Rendering Salient Regions and Interaction Maps Using GPU

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Overview

- GPU SIMD architecture
- Details of descriptor space selection
  - Using non-linear subspace embedding
  - Visualization of descriptor space
- Direct volume rendering and salient regions
  - Need for saliency
  - Examples of visualizations
GPU architecture
GPU Programming model

• SIMD
  – Single instruction multiple data
  – All vertices on a 3D mesh
  – All droplets in a simulation
nVidia GeForce GTX 570

- **GPU Engine Specs:**
  - 480 CUDA Cores
  - 732 Graphics Clock (MHz)
  - 1464 Processor Clock (MHz)
  - 43.9 Texture Fill Rate (billion/sec)

- **Memory Specs:**
  - 1900 MHz (3800 data rate) Memory Clock
  - 1280 Standard Memory Config
  - GDDR5 Memory Interface
  - 320-bit Memory Interface Width
  - 152.0 Memory Bandwidth (GB/sec)
Exploration

• Design descriptors of volumetric data
• Use the training data for calculating various probabilities of droplet attributes based on the trajectory data and mapping them to the descriptors
• Use the mapping model to define saliency of regions at time of rendering
• Mapping saliency to rendering parameters for a coherent rendering
Question

• What kind of flow in a region leads to an interesting visualization?

• What kind of “2” is easier for mail-man to read?
Training data

• Subset of volume for estimating the statistics of the simulation

• Training data will be analyzed in detail
  – Every position of every droplet will be processed to find descriptor statistics
  – Should contain small number of droplets

• 64x64x64 grid points as training volume, 8000 particles of each size
Requirements

- Similar subvolumes (subvolumes with similar flow structures) to be similar or the descriptor vectors to be near each other.
  - Measured by residual variance
- Descriptor of two subvolumes which are near each other in physical space must be similar.
  - Measured by total variation
- Descriptor space must be amenable to easy interpretation by the user.
  - The descriptor should be low dimensional
  - Components of the descriptor vector should roughly correspond to properties of the flow already familiar to the user
  - Geometry of the descriptor space should be such that it provides a uniform distribution of data so as to utilize the visualization space effectively
Dimensionality reduction

• Inputs (high dimensional)
  \[ \vec{x}_i \in \mathbb{R}^D \text{ with } i = 1, 2, \ldots, n \]

• Outputs (low dimensional)
  \[ \vec{y}_i \in \mathbb{R}^d \text{ where } d \ll D \]

• Goals
  – Estimate a mapping from input space to output space
  – Nearby points remain nearby. Distant points remain distant.
Dimensionality reduction

Fig. 3. The “Swiss roll” data set, illustrating how Isomap exploits geodesic paths for nonlinear dimensionality reduction. (A) For two arbitrary points (circled) on a nonlinear manifold, their Euclidean distance in the high-dimensional input space (length of dashed line) may not accurately reflect their intrinsic similarity, as measured by geodesic distance along the low-dimensional manifold (length of solid curve). (B) The neighborhood graph $G$ constructed in step one of Isomap (with $K = 7$ and $N = 1000$ data points) allows an approximation (red segments) to the true geodesic path to be computed efficiently in step two, as the shortest path in $G$. (C) The two-dimensional embedding recovered by Isomap in step three, which best preserves the shortest path distances in the neighborhood graph (overlaid). Straight lines in the embedding (blue) now represent simpler and cleaner approximations to the true geodesic paths than do the corresponding graph paths (red).
Residual Variance

Dimension
Descriptors for vorticity magnitude

- Sample subvolumes in the simulation grid
  - Small subvolumes have nearly one dimensional distribution
  - Large subvolumes have too much variation to be captured in a low dimensional descriptor
  - \(7 \times 7 \times 7\) cubes with 50\% overlap (Can cover 91\% variance with a three dimensional descriptor)

- Compute descriptors for subvolumes using Isomap
Simulation parameters

- $256^3$ Reynold’s number - 142.92 (deterministic forcing)

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Higher increase in Settling velocity

Higher clustering
Resultant embedding
Alternate descriptor
Comparison

Isomap descriptor

- 91% variance captured (9% residual variance)
- 36% total variation
- Not easily interpretable

Mean-Deviation Descriptor

- 83% variance captured (17% residual variance)
- 13% total variation
- Easily interpretable statistics
Visualization of descriptor space
Visualizing vorticity

Left: Isosurfaces, Middle: Direct volume visualization, Right: Direct volume visualization with spatially invariant saliency
Flow+Droplets
Need for saliency

- Transparency map is usually only value dependent
- The interaction of the droplet may not be clearly visible when the whole volume is rendered
- Need space dependent transparency to highlight the phenomena effectively
Direct volume rendering

- Shoot one ray per pixel into the volume
- Integrate color and opacity along the ray to decide the pixel color
Raycasting

volumetric compositing

object (color, opacity)
Raycasting

volumetric compositing

object (color, opacity)
Raycasting

volumetric compositing

object (color, opacity)
Raycasting

volumetric compositing

object \,(color, \, opacity)
Raycasting

volumetric compositing

object (color, opacity)
Results
More examples
20 micron droplet
Strong interaction with fluid
(3X slower)
Frames per second versus rendering parameters

Fig. 7. Effect of changing rendering parameters on frame rate. $\alpha$ controls the range of the salient region around the selected subvolume (lower $\alpha$ refers to narrower region) and $\beta$ controls the subsampling of the ray in DVR. The plot shows frame rate in frames per second (fps) in a 1024x1024 window.
Conclusion

• GPU computing can be used to compute descriptors as it can be evaluated in parallel
• Descriptors can be identified through non-linear subspace embedding or heuristics
• Saliency based Direct volume rendering may be useful for visualizing individual droplet trajectories
Global map

Global map of collisions based on vorticity values
Thank you
Summarization
Using GPU to generate interaction maps

- Generate vorticity isosurfaces using Marching cubes algorithm
- Separate connected components and label with indices
Using GPU to generate interaction maps

- Generate lookup table for each cell with corresponding index of connected components
- Use one thread/droplet and count the interaction of the droplet with each component
- Accumulate the results of all threads to get final interaction map
Changes with time
Changes with time