Interactive Interface Design for Scalable Large Multivariate Volume Visualization

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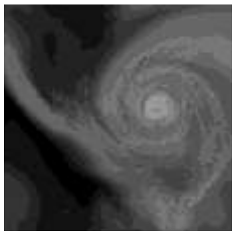
Outline

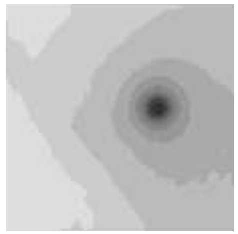
- Motivation
- Multivariate Volume Transfer Function Design
  - Parallel coordinates & MDS
  - Scattering Points in Parallel coordinates
- Parallel extension of the TF design
  - Scalable Pivot MDS
  - Adaptive Continuous Parallel Coordinates

High Dimensional/Multivariate Data Set

- **Isabel Hurricane**

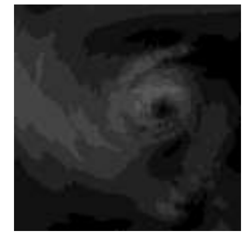


QVAPOR



QCLOUD

Pressure



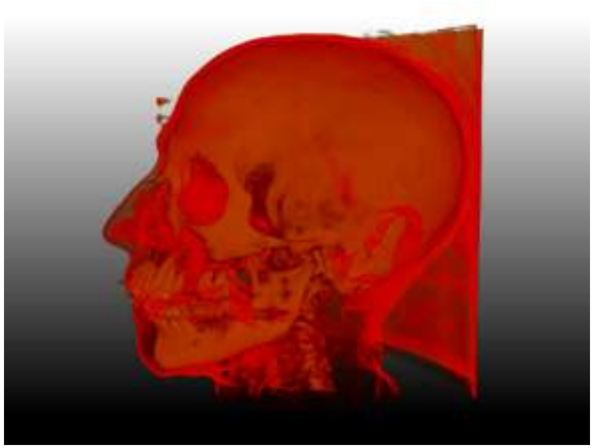
Speed

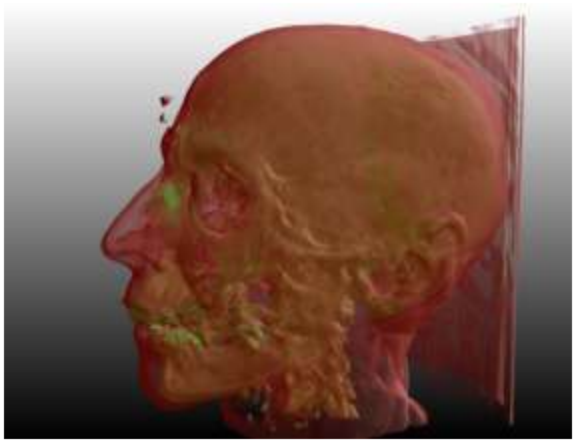
…

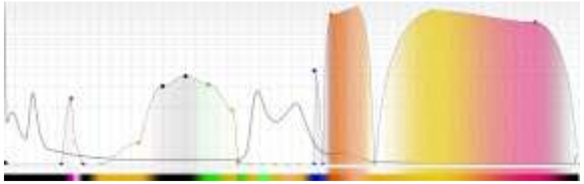
Variable	Description	Min / Max	Units
QCLOUD	Cloud water	0.00000 / 0.00332	kg/kg
QGRAUP	Graupel	0.00000 / 0.01638	kg/kg
QICE	Cloud ice	0.00000 / 0.00099	kg/kg
QRAIN	Rain	0.00000 / 0.01132	kg/kg
QSNOW	Snow	0.00000 / 0.00135	kg/kg
QVAPOR	Water vapor	0.00000 / 0.02368	kg/kg
CLOUD	Total cloud (QICE + QCLOUD)	0.00000 / 0.00332	kg/kg
PRECIP	Total precipitation (QGRAUP+QRAIN+QSNOW)	0.00000 / 0.01672	kg/kg
P	Pressure: weight of the atmosphere above a grid point	-5471.85791 / 3225.42578	Pascals
TC	Tempreature	-83.00402/31.51576	Degrees Celcius
U	X wind component: west-east wind component in model coordinate; positive means winds blow from west to east	-79.47297/85.17703	
V	Y wind component: south-north wind component in model coordinate; positive means winds blow from south to north	-76.03391/82.95293	
W	Z wind component: vertical wind component in model coordinate; positive means upward motion	-9.06026/28.61434	

Transfer Functions

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

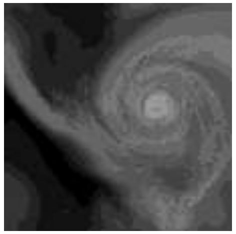




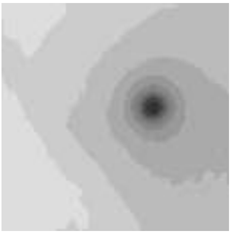


Transfer Functions

- Multivariate TFs for multi-modal data

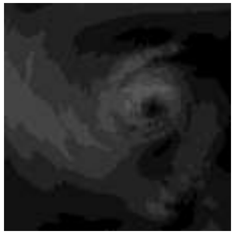


QVAPOR



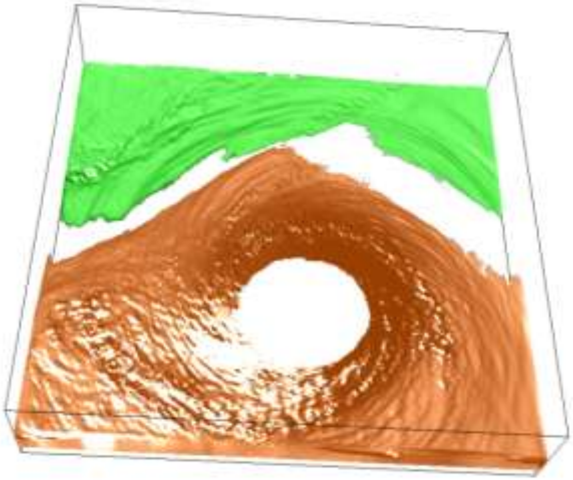
QCLOUD

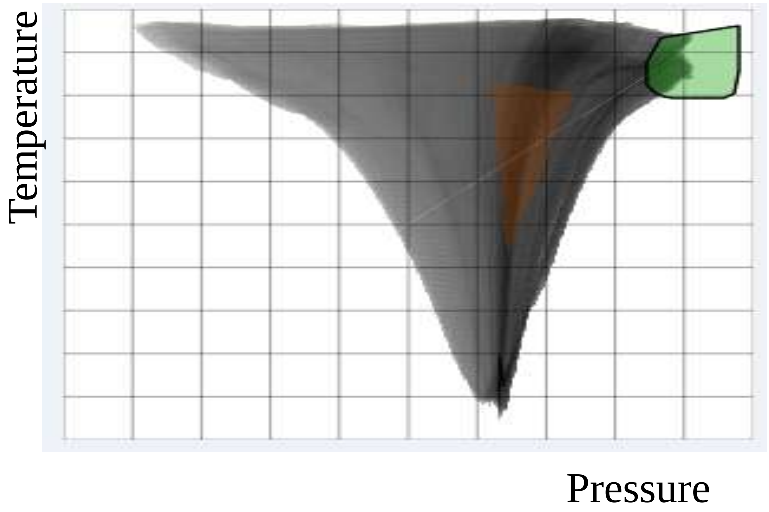
Pressure



Speed

…

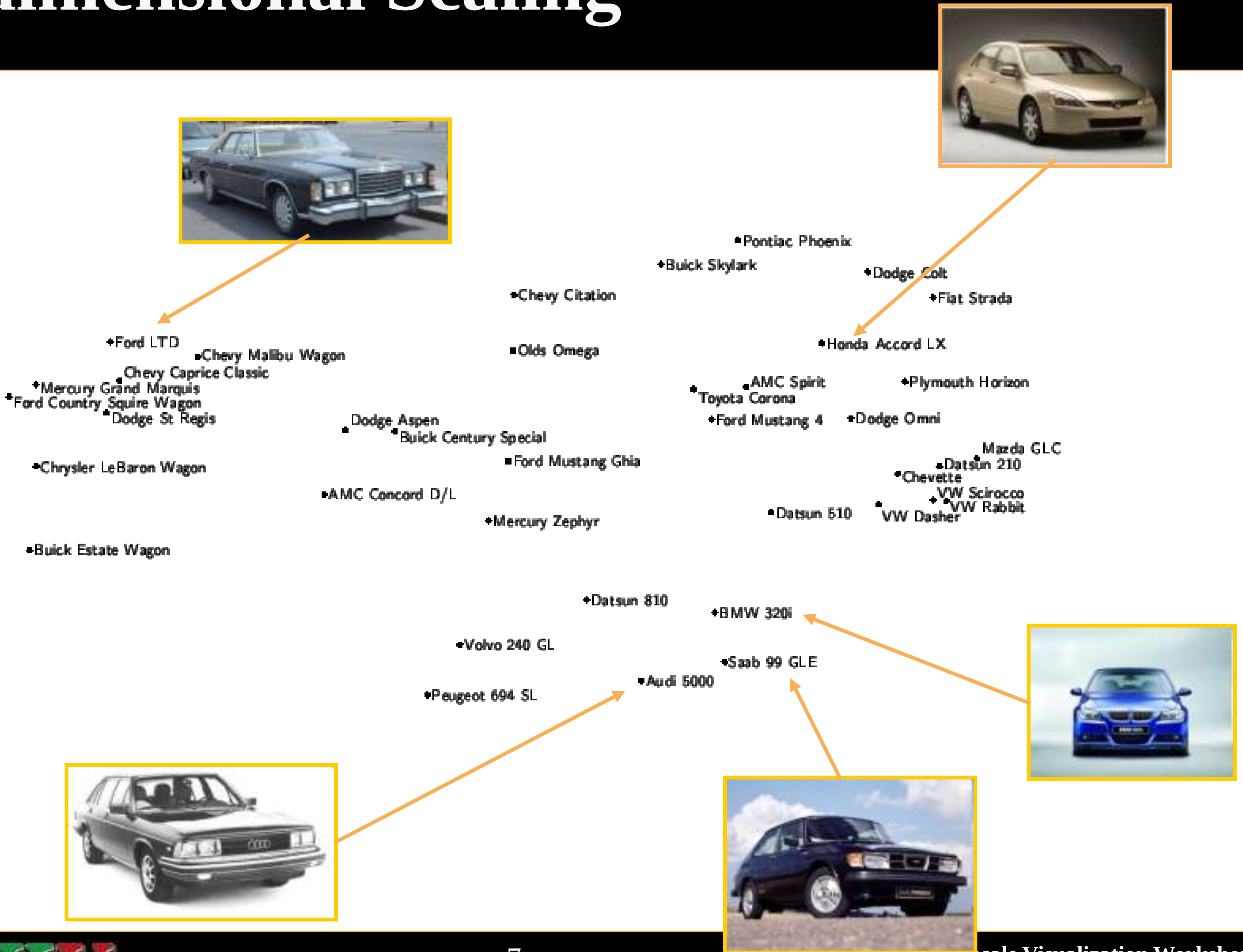




Methods of Visualizing Multi-dimensional Data

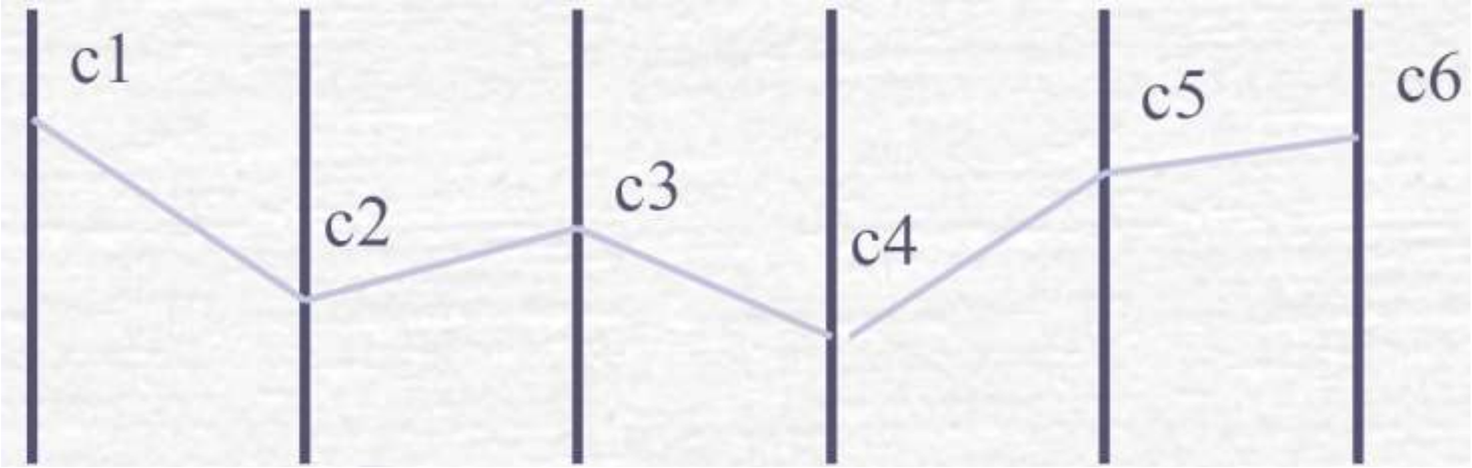
- **Scatterplot Matrix**
- **Star Glyphs**
- **Chernoff Faces**
- **Multidimensional Scaling (MDS)**
- **Parallel Coordinates**
- **etc.**

Multidimensional Scaling

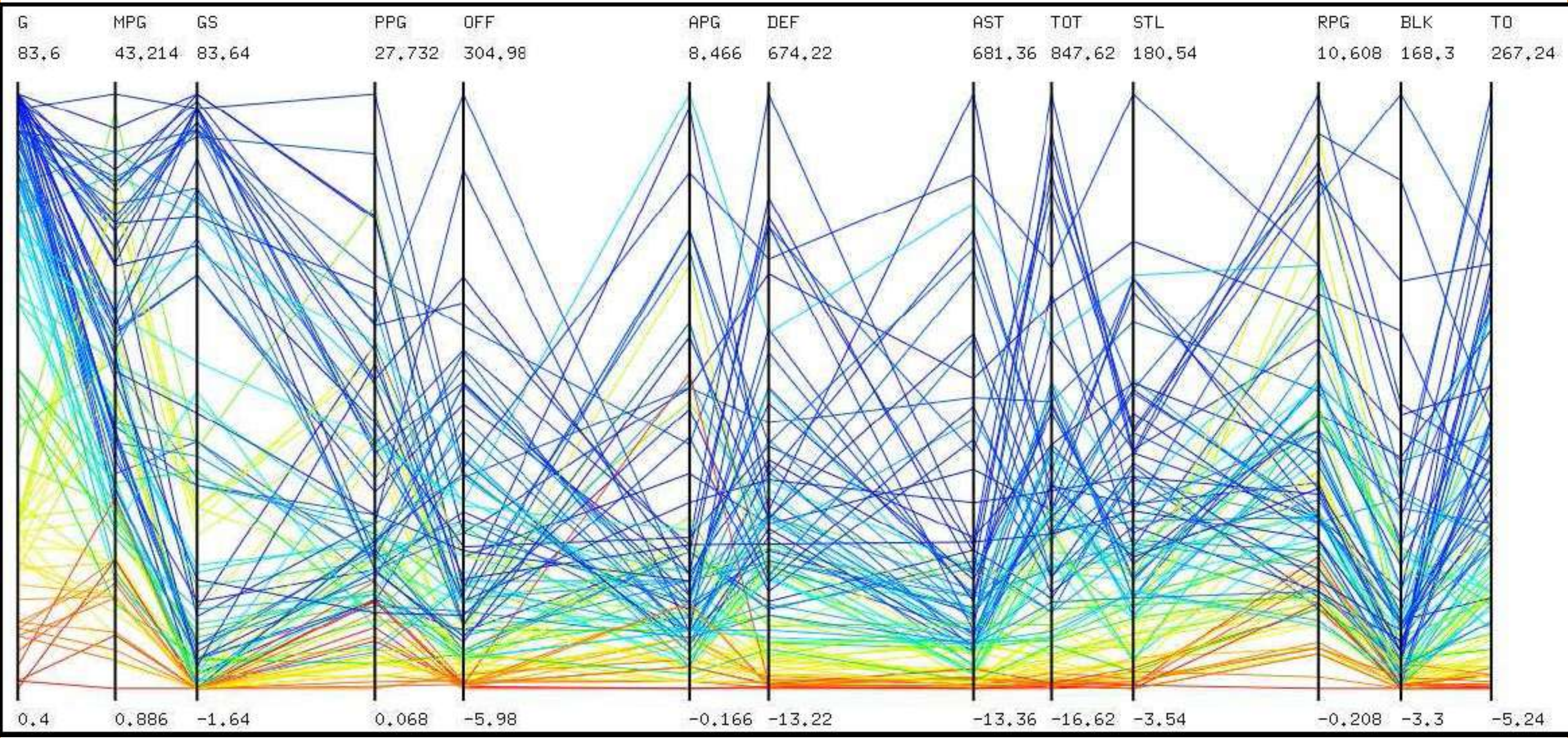


Parallel Coordinates

- To represent N dimensional data
  - Set N vertical axes in parallel
  - Put data to intersects on corresponding axes
  - Connect intersects

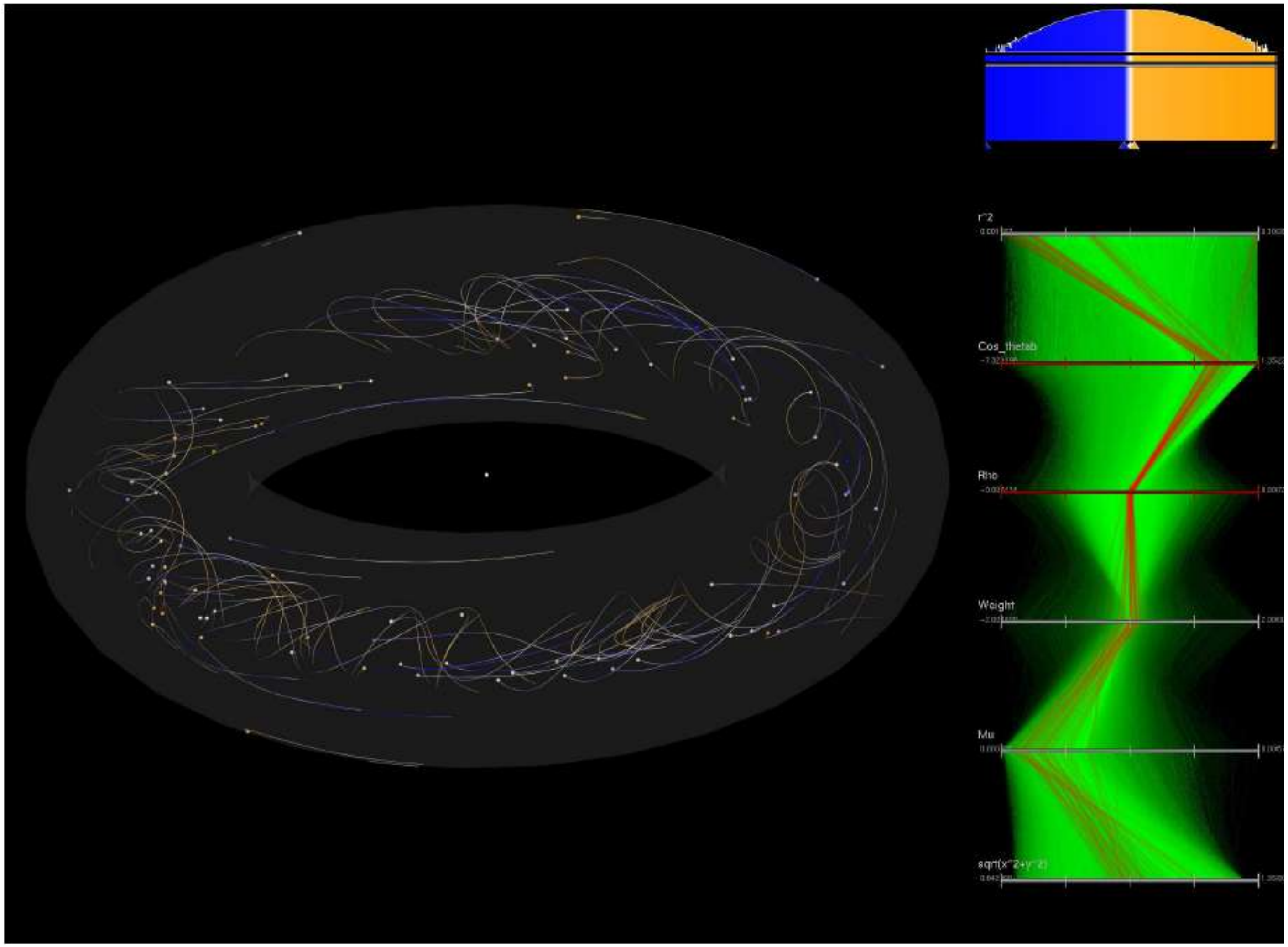


Data Exploration with PC



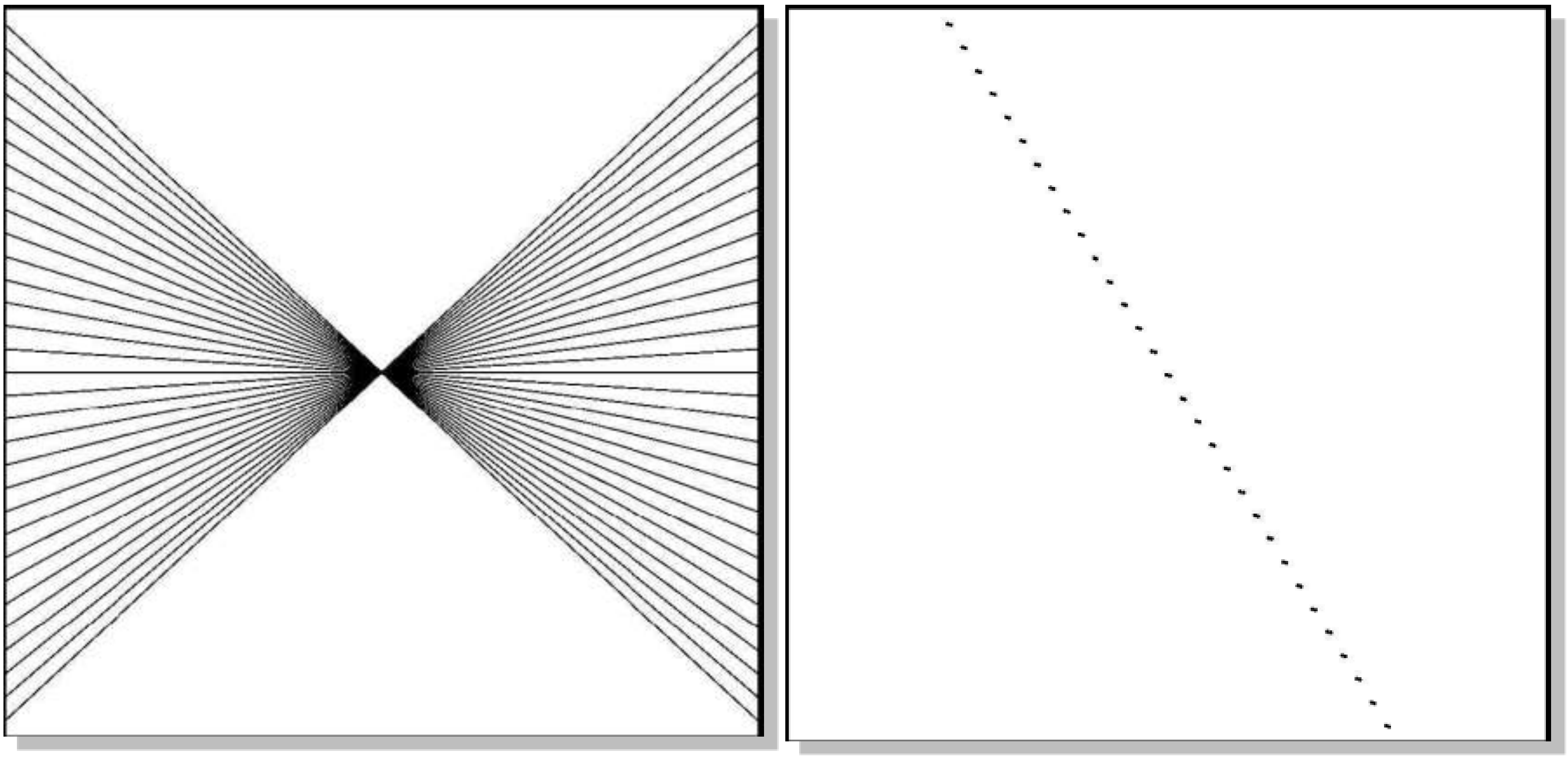
[Yuan et al. TVCG 2009]

Multivariate Visualization with Parallel Coordinates

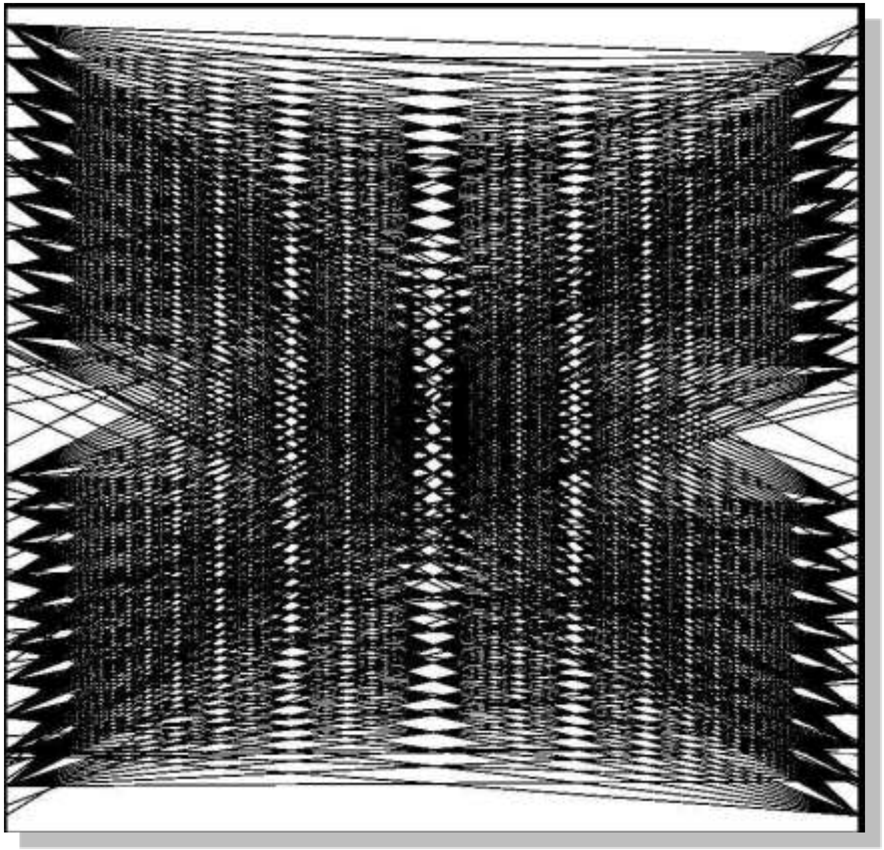


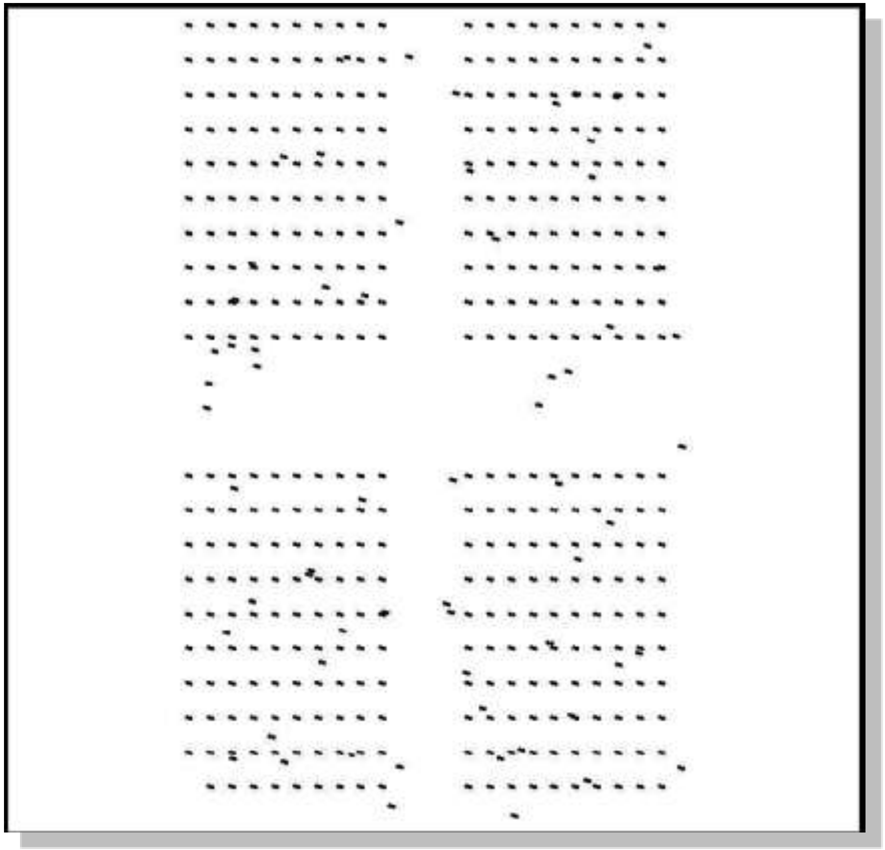
[Jones et al, 2008]

Line vs. Point Representation

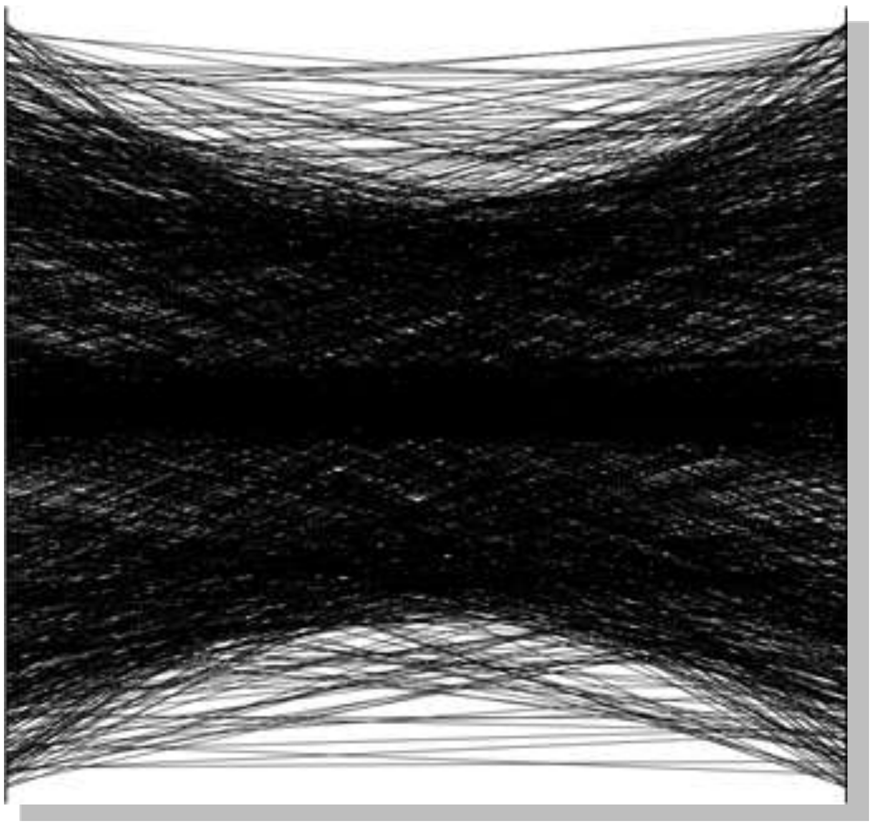


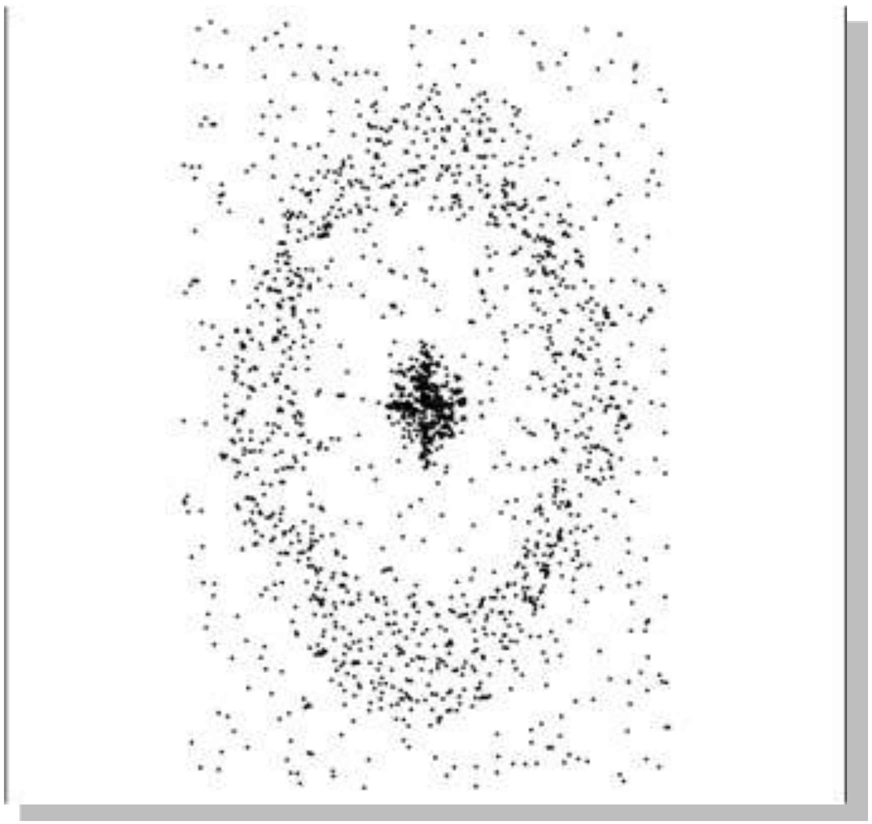
Line vs. Point Representation



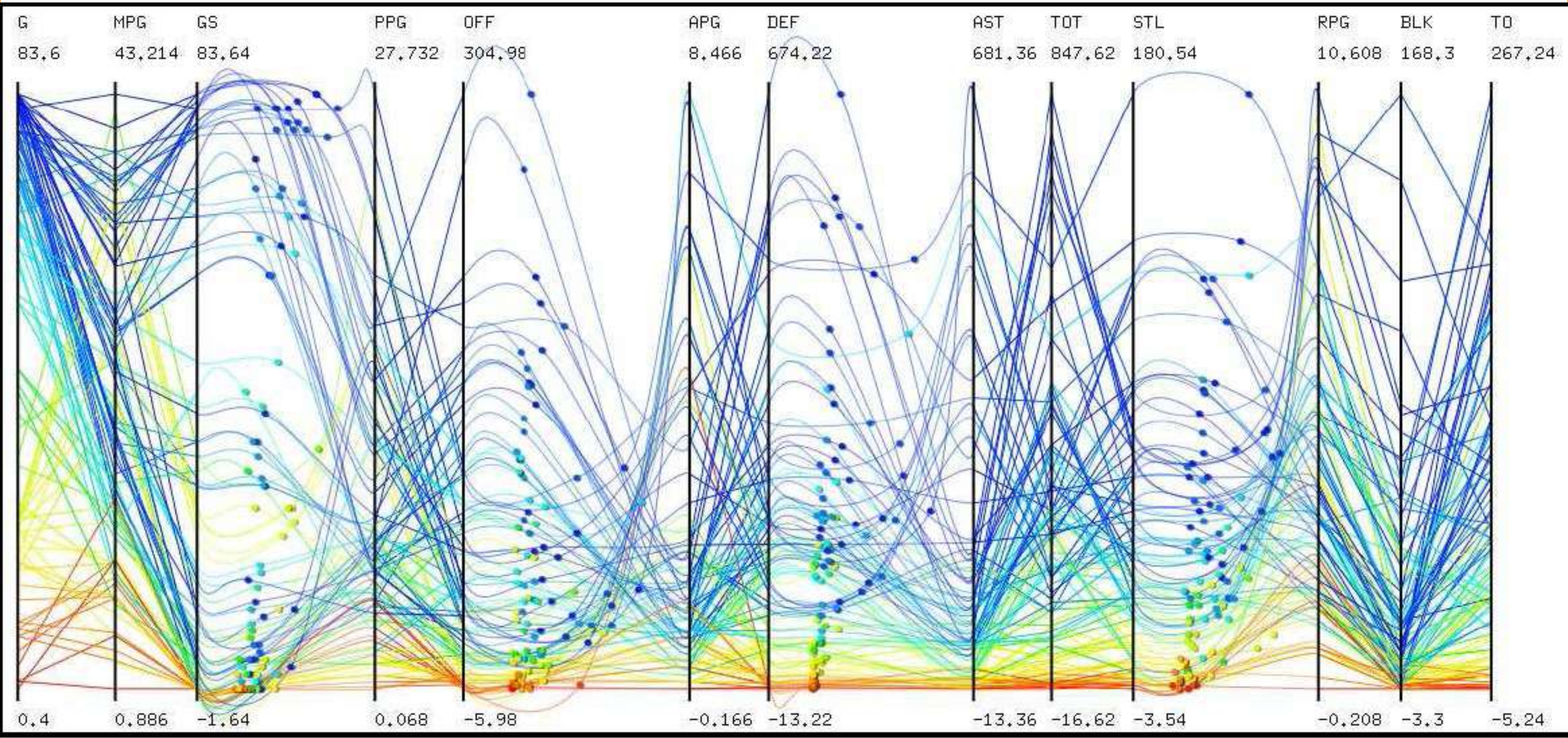


Line vs. Point Representation



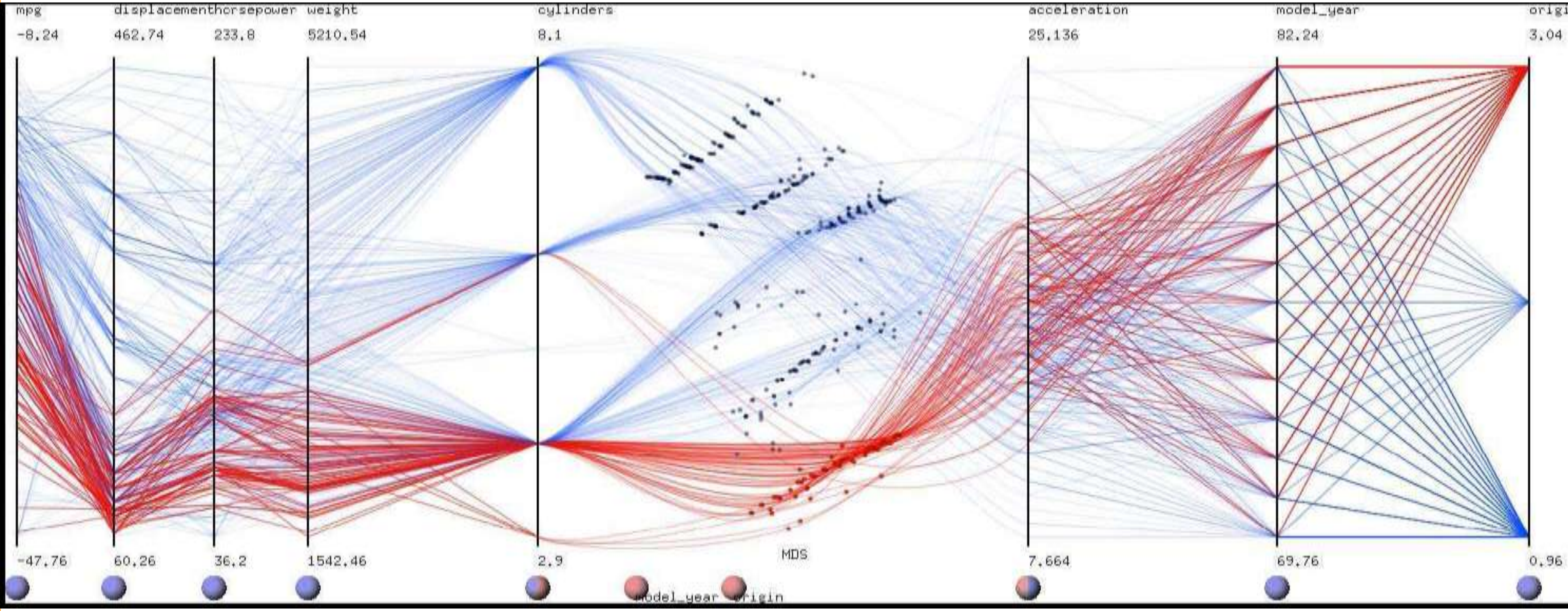


Data Exploration with SPPC



[Yuan et al. TVCG 2009]

Data Exploration with SPPC

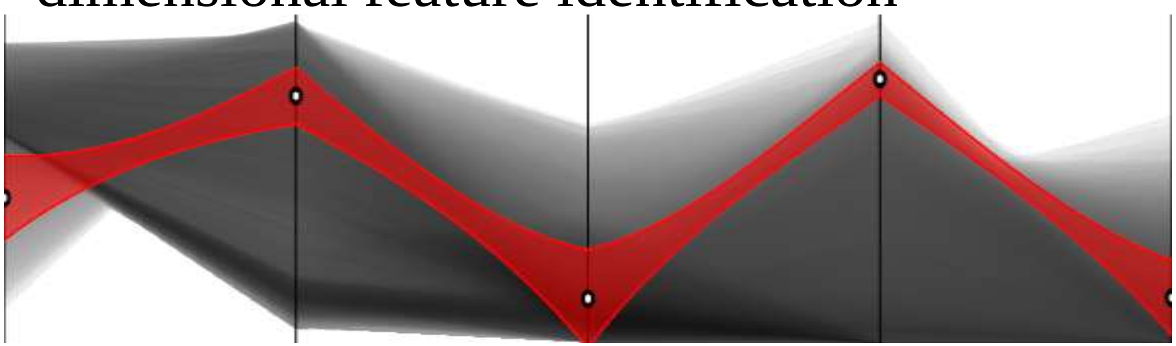


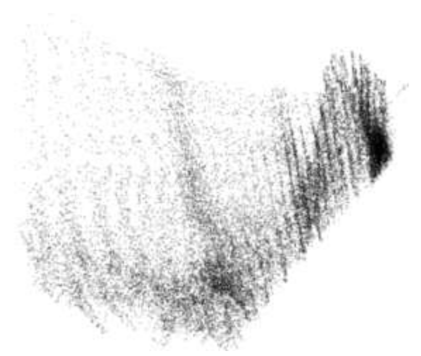
[Yuan et al. TVCG 2009]

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

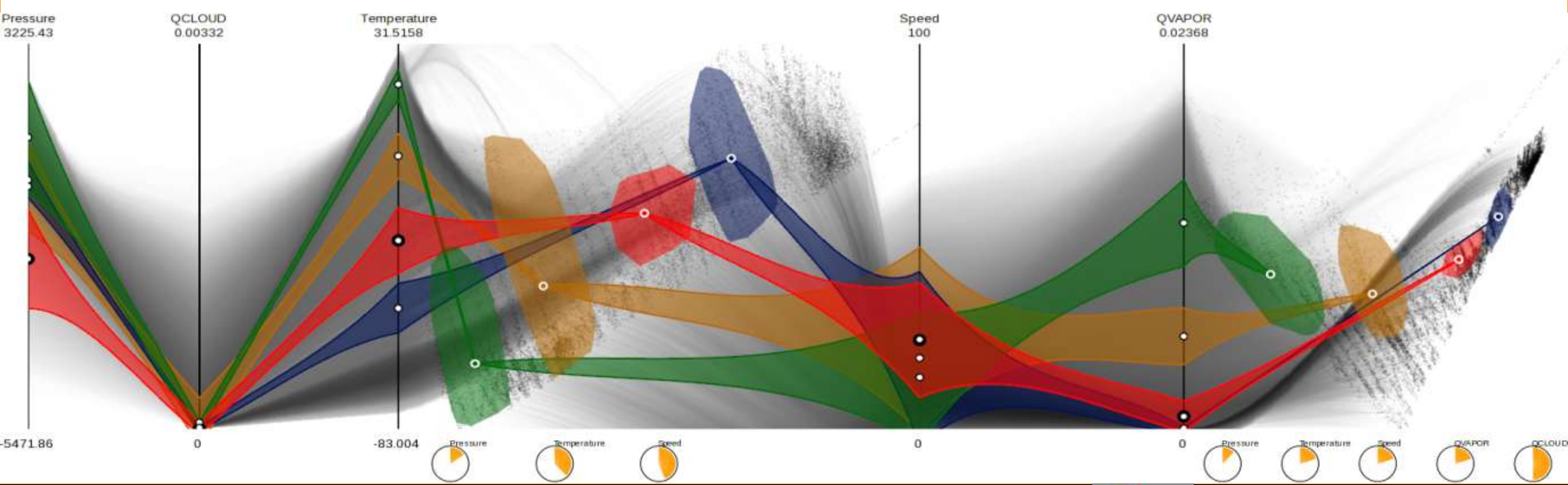


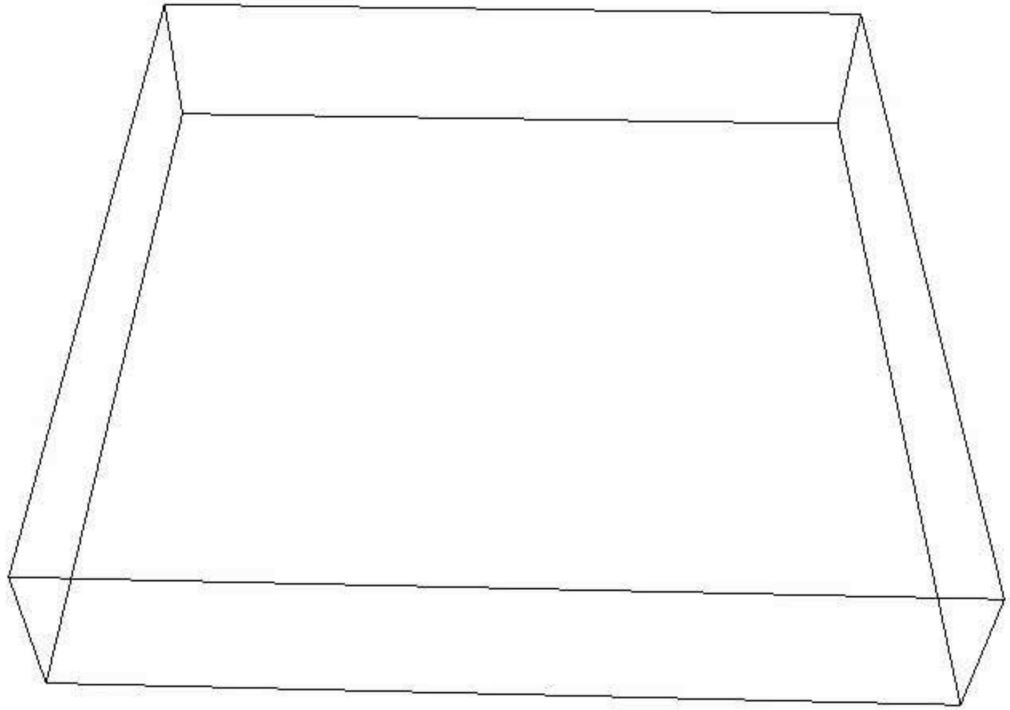


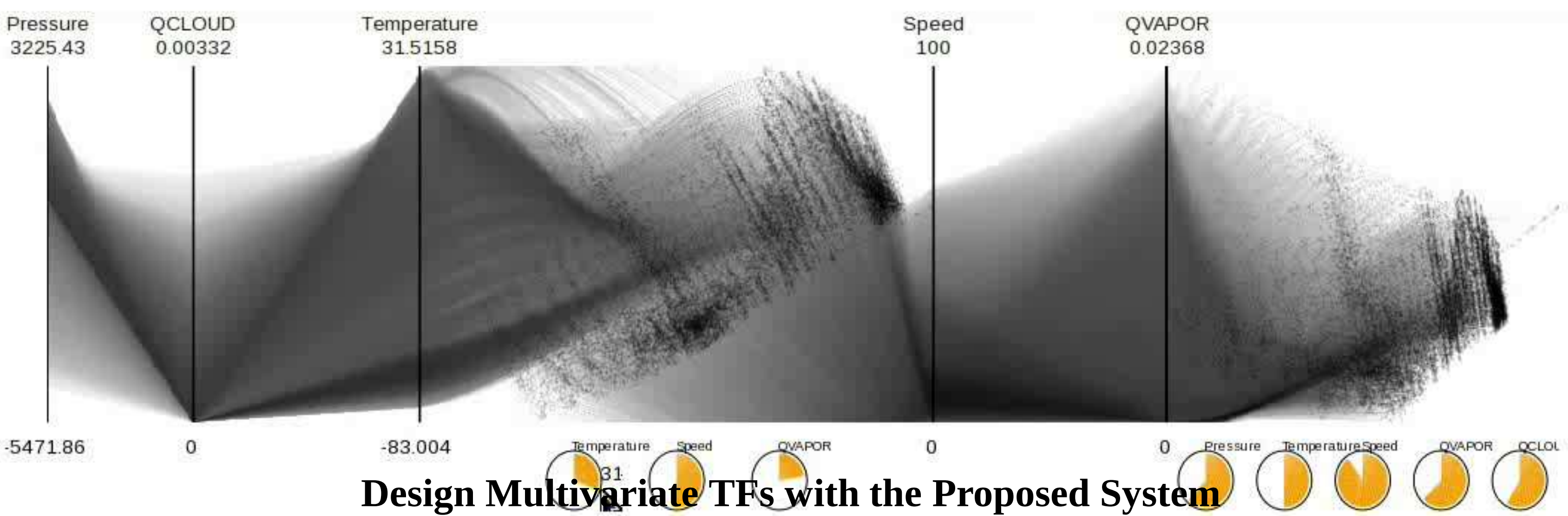
High Dimensional Transfer Function Design

- 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

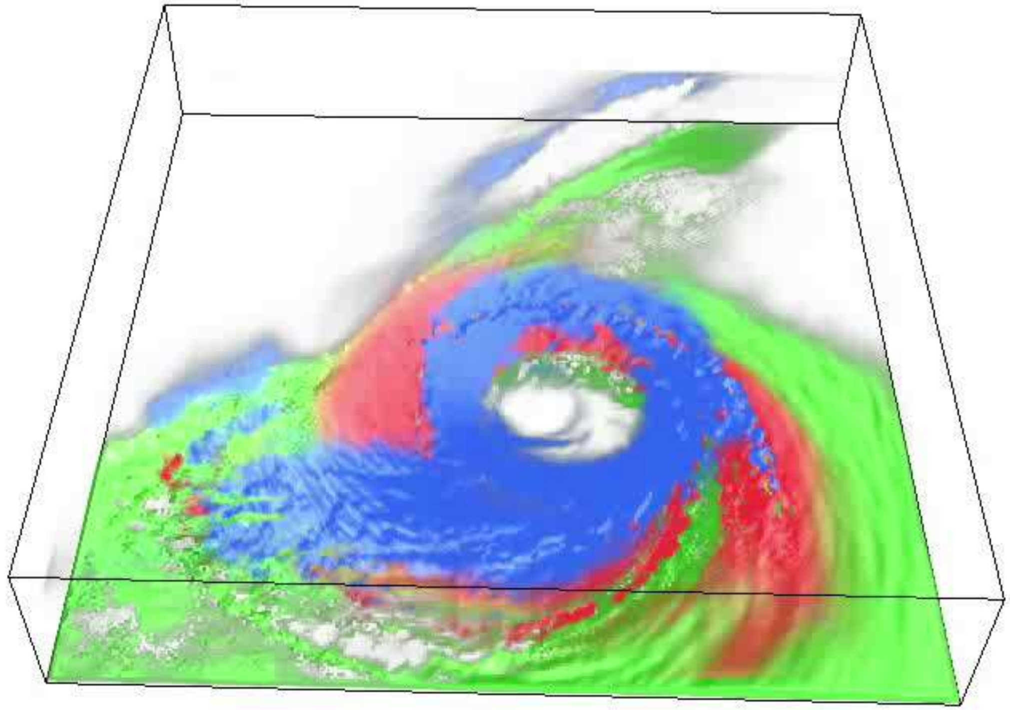
[Guo, Xiao &Yuan, PacificVis 2011]

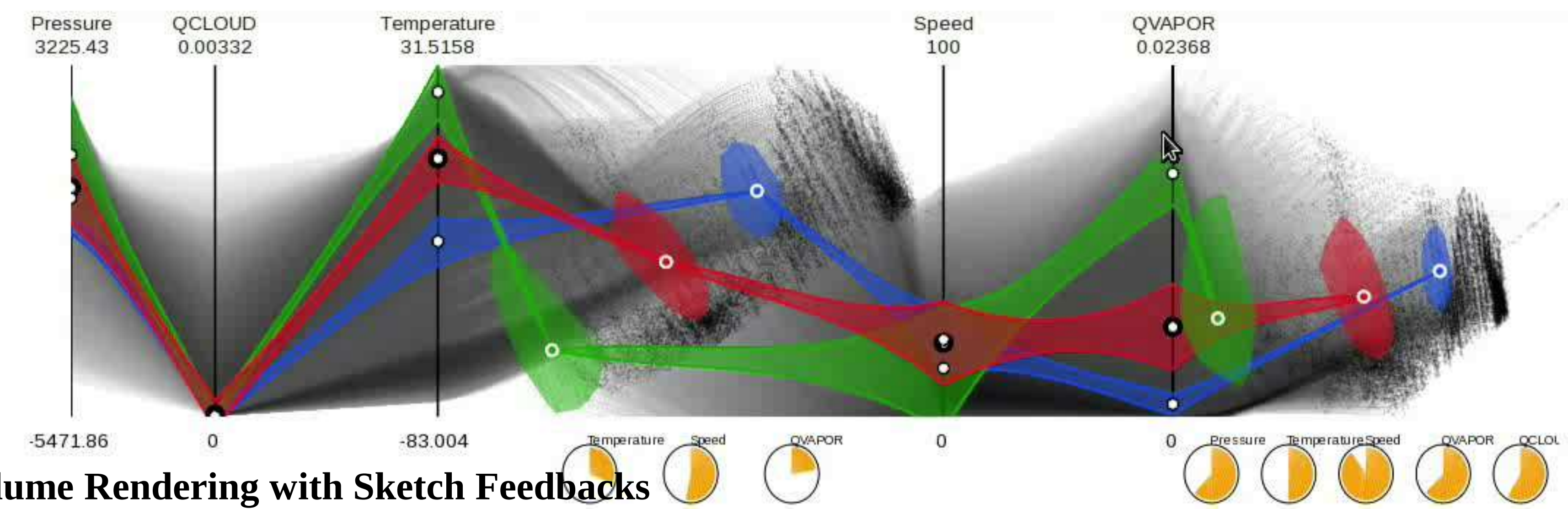






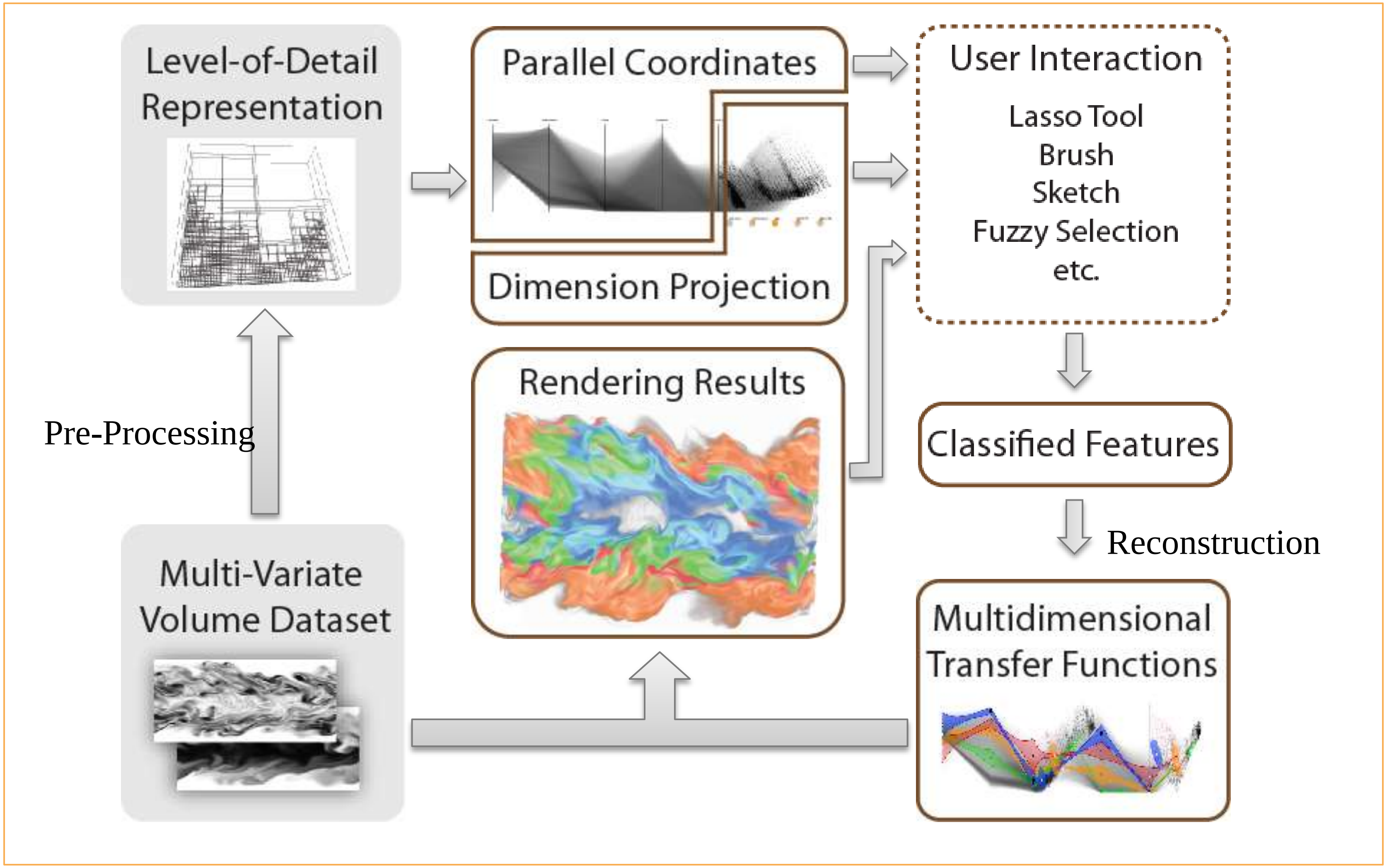
Design Multivariate TFs with the Proposed System



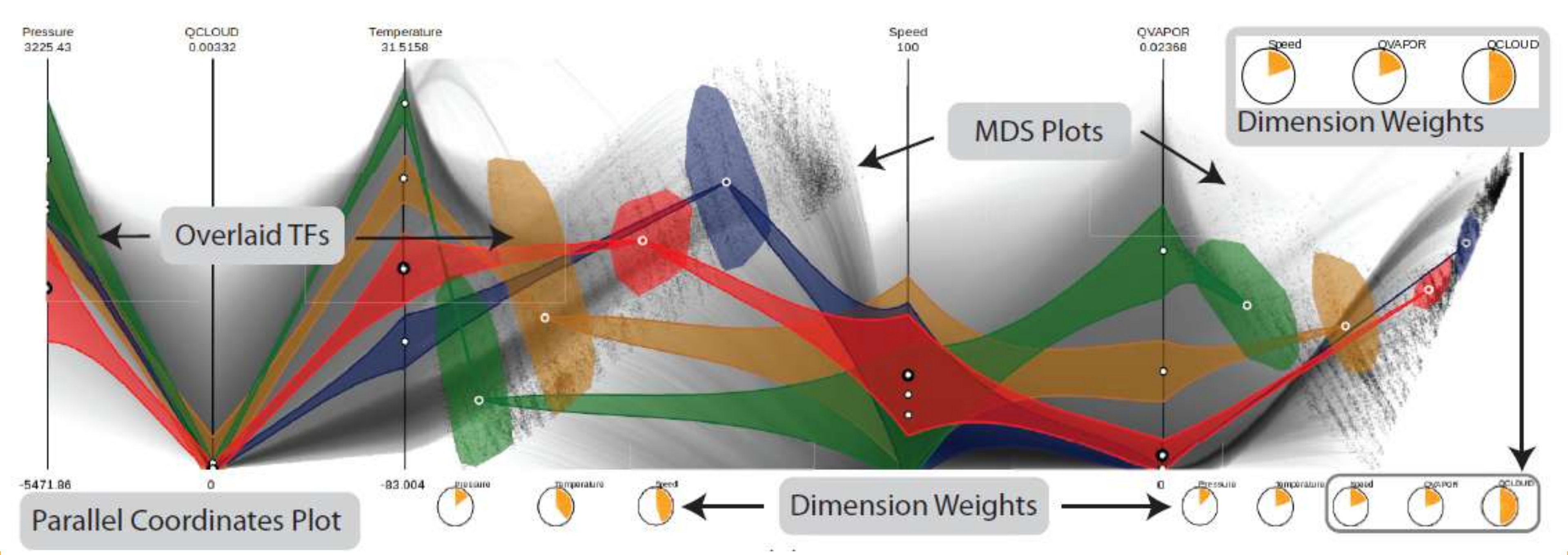


Volume Rendering with Sketch Feedbacks

System Pipeline (Non-parallel version)

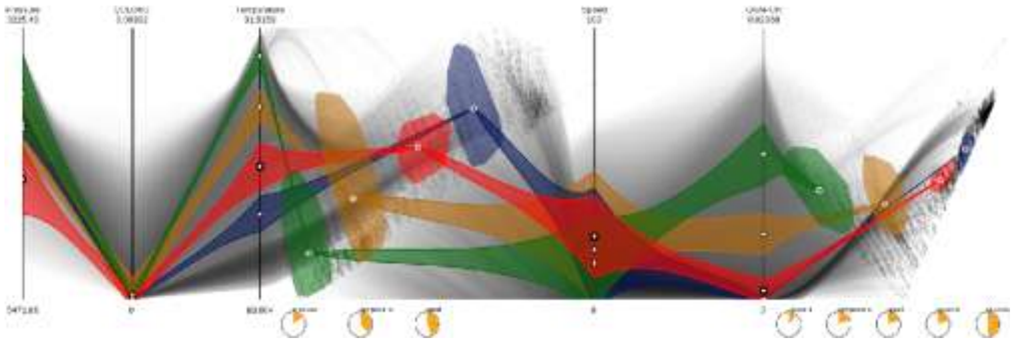


Transfer Function User Interface



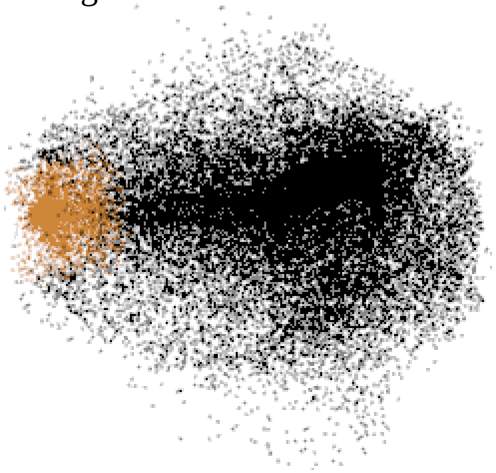
Transfer Function User Interface

- User interactions
  - Brushing on axes
  - Lasso on points
  - Magic wand on points

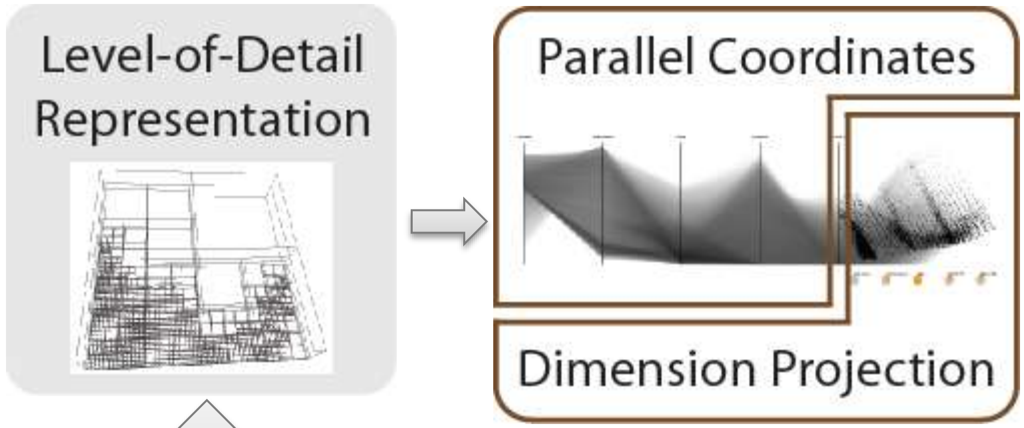


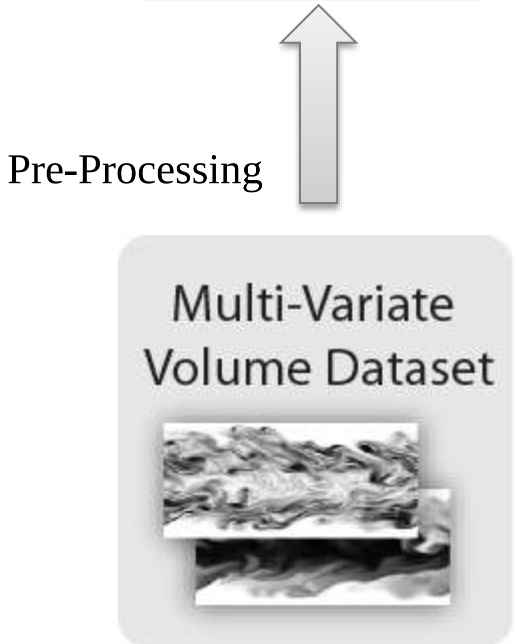
Lasso Tool

Magic Wand Tool



PCP and MDS Generation



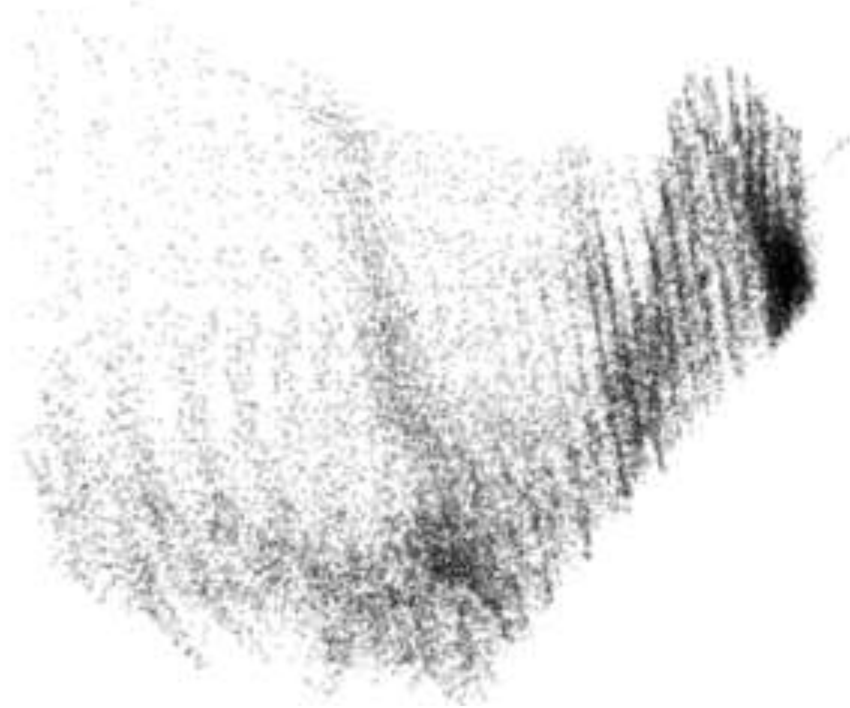


- Subroutines:
  - Embedding MDS Plot into Continuous PCP
  - Generation of Weight-Adjustable MDS Plot
  - Adaptive Rendering of Continuous PCP

MDS Plot

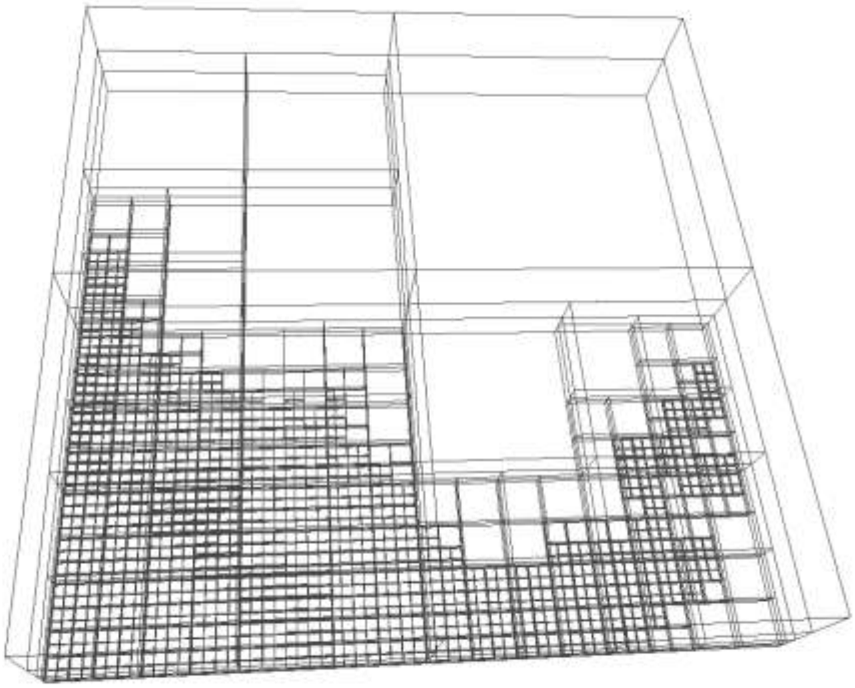
- Pivot MDS [Brandes and Pich 2007]
  - Low storage and low computational complexity

MDS works better for feature identification and selection



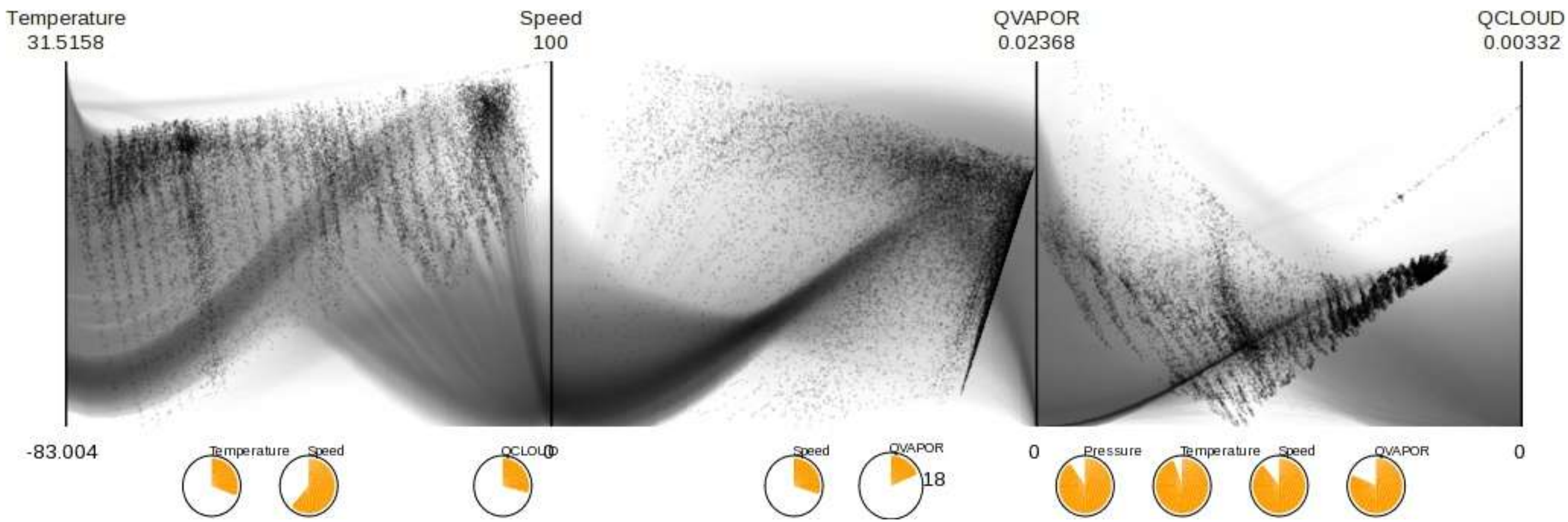
MDS Plot

- 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

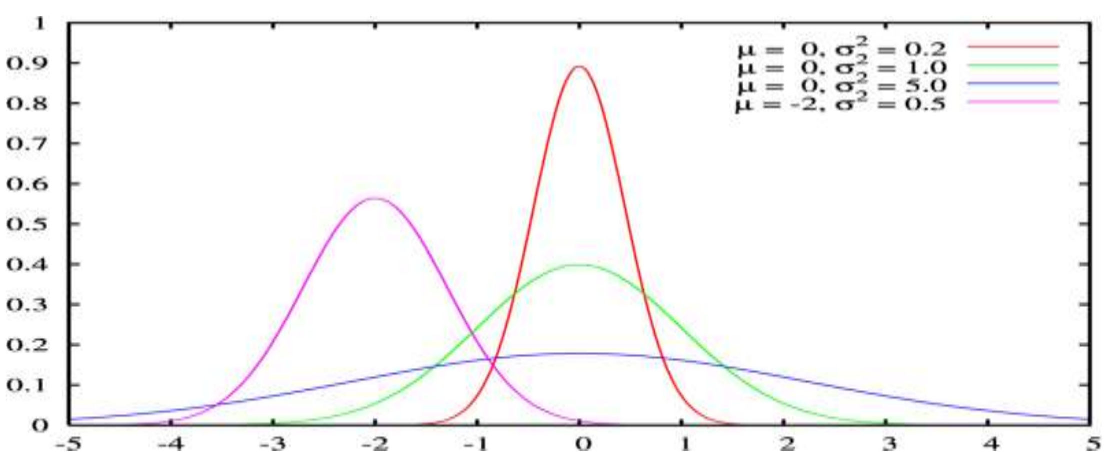


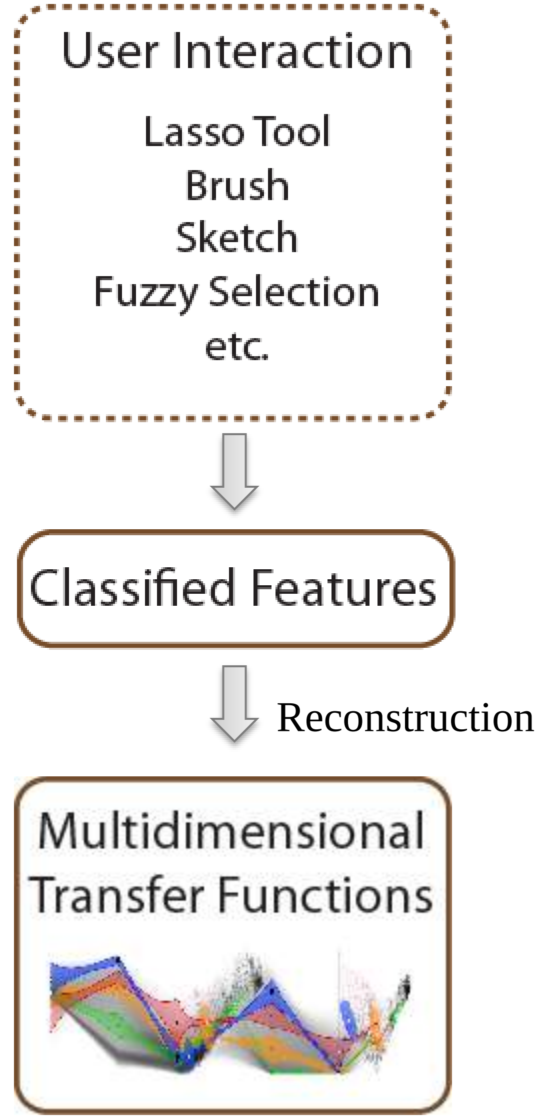
TF Construction

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

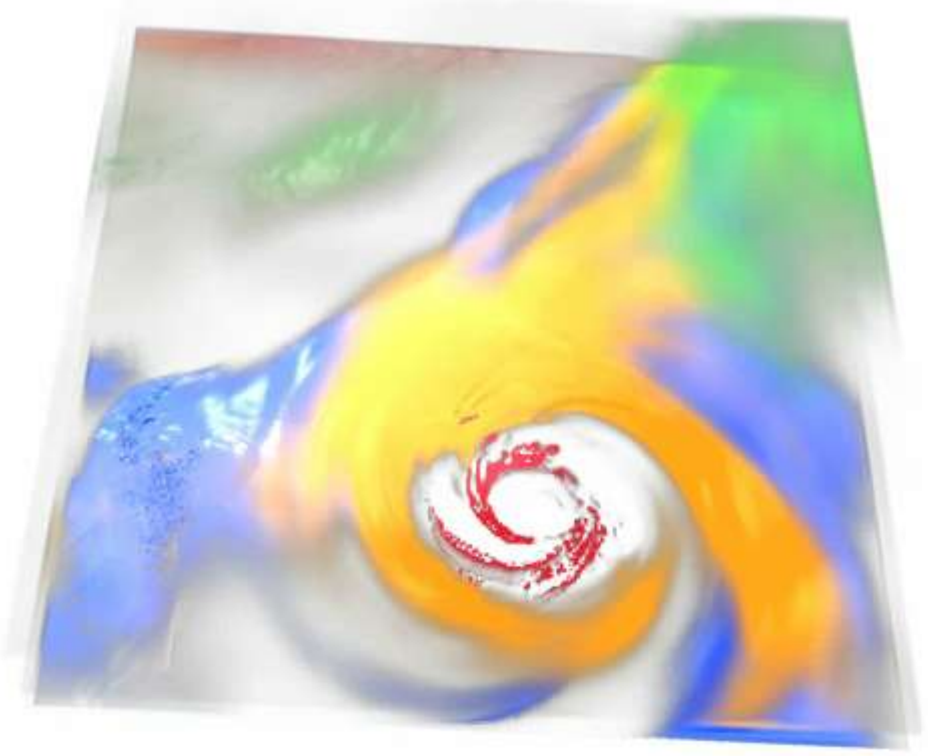
$$\sum_{k=1}^{m} \mu_k G_k(\mathbf{v}) = \sum_{i=1}^{n} \omega_i m_i G_i(\mathbf{v}) + \varepsilon(\mathbf{v})$$

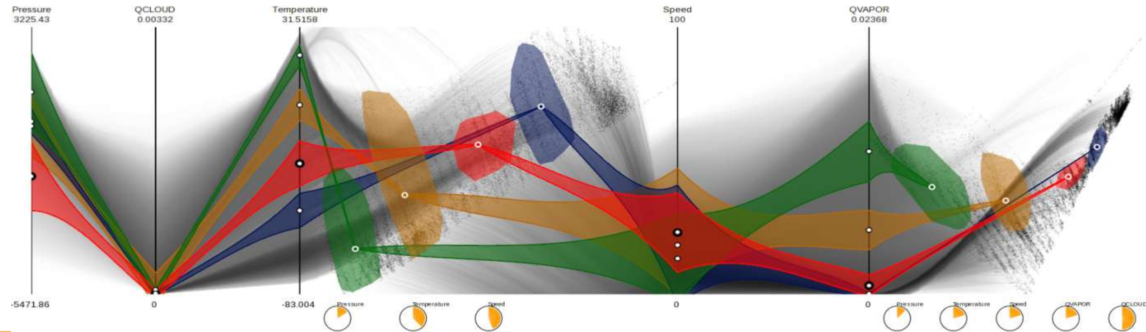
$$GTF(\mathbf{v}) = \alpha_{max} \sum_{k=0}^{m} \mu_k G_k(\mathbf{v})$$





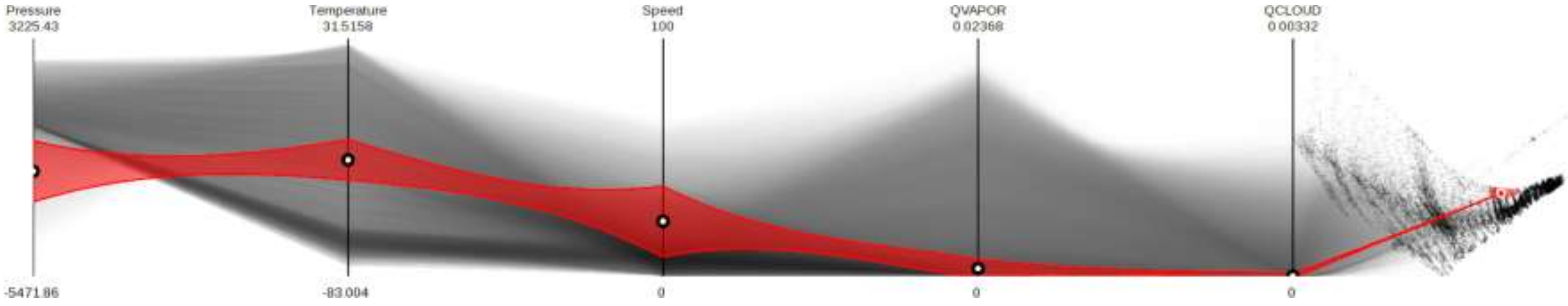
Hurricane Isabel





Hurricane Isabel

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

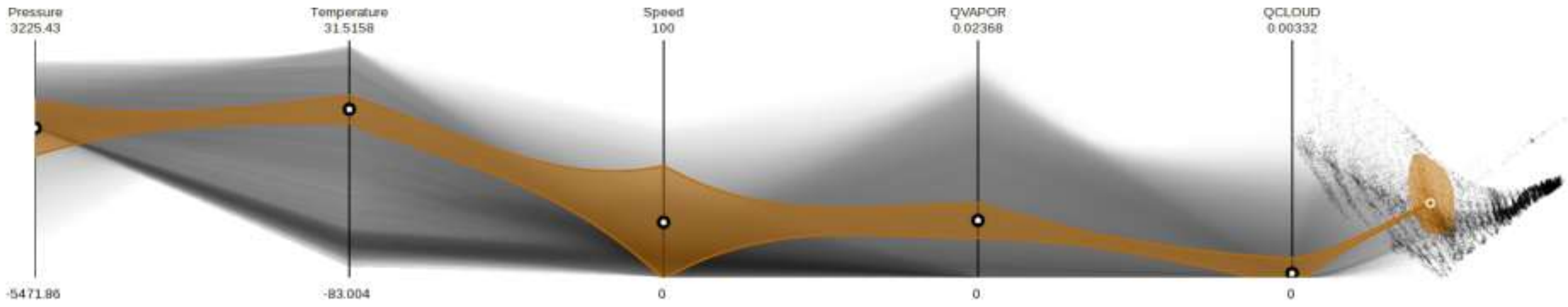


Hurricane Isabel

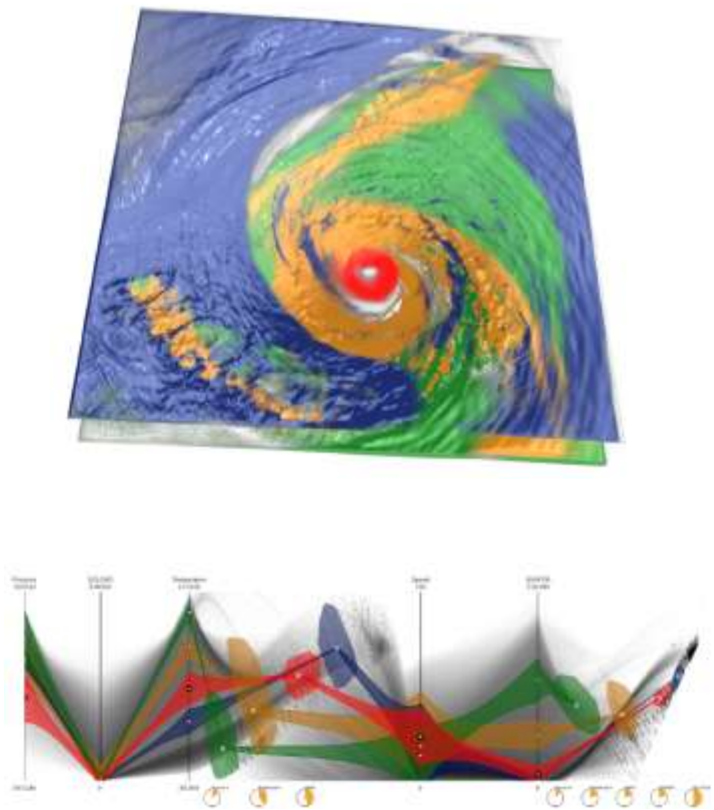
Yellow part:

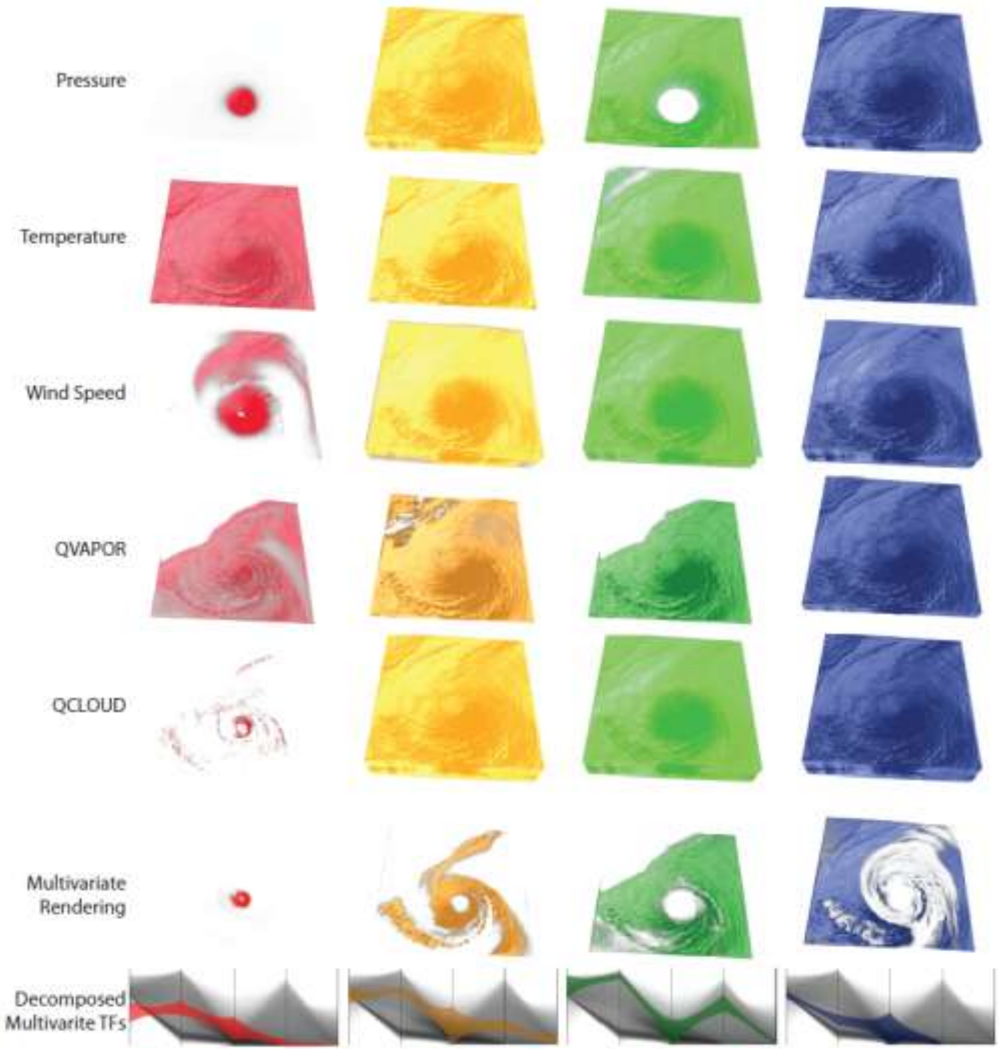
higher pressure

lower wind speed

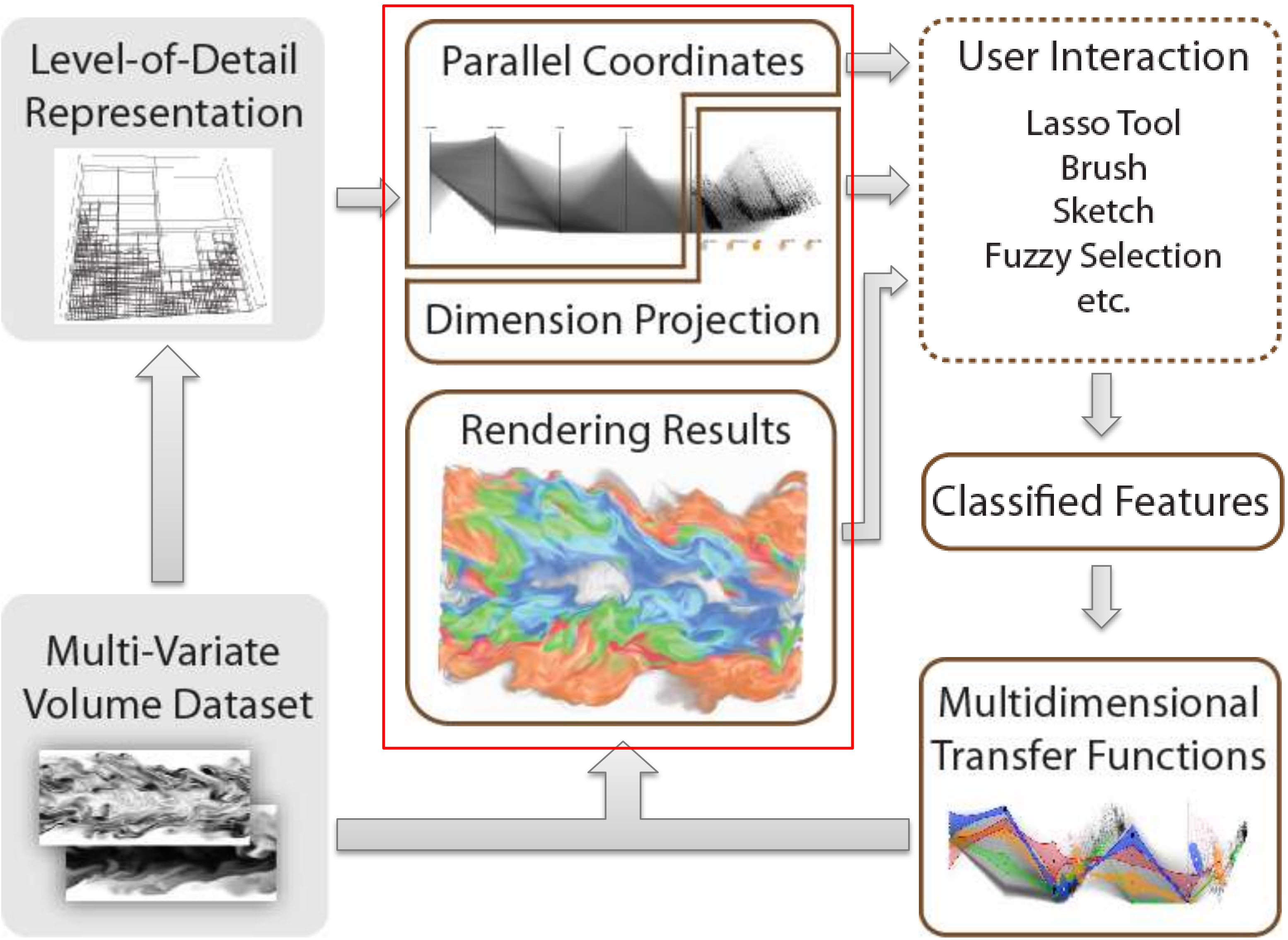


Hurricane Isabel

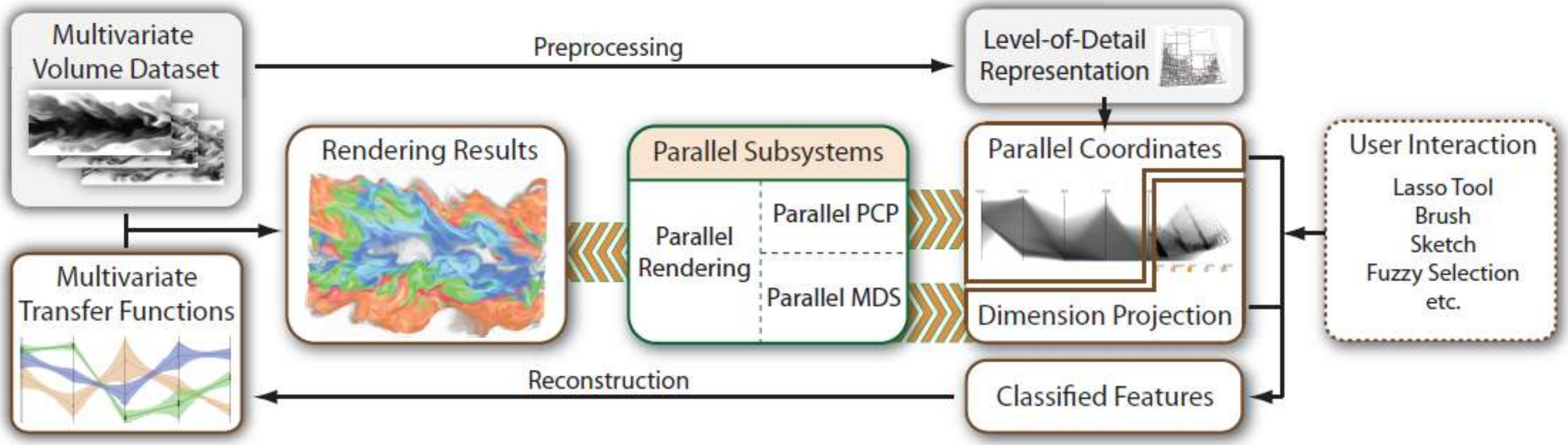




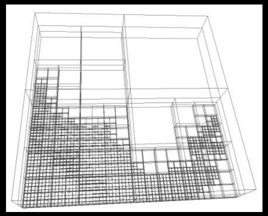
System Pipeline

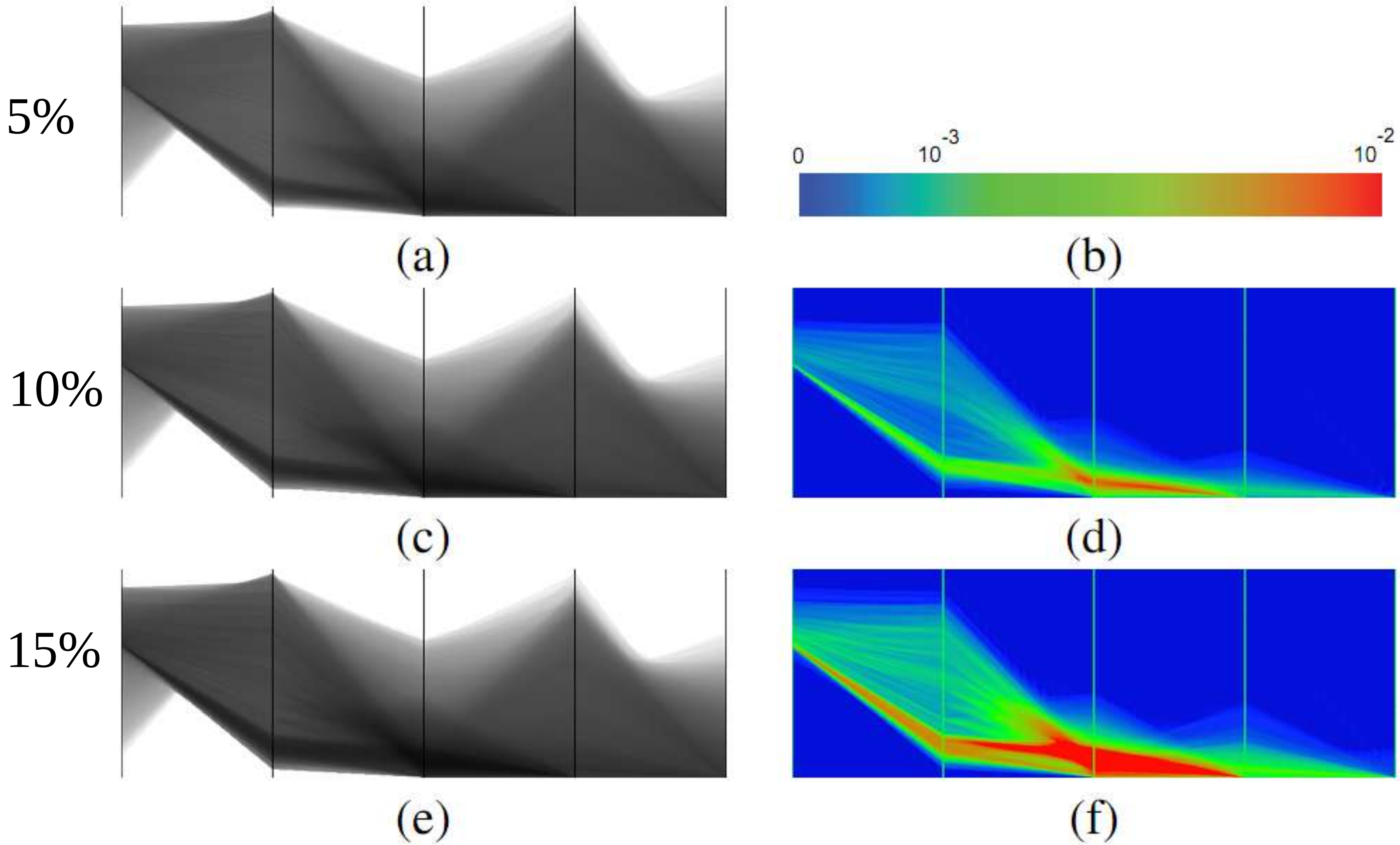


System Pipeline – Parallel Environment



Adaptive Continuous PCP

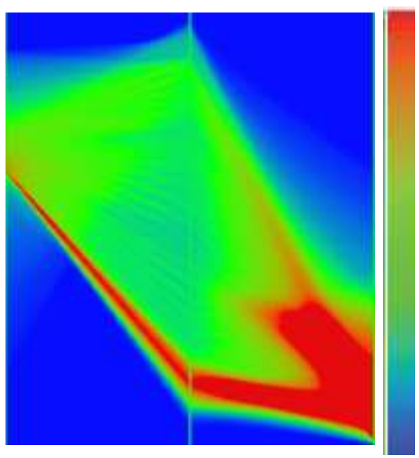




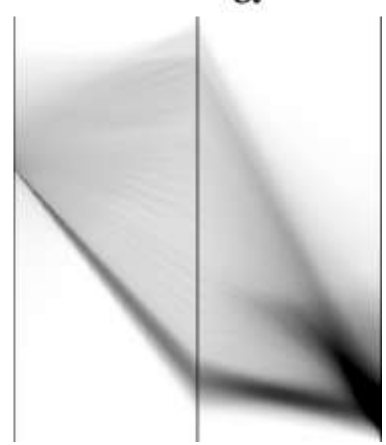
Adaptive Continuous PCP

- 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

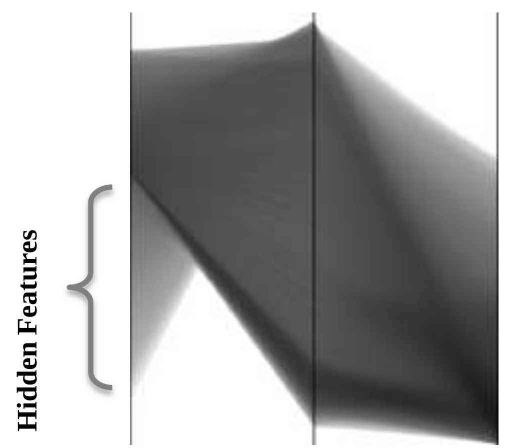
$$I' = 1 - \frac{ln((1-e^{-\alpha})I + e^{-\alpha})}{-\alpha}$$



Pseudo Color



Linear



Logarithm

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 Δ;
- Construct the double-centered dissimilarity matrix $\mathbf{C}(c_{ij})$ between pivot items and all input items, whose elements are defined as

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

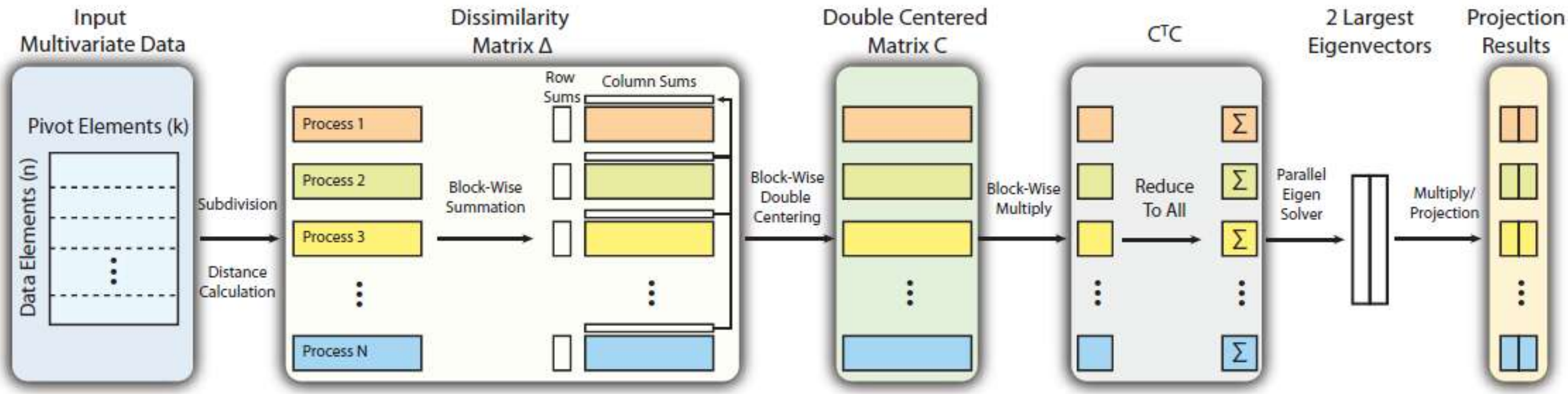
- Calculate the eigenvalues and eigenvectors of the matrix $\mathbf{C}^T\mathbf{C}$
- Pick up the largest d eigenvectors $\{\mathbf{v}\}$. The low dimension embedding is achieved by

$$\mathbf{x}_i = C\mathbf{v}_i,\ i \in \{0,\ 1,\ 2,\ \ldots,\ d\}$$

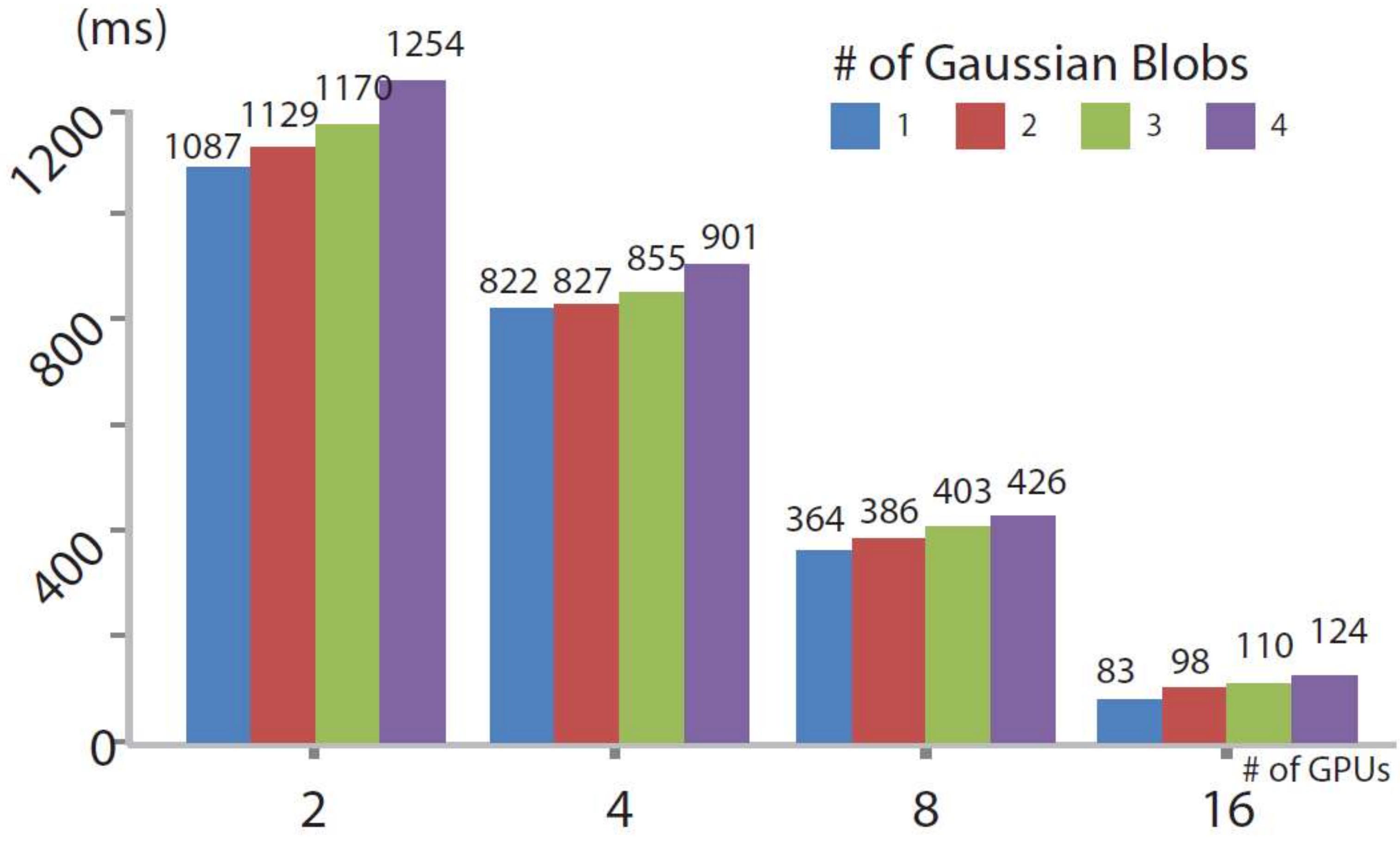
Pivot MDS Parallization

- Computation of squared distance matrix Δ
- Double centered sub-matrix $\boldsymbol{C}$
- Inner product $\mathbf{C}^T\mathbf{C}$
- Eigensolver

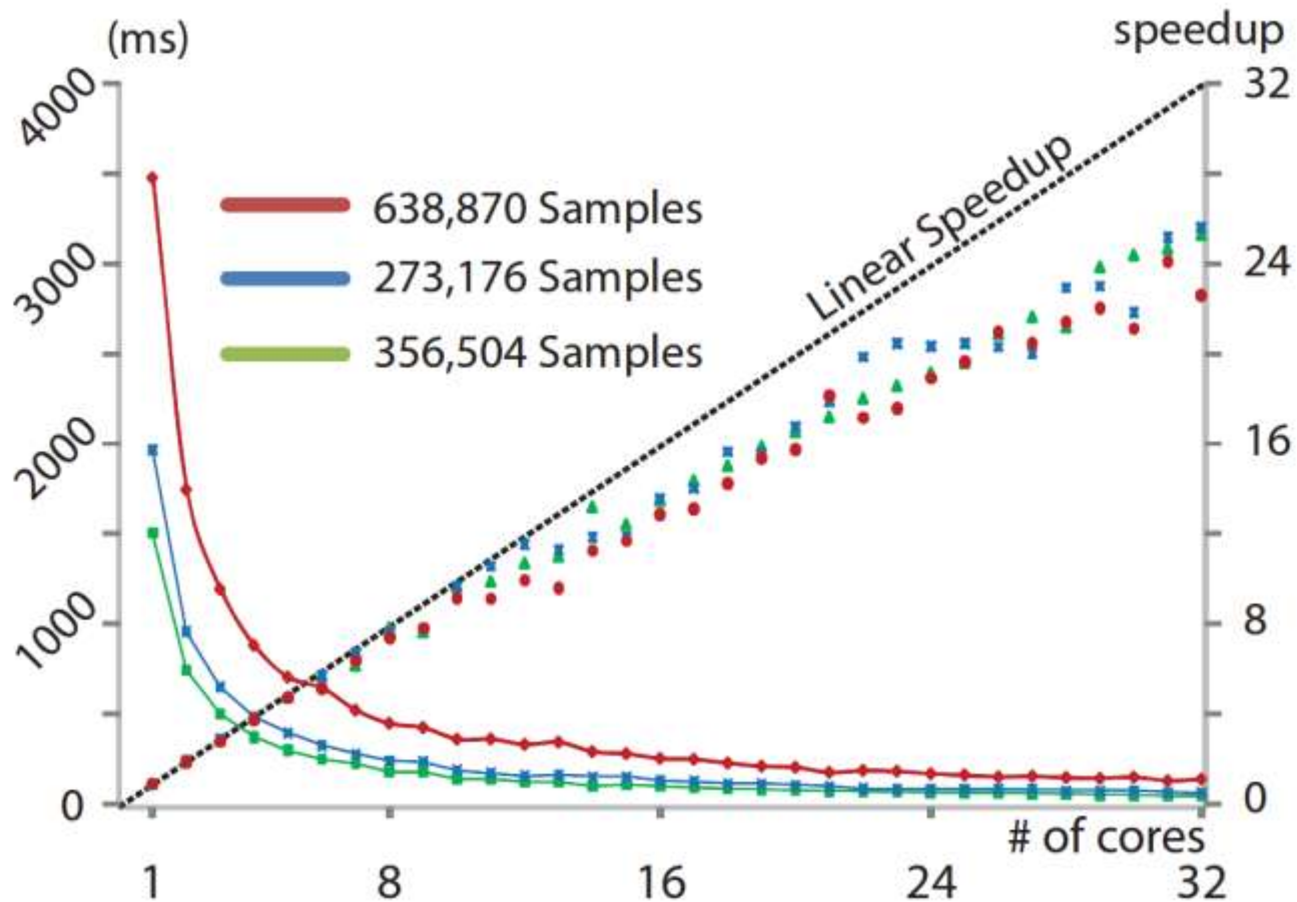
Scalable Pivot MDS



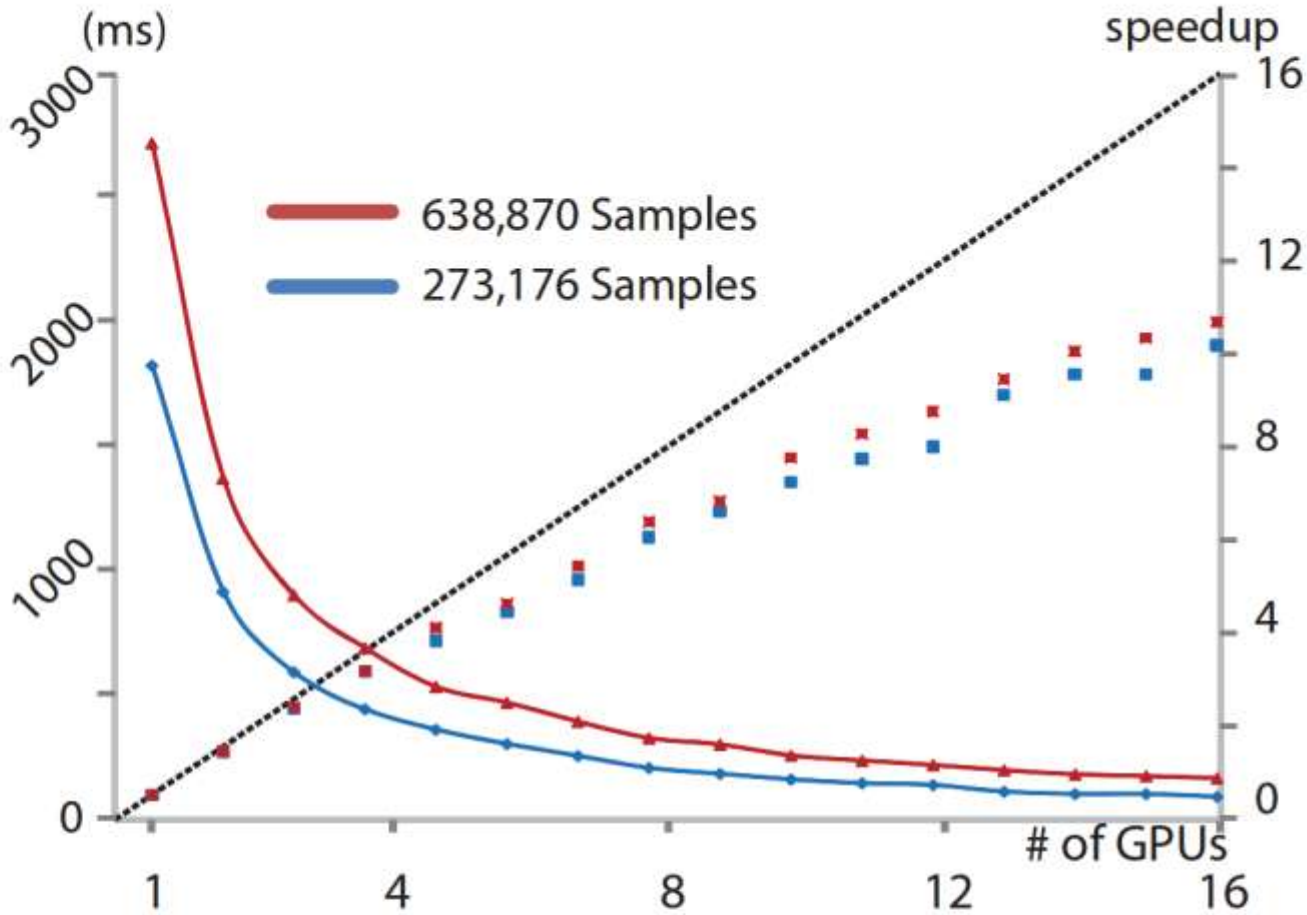
Performance –Parallel Multivariate Volume Rendering



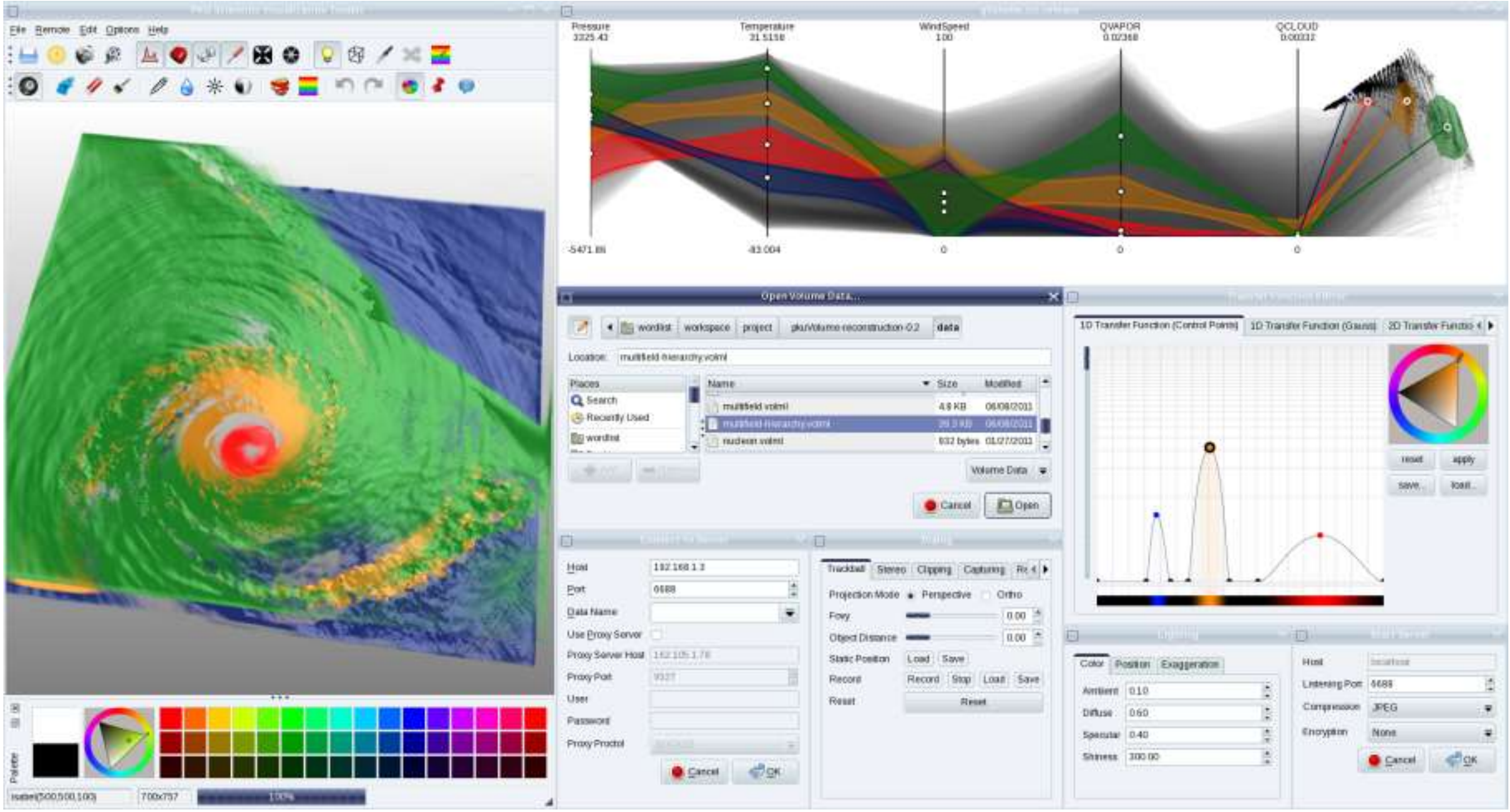
Performance –Parallel MDS Projection



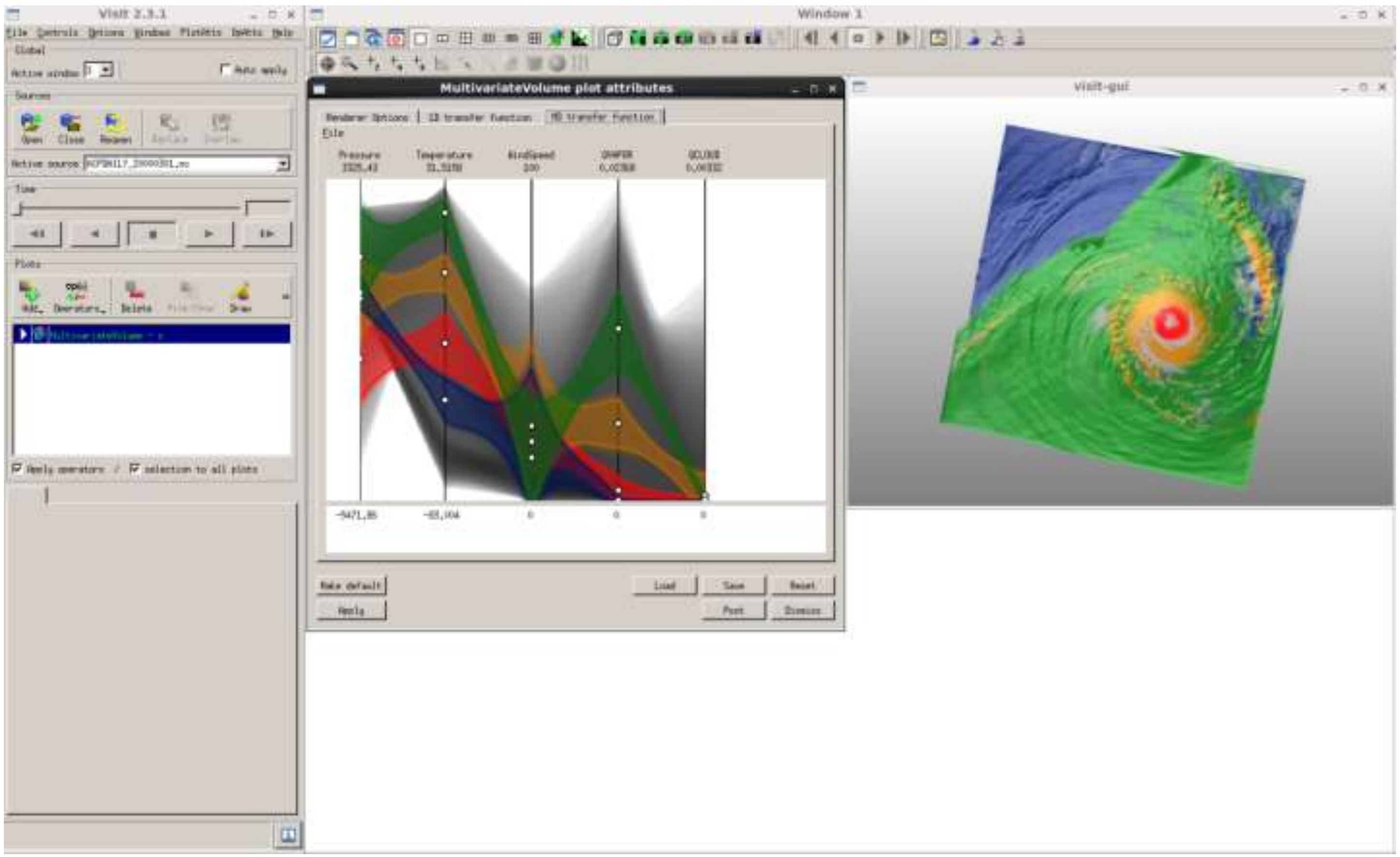
Performance –Parallel PCP Rendering



Integrated System Interface



VisIt Plug-in (ongoing)



Related Publications

- H. Guo, H. Xiao, and X. Yuan. "Multi-dimensional transfer function design based on flexible dimension projection embedded in parallel coordinates". In *Proceedings of IEEE Pacific Visualization Symposium 2011, pages 19–26, 2011*.
- H. Guo, H. Xiao, and X. Yuan. "Scalable Multivariate Volume Visualization and Analysis based on Dimension Projection and Parallel Coordinates". *IEEE Transactions on Visualization and Computer Graphics. Under revision.*

Acknowledgement

- Students
  - Hanqi Guo, Xiao He
- Collaborator
  - CNIC CAS (parallel computing environment)
- Funds
  - NSFC 60903062, NSFC 61170204
  - Beijing NSFC 4092021
  - 863 Project 2010AA012400
  - Chinese Ministry of Education Key Project No. 109001.

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