Navigating Large Scale Scalar Volumes

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Ultra Scale Data Exploration

- Large-scale data sets are common in both medical and scientific applications
- Large data size makes interactive visualization difficult
  - High memory/texture memory requirement
  - Slower rendering speed
Multi-resolution Volume Rendering

- Error Tolerance
- Down Sample
- Raw Data
- Error metric
- Render and Composite
- Error metric
Research Questions

- How do we measure and compare the quality of different LOD selections?
- Are the computation resources effectively distributed?
- Can we visualize what are being visualized and make changes?
Global LOD Quality Metric

- Measure the amount of information contained in the selected LOD
  - Compare LODs
  - Decide whether the computation resources are distributed evenly to render-worthy blocks
  - LOD adjustment
- Approach: Employ information theory
Shannon Entropy

- The source of information takes a sequence of symbols \{a_1, a_2, a_3, \ldots, a_M\} with probabilities \{p_1, p_2, p_3, \ldots, p_M\}.
- The amount of information contained is defined as:
  \[
  H(X) = - \sum_{i=1}^{M} p_i \log p_i
  \]
- Maximize the entropy function when \(p_i\) are all equal.

An example of three dimensional Probability vector \{p_1, p_2, p_3\}
LOD Entropy

\[ H(X) = - \sum_{i=1}^{M} p_i \log p_i \]

- A LOD contains a sequence of blocks \( B_i \) at particular resolutions
- \( P_i \), the ‘probability’ of a data block \( B_i \) at a particular resolution, is defined as:
  \[ p_i = \frac{C_i \cdot D_i}{S} \quad S = \sum_{i=1}^{M} C_i \cdot D_i \]
- \( C_i \) and \( D_i \) are the block’s contribution and distortion (if it is a low resolution block)
LOD Entropy

The value of the entropy function is maximized when \( P_i \) are all equal

\[
H(X) = - \sum_{i=1}^{M} p_i \log p_i
\]

\[
p_i = \frac{C_i \cdot D_i}{S}
\]

(high resolution)

(low resolution)

The entropy function prefers that a block’s resolution matches its contribution to the final image
Contribution and Distortion

- Contribution: the block’s color ($\mu$), projection size ($a$), thickness ($t$), visibility ($v$)
  
  \[ C_i = \mu \cdot t \cdot a \cdot v \]

- Distortion: the difference between the block’s data values and those of a higher resolution block
  
  \[ d_{ij} = \sigma_{ij} \cdot \frac{\mu_i^2 + \mu_j^2 + C_1}{2\mu_i\mu_j + C_1} \cdot \frac{\sigma_i^2 + \sigma_j^2 + C_2}{2\sigma_i\sigma_j + C_2} \]

  - covariance
  - luminance
  - contrast
LOD Comparisons using Entropy

\[ H(X) = - \sum_{i=1}^{M} p_i \log p_i \]

A higher entropy value indicates a balanced probability distribution, thus a better overall quality
Entropy vs. Quality

Entropy = 0.166  (34 blocks)  Entropy = 0.316 (259 blocks)
Entropy vs. # of Blocks
Visual Representation of LOD Quality

- An optimal selection of LOD is an NP complete problem
- Fine tuning of LOD selection is often necessary
- Can we visualize what are being selected, and make adjustments if necessary?
LOD Map

- A visual user interface to visualize the LOD selection
- Allow the user to see individual block’s contribution vs. distortion, i.e., visualize the entropy terms
Treemap

- A space-filling method to visualize hierarchical information [Shneiderman et al. 1992]
  - Recursive subdivision of a given display area
  - Information of each individual node
    - Color and size of its bounding rectangle
LOD Map

- Display the blocks belong to the selected LOD in a tree-map like manner
- Color (blue to red) is used to encode the block’s distortion ($D_i$)
- The contribution of the block ($\mu.t.a.v$) is divided into two parts
  - The size of rectangle is to encode $\mu.t.a$
  - The opacity of rectangle is to encode $v$
LOD Map
How Can LOD Map Help

Comparisons of different LOD selection schemes
How Can LOD Map Help

- Spot problematic regions in the current LOD
  - Large red rectangles – high contribution blocks rendered with low resolutions
    - Action: split the blocks and increase the resolutions
  - Small blue rectangles – low contribution blocks rendered with high resolutions
    - Action: join the blocks and reduce the resolutions
  - Dark rectangles – low visibility blocks
    - Action: join them and reduce the resolutions
LOD Adjustment

before, 108 blocks

after, 108 blocks
How Can LOD Map Help

- View selection on the fly - High entropy and brighter LOD map for better views

(a) entropy = 0.330  (b) entropy = 0.343  (c) entropy = 0.384  (d) entropy = 0.390
How Can LOD Map Help

- Budget Control - Render fewer blocks, i.e., lower Resolutions in certain regions, for the same entropy

(a) entropy = 0.448, 365 blocks  (b) entropy = 0.476, 274 blocks
Summary

- Entropy is used as a way to quantify the LOD quality
- LOD Map is used to provide visual feedback for the LOD adjustment
- An image based metric is used to measure the actual contribution of a block to the final image
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