two-dimensional space. Second, Interval Trees, described by Cignoni et al. [8], provide an optimal interval search algorithm.

Bordoloi and Shen [9] presented an algorithm for storing intervals more efficiently than in the Span Space, using transform coding.

Recently, Gregorski et al. [10] presented a technique for progressive isosurface extraction with adaptive refinement from compressed, time-dependent data sets. However, they are restricted to playing forward and