Modeling and visualization approaches for time-varying volume data

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Introduction

A time-varying volume dataset consists of
- a set of points in 3D Euclidean space
- describing one or more scalar quantity
- at different instances of time

The major distinction between models of time-varying datasets lies in their treatment of the temporal dimension
- A collection of 3D scalar fields
  - Video metaphor
- A single 4D Scalar field
  - Time treated as a spatial dimension

Methods that treat the temporal and spatial dimensions differently

	Primary	Secondary	Methods
Spatial	Octree	None	T-Bon[Sutton99]
		Binary Tree	TSP [Shen99] WTSP [Wang05]
Temporal	Linear Sequence	Keyframes	[Waters06]
		Diamonds	[Gregorski04]
	Binary Time Tree	Span Space	THIT [Shen98] [Chiang03] [Vrolijk06]

Methods that treat the temporal and spatial dimensions equally

	Cell Type	
	Hypercube	Simplicial
None	[Roberts99] [Bhaniramka04]	[Weigle98]
Spatial	POT [Shi06]	-
Multiresolution	[Westermann94]	[Lee04] [Linsen04] [Ponchio08]

Cell-based decomposition

Decompose the domain into cells and apply a divide and conquer approach to extract mesh *patches* from each cell.

Isosurfacing:

Surface of isovalue α passes through any cell having at least one vertex whose value is above α and at least one vertex whose value is below α.

Interval volume:

Generalization of isosurfaces to include the set of points enclosed between two surfaces.

Time-varying approaches

Hypercubic cells
- [Roberts99] Composes cases from subcases containing a single connected component
- [Bhaniramka04] Generates cases on the fly and caches frequent cases
- [Ji02] Interval volume cases created via a projection from 5D cells down to 4D
  - The extra dimension is the scalar value

Pentatopic cells
- [Weigle98] Recursive extraction of (d-1)-dimensional simplexes from *d-simplices*.
  1. Given isovalue, extract a 3D *envelope* containing all isosurfaces
  2. Given a time value, extract a surface

Comment: Types of symmetry used to create cases determines the number of distinct cases. [Weigle98] has high overhead from subdividing a hypercube into 192 pentatopes.

Indexing approaches

Only a small fraction of the cells intersect a particular isosurface or interval volume. Indexing the cells by their extreme values saves time by culling the empty cells.

Hierarchical spatial indexing

Branch on Need Octree (BONO) maintains the minimum and maximum value contained within each node to cull the empty cells.

Value-based indexing

Cells are projected into the 2D *span space*. Position of a cell is determined by the minimum and maximum values it contains. A spatial index is created for the span space.

Time-varying approaches

- T-BON - A BONO is created for each timestep but does not exploit temporal coherence.
- POT - BON octree tracks changes in cells as values increase.
- THIT - Projects cells from each timestep into span space and coalesces coherent cells into a binary time tree.

Out-of-core variations of THIT
- [Chiang03] - Uses cache-oblivious time tree and clusters spatially coherent cells.
- [Vrolijk06] - Renders approximate surfaces using only the span-space location.
- [Waters06] - Updates between timesteps stored in space as difference intervals. Keyframes accelerate random access.

Comment: Speedup associated with indexing techniques is data dependent and assumes a high degree of coherence within the dataset.

Multiresolution approaches

Underlying domain is typically at much higher resolution than can be meaningfully analyzed. Multiresolution models enable extraction of variable-resolution representations where resources can be focused on relevant regions.

Mesh based models

Typically nested hierarchies such as octrees and Longest Edge Bisection(LEB) hierarchies.

Wavelets based models

Multiresolution behavior determined by space of functions.

Mesh based time-varying approaches

- TSP Tree- Octree partitioning over 3D domain. Each node is a binary tree of temporal values.
- No 4D octree methods
- [Lee04] LEB of 4D pentatopes.
- [Gregorski04] Sequence of 3D LEB hierarchies for each timestep. Exploits temporal coherence by starting with previous mesh.
- [Ponchio08] Batched Multi-Tessellation over isosurface extracted from hypercubes.

Wavelet time-varying approaches

- [Westermann94] Lossy wavelet projection.
- [Linsen04] Uses lifting scheme on hierarchy of B-spline filters. Similar adaptability as LEB.
- WTSP - Distributed wavelet extension of TSP. Dependency between nodes reduced through redundant storage (similar to keyframes).

Comment: Wavelets can require expensive runtime reconstruction. Bilinear B-spline basis offer best time-space tradeoffs.

Conclusions

Due to the large size of the datasets, most models are optimized for specific visualization operations. These often involve rearranging the datasets (value-based indexing) or modifying the values (wavelets).

Since value-based indexing methods hash the data, they lose the spatial relationships between cells.

Video metaphor useful when trying to understand evolution of features within the dataset. Direct 4D techniques maintain correspondences between timesteps enabling smoother interpolation.

Multiresolution enables application-dependent variable-resolution inspection of huge datasets. Wavelets do not guarantee topology of extracted meshes so are more appropriate for DVR applications. Mesh-based approaches enable morphological analysis to be incorporated into the extraction process.

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