Interactive Interface Design for Scalable Large Multivariate Volume Visualization

Xiaoru Yuan
Key Laboratory on Machine Perception, MOE
School of EECS, Peking University

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Outline

• Motivation

• Multivariate Volume Transfer Function Design
  • Parallel coordinates & MDS
  • Scattering Points in Parallel coordinates

• Parallel extension of the TF design
  • Scalable Pivot MDS
  • Adaptive Continuous Parallel Coordinates
High Dimensional/Multivariate Data Set

- Isabel Hurricane

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Min / Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>QVAPOR</td>
<td>Cloud water</td>
<td>0.00000 / 0.00332</td>
<td>kg/kg</td>
</tr>
<tr>
<td>QGRAUP</td>
<td>Graupel</td>
<td>0.00000 / 0.01638</td>
<td>kg/kg</td>
</tr>
<tr>
<td>QICE</td>
<td>Cloud ice</td>
<td>0.00000 / 0.00099</td>
<td>kg/kg</td>
</tr>
<tr>
<td>QRAIN</td>
<td>Rain</td>
<td>0.00000 / 0.01132</td>
<td>kg/kg</td>
</tr>
<tr>
<td>QSNOW</td>
<td>Snow</td>
<td>0.00000 / 0.00135</td>
<td>kg/kg</td>
</tr>
<tr>
<td>QVapor</td>
<td>Water vapor</td>
<td>0.00000 / 0.02368</td>
<td>kg/kg</td>
</tr>
<tr>
<td>CLOUD</td>
<td>Total cloud (QICE + QCLOUD)</td>
<td>0.00000 / 0.00332</td>
<td>kg/kg</td>
</tr>
<tr>
<td>PRECIP</td>
<td>Total precipitation (QGRAUP+QRAIN+QSNOW)</td>
<td>0.00000 / 0.01672</td>
<td>kg/kg</td>
</tr>
<tr>
<td>P</td>
<td>Pressure: weight of the atmosphere above a grid point</td>
<td>-5471.85791 / 3225.42578</td>
<td>Pascals</td>
</tr>
<tr>
<td>TC</td>
<td>Temperature</td>
<td>-83.00402 / 31.51576</td>
<td>Degrees Celsius</td>
</tr>
<tr>
<td>U</td>
<td>X wind component: west-east wind component in model coordinate; positive means winds blow from west to east</td>
<td>-79.47297 / 85.17703</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>Y wind component: south-north wind component in model coordinate; positive means winds blow from south to north</td>
<td>-76.83391 / 82.95293</td>
<td></td>
</tr>
<tr>
<td>W</td>
<td>Z wind component: vertical wind component in model coordinate; positive means upward motion</td>
<td>-9.06026 / 28.61434</td>
<td></td>
</tr>
</tbody>
</table>
Transfer Functions

- Transfer functions map the voxels values to colors and opacities, generating insightful results.
Transfer Functions

- Multivariate TFs for multi-modal data
Methods of Visualizing Multi-dimensional Data

- Scatterplot Matrix
- Star Glyphs
- Chernoff Faces
- Multidimensional Scaling (MDS)
- Parallel Coordinates
- etc.
Multidimensional Scaling
Parallel Coordinates

- To represent $N$ dimensional data
  - Set $N$ vertical axes in parallel
  - Put data to intersects on corresponding axes
  - Connect intersects
Data Exploration with PC

[Yuan et al. TVCG 2009]
Multivariate Visualization with Parallel Coordinates
Line vs. Point Representation
Line vs. Point Representation
Line vs. Point Representation
Data Exploration with SPPC

[Yuan et al. TVCG 2009]
Data Exploration with SPPC

[Yuan et al. TVCG 2009]
High Dimensional Transfer Function Design

• Key issue in multivariate TF design:
  Identifying features in multi-dimensional space
• Multidimensional data visualization in InfoVis community applied on TF design:
  – Parallel coordinates plot (PCP), which keeps information on each dimension
  – Multidimensional scaling (MDS), which works better on multi-dimensional feature identification
High Dimensional Transfer Function Design

• Integrate MDS into PCP to facilitate multivariate TF design.
  – Avoids context jumps between polyline and point regions when exploring data clusters
  – Provides multiple perspective views upon the data, supporting linked queries

[Guo, Xiao & Yuan, PacificVis 2011]
Design Multivariate TFs with the Proposed System
Volume Rendering with Sketch Feedbacks
System Pipeline (Non-parallel version)

- Multi-Variate Volume Dataset
- Pre-Processing
- Level-of-Detail Representation
- Parallel Coordinates
- Dimension Projection
- Rendering Results
- Classified Features
- Reconstruction
- User Interaction
  - Lasso Tool
  - Brush
  - Sketch
  - Fuzzy Selection
  - etc.
Transfer Function User Interface
Transfer Function User Interface

- User interactions
  - Brushing on axes
  - Lasso on points
  - Magic wand on points
PCP and MDS Generation

- Subroutines:
  - Embedding MDS Plot into Continuous PCP
  - Generation of Weight-Adjustable MDS Plot
  - Adaptive Rendering of Continuous PCP
MDS Plot

- **Pivot MDS** [Brandes and Pich 2007]
  - Low storage and low computational complexity
MDS Plot

- Hierarchical adaptive sampling can be exploited to reduce the data amount to progressively reaching optimal
MDS Plot

- Metric adjustable MDS
  - Allows user to define different impacts from the dimensions on MDS layouts
TF Construction

- Gaussian Mixture Model (GMM)
  - Use several Gaussian blobs to fit the distribution of user selected clusters

\[ \sum_{k=1}^{m} \mu_k G_k(v) = \sum_{i=1}^{n} \omega_i m_i G_i(v) + \varepsilon(v) \]

\[ GTF(v) = \alpha_{\text{max}} \sum_{k=0}^{m} \mu_k G_k(v) \]
Hurricane Isabel
Hurricane Isabel

Red part (hurricane eye):
low pressure,
medium temperature,
lower QCLOUD,
high wind speed
Hurricane Isabel

Yellow part:
- higher pressure
- lower wind speed
Hurricane Isabel
System Pipeline

Level-of-Detail Representation

Parallel Coordinates

User Interaction
Lasso Tool
Brush
Sketch
Fuzzy Selection etc.

Dimension Projection

Classified Features

Rendering Results

Multidimensional Transfer Functions

Multi-Variate Volume Dataset
System Pipeline – Parallel Environment

- Multivariate Volume Dataset
- Rendering Results
- Multivariate Transfer Functions
- Preprocessing
- Parallel Subsystems
  - Parallel Rendering
  - Parallel PCP
  - Parallel MDS
- Level-of-Detail Representation
- Parallel Coordinates
- Dimension Projection
- Classified Features
- User Interaction
  - Lasso Tool
  - Brush
  - Sketch
  - Fuzzy Selection etc.
Adaptive Continuous PCP

5%

10%

15%

(a)

(b)

(c)

(d)

(e)

(f)
Adaptive Continuous PCP

• The continuous PCP is a HDRI (High Dynamic Range Image). Features may be hidden without proper mapping strategy.

• A logarithm tone-mapping is utilized to enhance the small features

\[ I' = 1 - \frac{\ln((1 - e^{-\alpha})I + e^{-\alpha})}{-\alpha} \]
Pivot MDS

- Randomly pick \( k \) pivot items from the input data set;
- Calculate the squared distance between each point and all pivot points, and store them in matrix \( \Delta \);
- Construct the double-centered dissimilarity matrix \( C(c_{ij}) \) between pivot items and all input items, whose elements are defined as

\[
c_{ij} = -0.5(\delta_{ij}^2 - \frac{1}{m} \sum_{r=1}^{n} \delta_{rj}^2 - \frac{1}{k} \sum_{s=1}^{k} \delta_{is}^2 + \frac{1}{mk} \sum_{r=1}^{n} \sum_{s=1}^{k} \delta_{rs}^2),
\]

- Calculate the eigenvalues and eigenvectors of the matrix \( C^T C \)
- Pick up the largest \( d \) eigenvectors \( \{v\} \). The low dimension embedding is achieved by

\[
x_i = Cv_i, \quad i \in \{0, 1, 2, \ldots, d\}
\]
Pivot MDS Parallization

- Computation of squared distance matrix $\Delta$
- Double centered sub-matrix $C$
- Inner product $C^TC$
- Eigensolver
Scalable Pivot MDS
Performance – Parallel Multivariate Volume Rendering

![Bar chart showing performance in milliseconds for different numbers of Gaussian Blobs and GPUs.](image)
Performance – Parallel MDS Projection

![Graph showing performance and speedup for different sample sizes. The graph plots time (ms) on the y-axis and number of cores on the x-axis. The graph includes lines for 638,870, 273,176, and 356,504 samples, each with a corresponding speedup line. The speedup is linear for the 638,870 samples, indicating efficient parallel processing.]
Performance – Parallel PCP Rendering

![Graph showing performance](image)

- Red line: 638,870 Samples
- Blue line: 273,176 Samples

Performance measurement over the number of GPUs.
Integrated System Interface
VisIt Plug-in (ongoing)
Related Publications

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  – Hanqi Guo, Xiao He

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http://vis.pku.edu.cn
http://vis.pku.edu.cn/wiki

Email: xiaoru.yuan@pku.edu.cn