### 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

<table>
<thead>
<tr>
<th></th>
<th>Primary</th>
<th>Secondary</th>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spatial</strong></td>
<td>Octree</td>
<td>None</td>
<td>T-BON[Sutton99]</td>
</tr>
<tr>
<td></td>
<td>Binary Tree</td>
<td></td>
<td>TSP [Shen99]  |  WTSP [Wang05]</td>
</tr>
<tr>
<td><strong>Temporal</strong></td>
<td>Linear Sequence</td>
<td>Keyframes</td>
<td>[Waters06]</td>
</tr>
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<td></td>
<td>Binary Time Tree</td>
<td>Span Space</td>
<td>THIT [Shen98] |  [Chiang03] |  [Vrolijk06]</td>
</tr>
<tr>
<td><strong>Cell-based decomposition</strong></td>
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<tr>
<td>Decompose the domain into cells and apply a divide and conquer approach to extract mesh patches from each cell.</td>
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</tbody>
</table>

**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 - Extra dimension is closer to the scalar value.

**Pentatopic cells**
- [Weigle98] Recursive extraction of (d-1)-dimensional simplices from 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.

#### Methods that treat the temporal and spatial dimensions equally

<table>
<thead>
<tr>
<th>Cell Type</th>
<th>Hypercube</th>
<th>Simplicial</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>[Roberts99] |  [Bhaniramka04]</td>
<td>[Weigle98]</td>
</tr>
<tr>
<td>Spatial</td>
<td>POT [Shi06]  -</td>
<td></td>
</tr>
<tr>
<td>Multiresolution</td>
<td>[Westermann94] |  [Lisen] |  [Ponchio08]</td>
<td></td>
</tr>
</tbody>
</table>

#### 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 in 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.

#### 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.
  - [Gregorik04] 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.
  - [Lisen] Using lifting scheme on hierarchy of B-spline filters. Similar adaptability as LEB.
  - WTSP - Distributed wavelet extraction of TSP. Dependency between nodes reduced through redundant storage (similar to keyframes).

Comment: Wavelets can require expensive redundant storage (similar to keyframes).

#### 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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