

Uncertainty Visualization

State of the Art

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Scientific Computing and Imaging Institute
University of Utah

NSF UQ Symposium
August 3, 2011

Advances in Technology



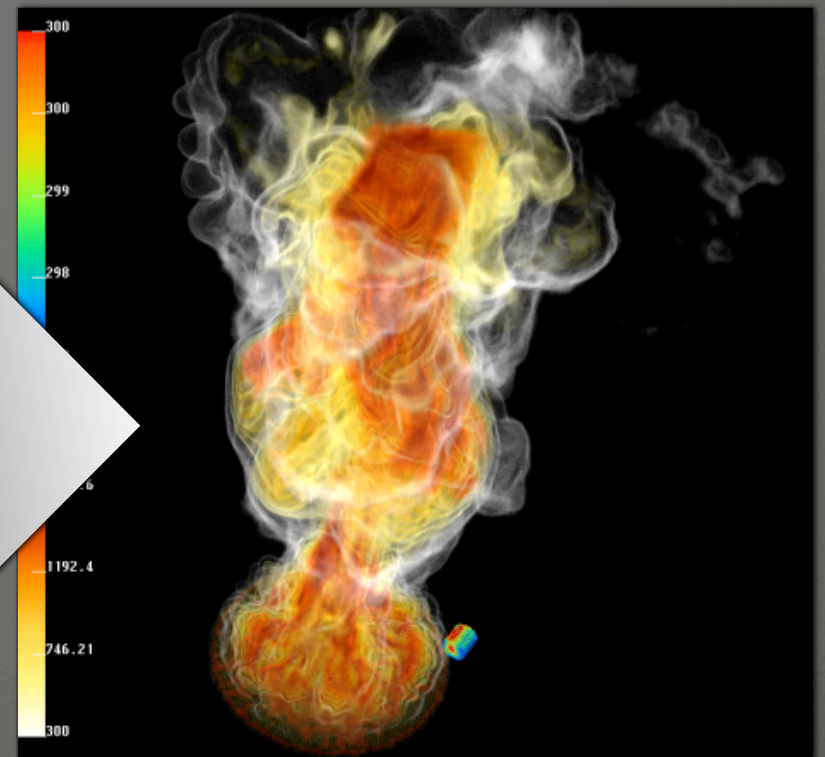
Jaguar Super Computer,
Oak Ridge National Lab

- More bandwidth, storage, & computational power
- Larger data sets:
 - Higher resolutions
 - Longer runs
 - More sophisticated models

All this leads to huge amounts of complex data!

Visualization is Communication

- Translate data into images, “see” the data
- Brings out relationships & features in data
- Lets scientists communicate within their fields and out to others



Scientists need to know about uncertainty too!

- What is the quality of the data?
- How much can the data be trusted?
- What is the risk in making decisions on the data?

$$3 + 2 = 6$$

Error

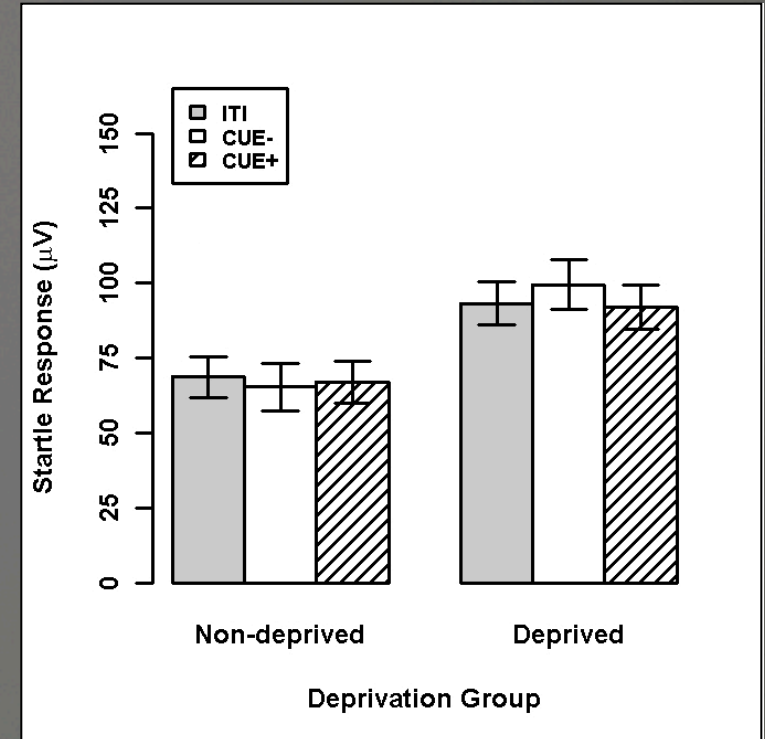
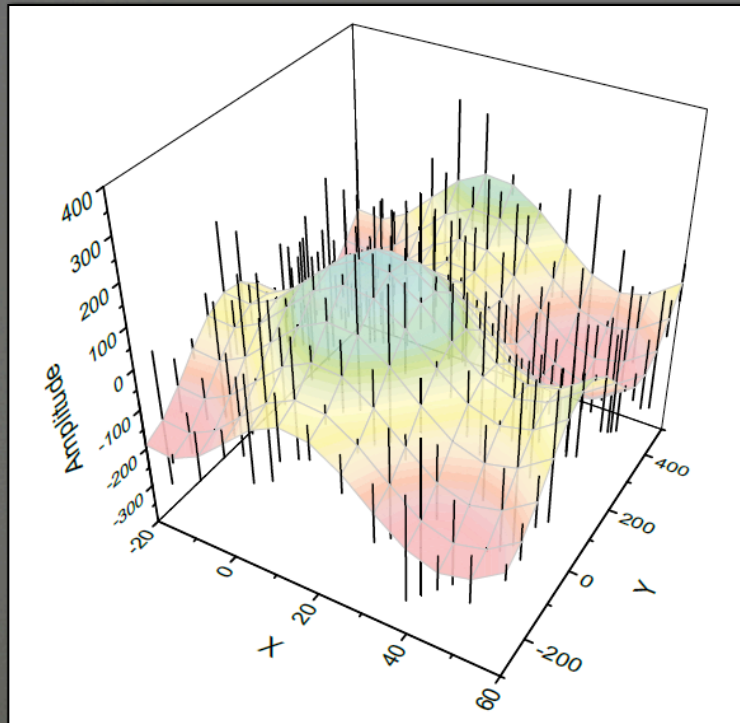


Motivation

- Most scientific papers are expected to include uncertainty information with data
- Typically 2D graphs with error/uncertainty
 - *If important in publications it should be important to visualization*
- Accurate & complete visualization primary goal
- Absent due to difficulty to visually express

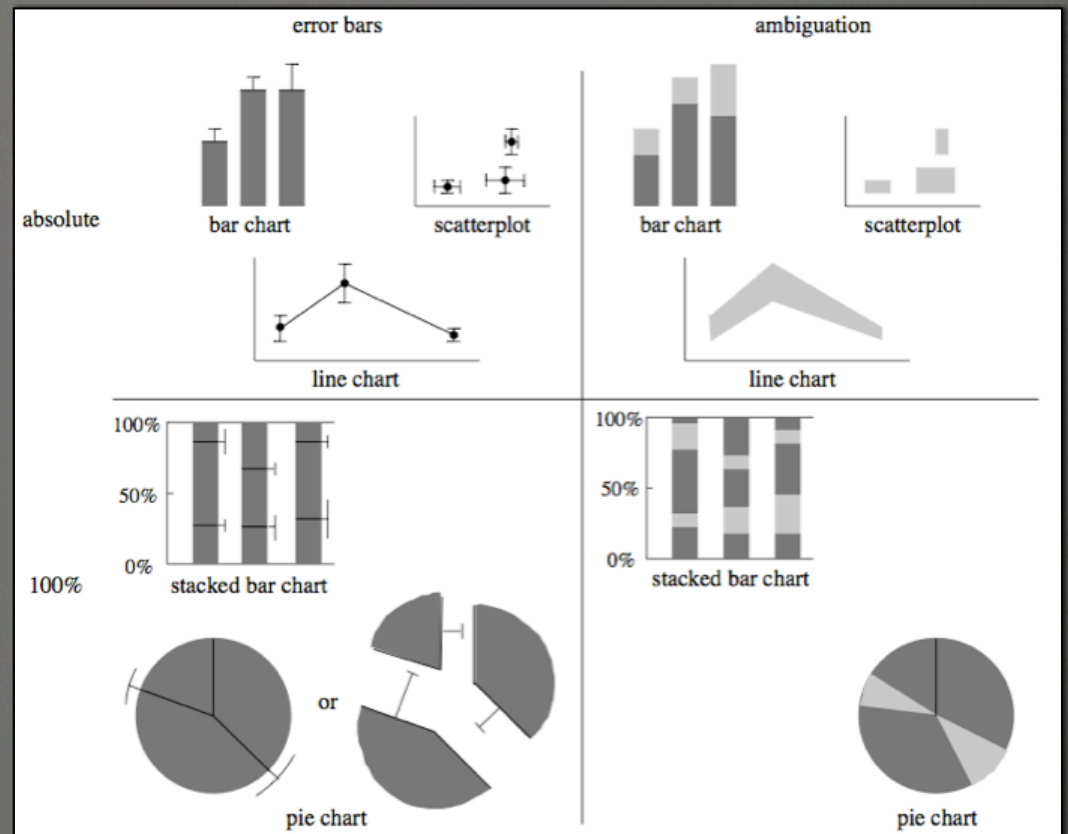
Traditional Display of Uncertainty

- Error bars
 - convey accuracy by amount of +/- error
 - std dev or std error



Bounded Uncertainty

- Numeric interval guaranteed to contain data value
- No assumptions about the pdf within the interval

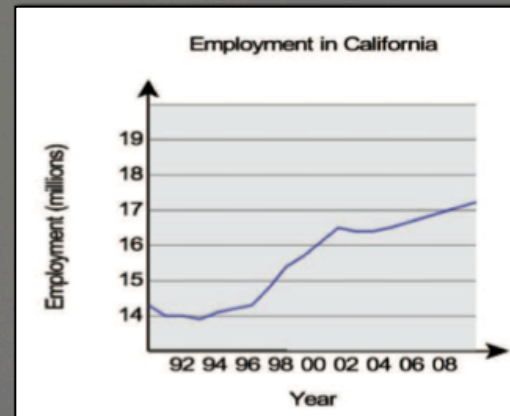


Statistical Uncertainty

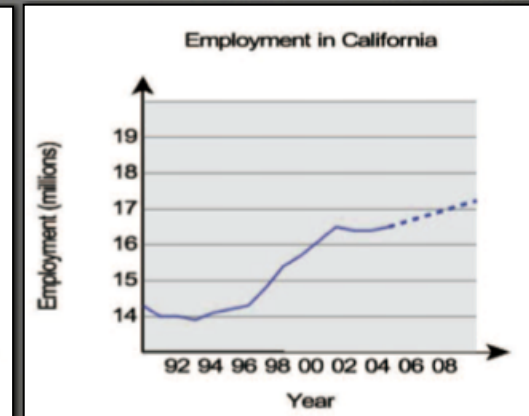
Bounded Uncertainty

Information Uncertainty

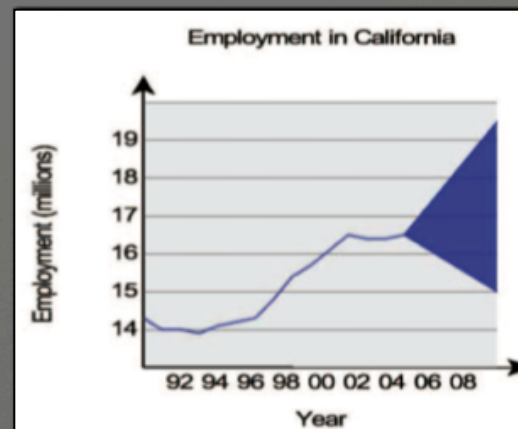
- Indication of how much confidence
- Qualitative rather than quantitative
- Spreadsheet interface characterizes the data



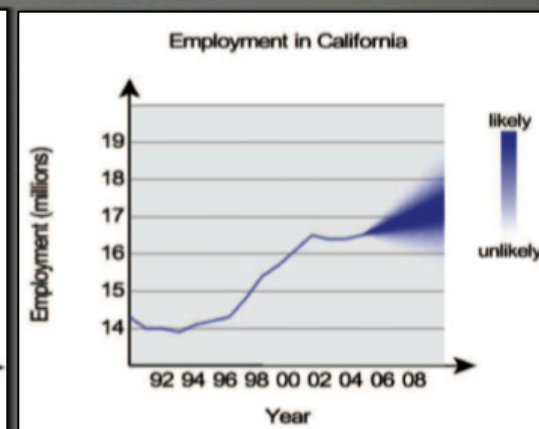
Average Growth



Estimated Growth



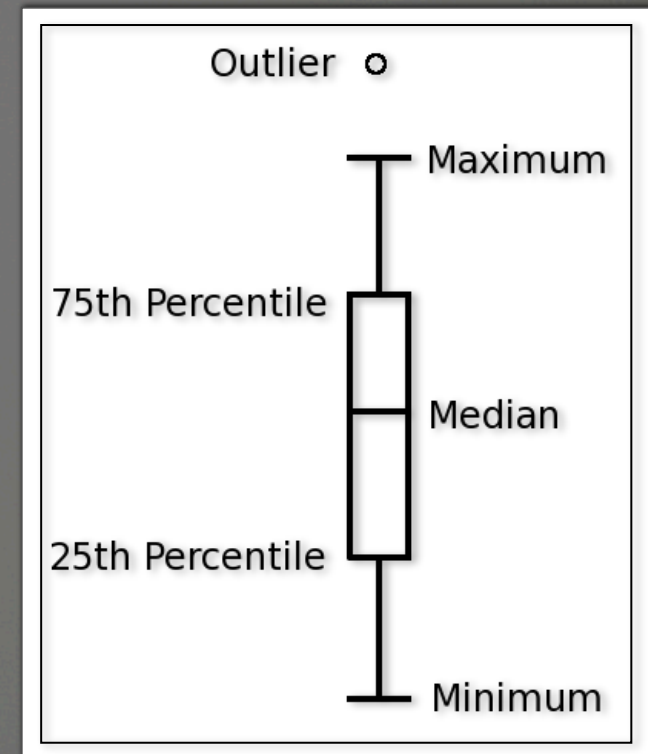
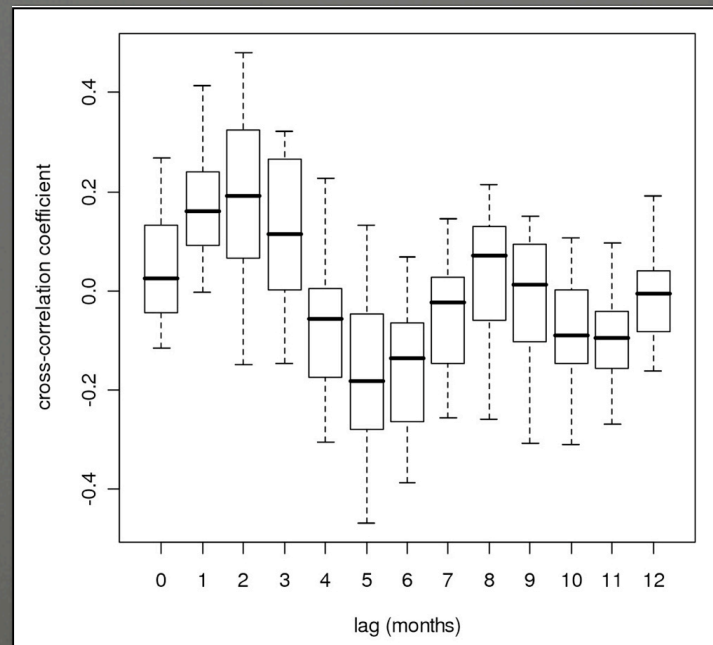
Possible Growth



Likely Growth

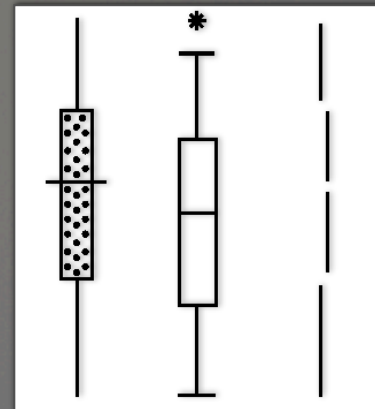
Traditional Display of Uncertainty

- Boxplots
 - Quartile range including median
 - Outliers
 - Assume Gaussian



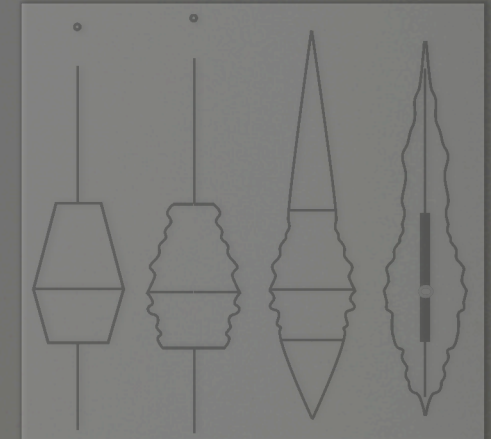
Boxplot Modifications

- Visual Modifications
 - Refinement for aesthetic purposes
- Density indications
 - Use the box sides to encode
- Data Characteristics
 - sample size, confidence levels
- Additional Statistics
 - skew, modality



Mary Eleanor Spear.
Charting Statistics.
McGraw-Hill, 1952

Edward Tufte,
The Visual Display of
Quantitative Information.
Graphics Press, 1983.

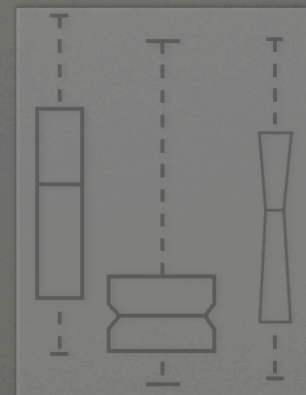


Y. Benjamini.
Opening the box of a boxplot.
TAS, 42(4), 1988.

W. Esty, J. Banfield.
The box-percentile plot.
JSS, 8(17), 2003.

John W. Tukey.
Exploratory Data Analysis.
Addison-Wesley, 1977.

J. Hintze, R. Nelson.
Violin plots.
TAS, 52(2), 1998.



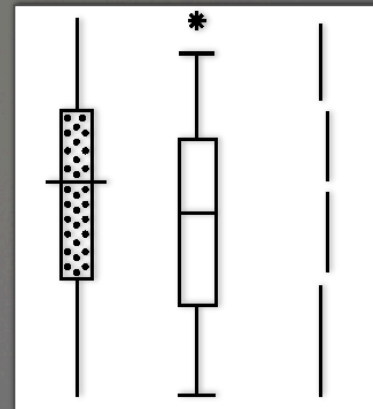
R. McGill, J. W. Tukey, W.A. Larsen,
Variations of box plots.
TAS, 32(1), 1978.



C. Choonpradub, D. McNeil.
Can the box plot be improved?
Songklanakarin J Sci Technol,
27(3), 2005.

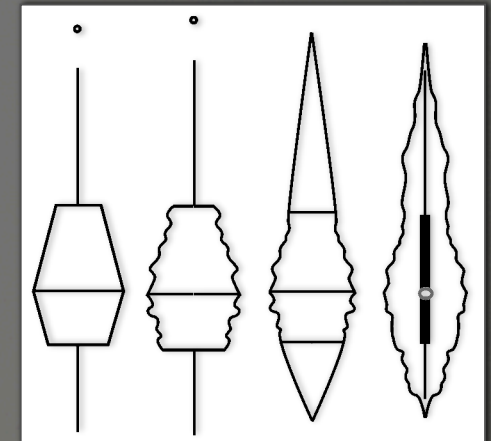
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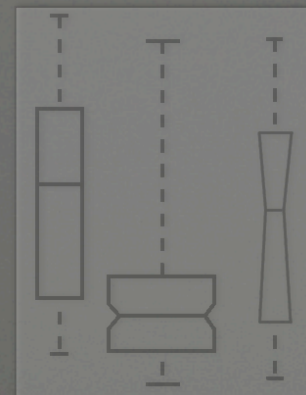


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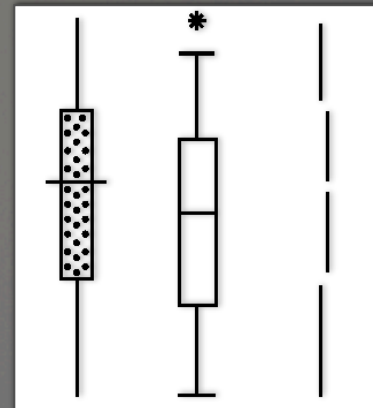
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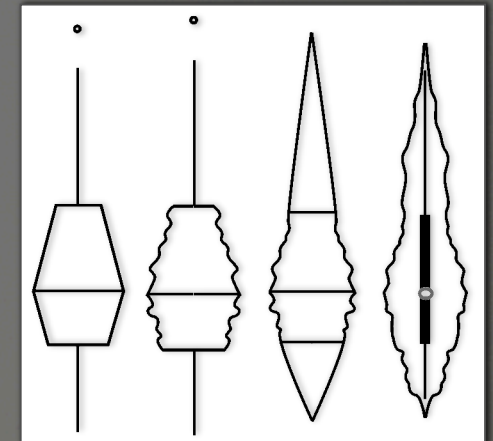
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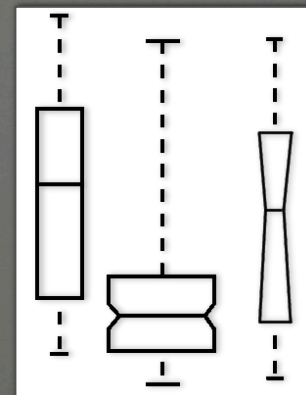


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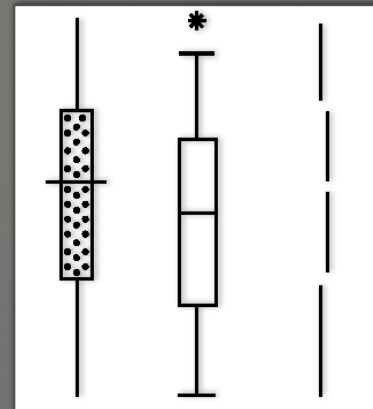
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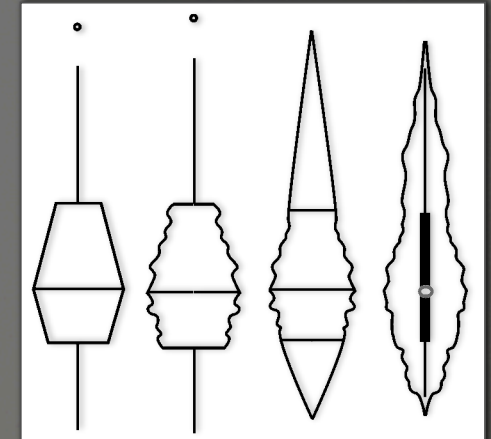
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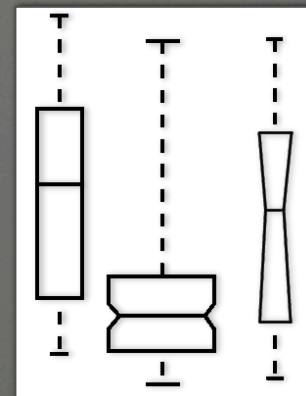


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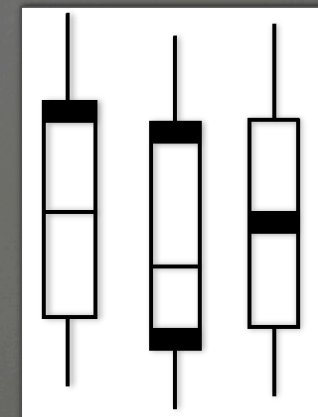
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Addison-Wesley, 1977.



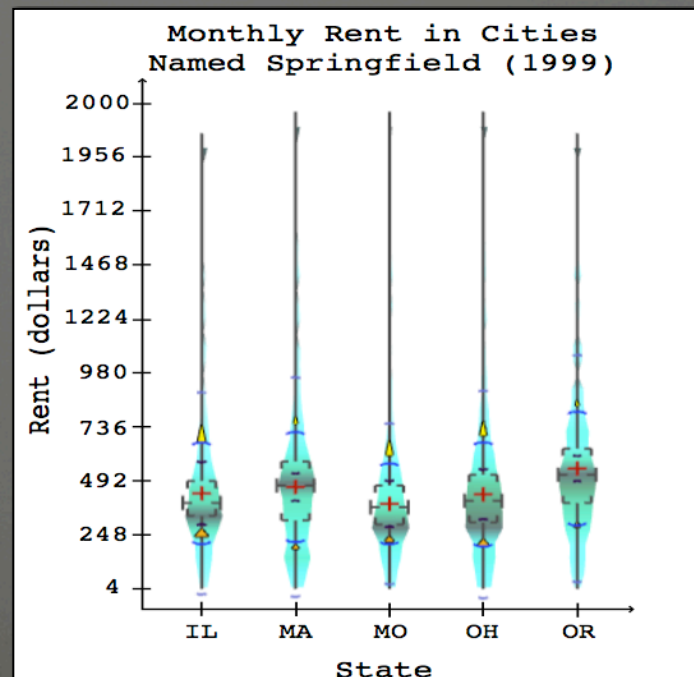
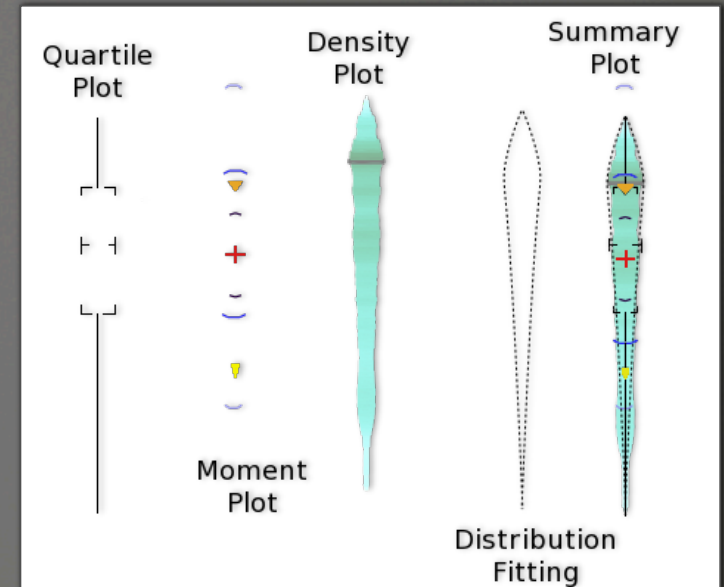
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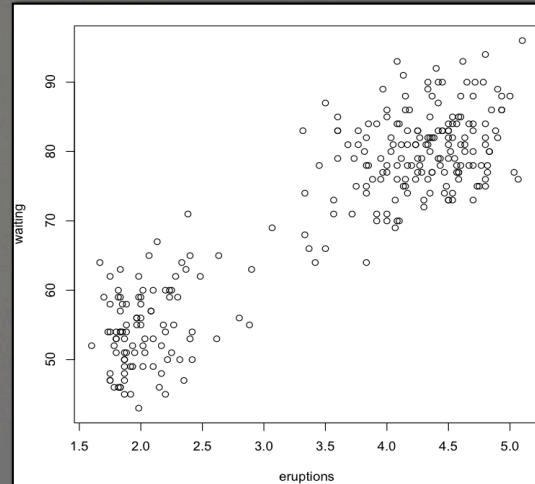
The Summary Plot

- Augment boxplot with numerous display techniques
- Emphasize characteristics other than mean/variance
- Indicate quantity & location of uncertainty

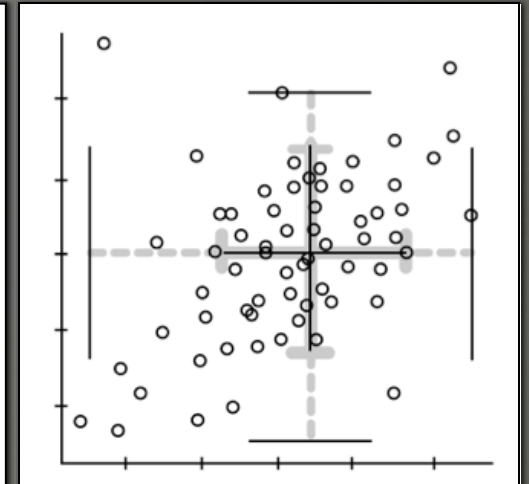


2D Box Plots

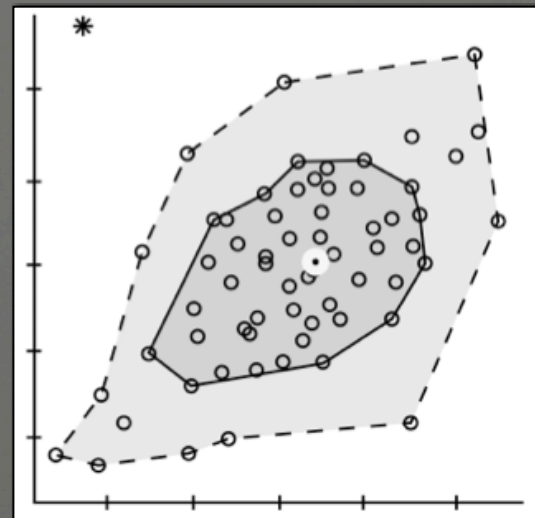
- Scatterplots
 - 2D position of samples
- RangeFinder Plot
 - 1D boxplot per axis
- Two-Dimensional Boxplot
 - Robust line partition
- Bagplot
 - Halfspace depth (spatial quartiles)



Scatterplot

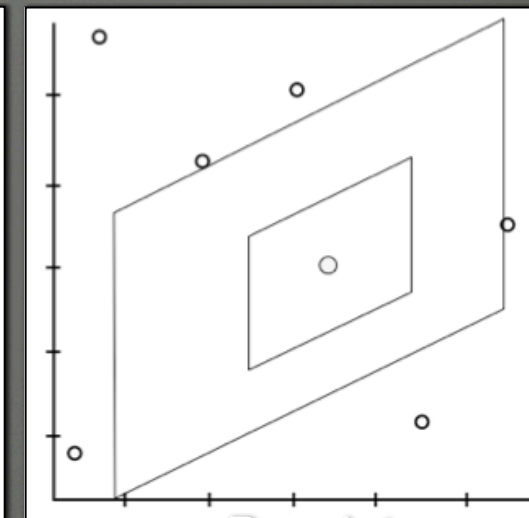


Rangefinder Plot



Two-Dimensional Boxplot

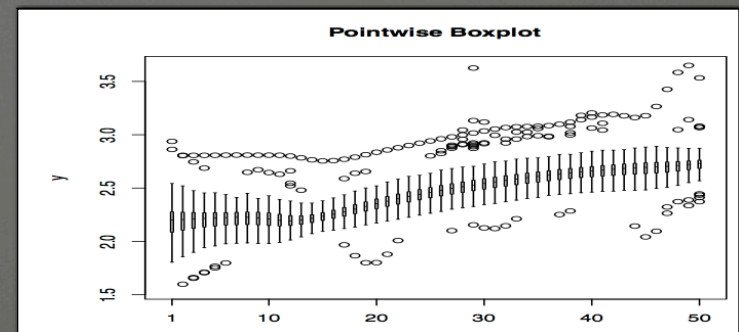
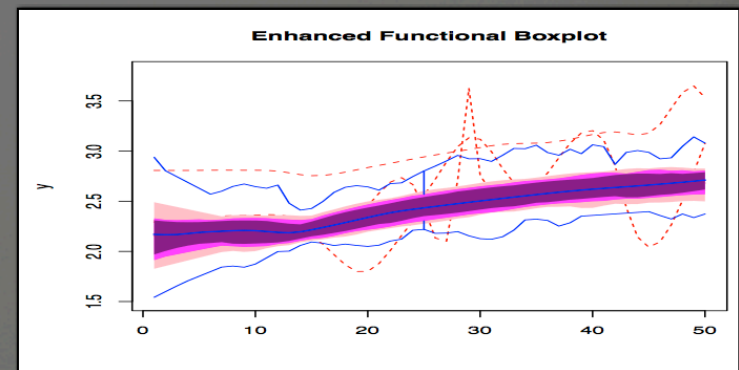
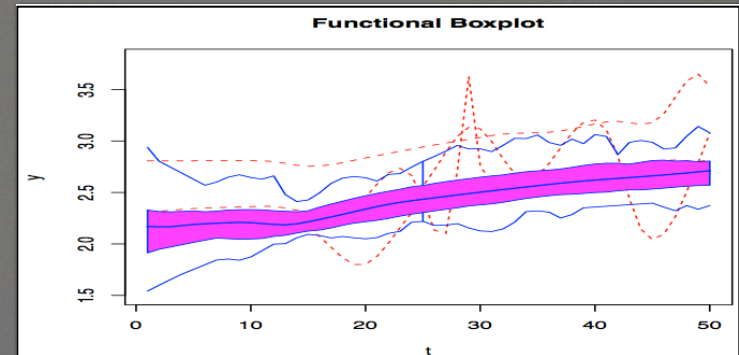
P. Tongkumchum,
Two-dimensional box plot.
Songklanakarin J Sci Technol, 27(4), 2005.



Bagplot

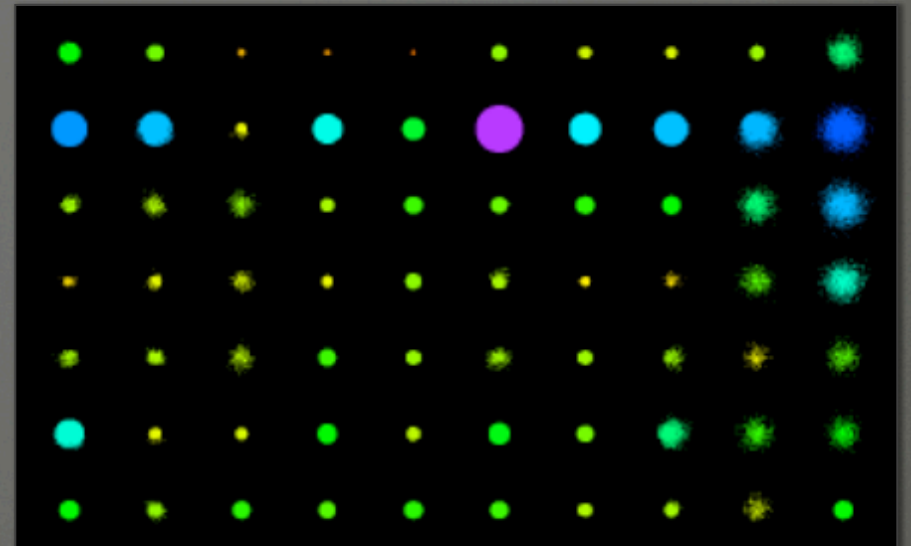
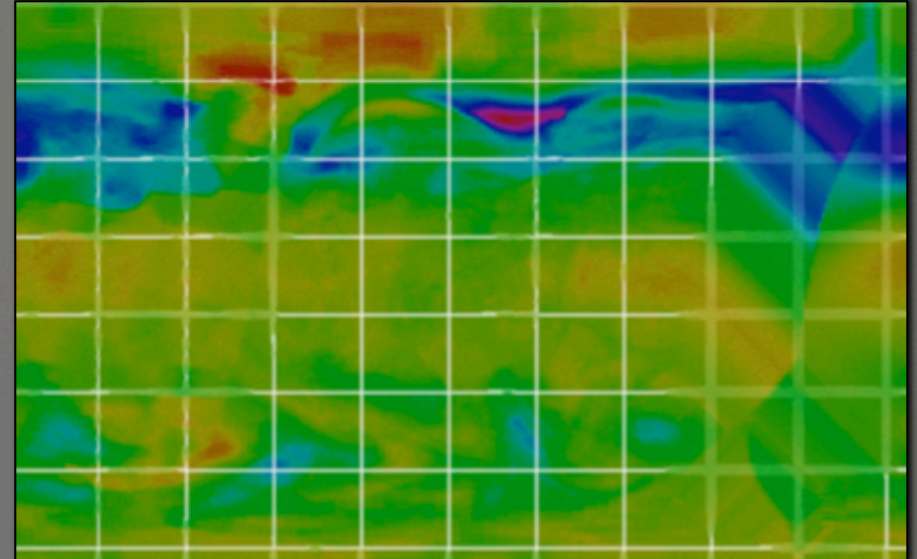
P.J. Rousseeuw, I.
Ruts, J. Tukey.
The bagplot: A
bivariate boxplot.
TAS, 53(4), 1999.

Functional Box plot



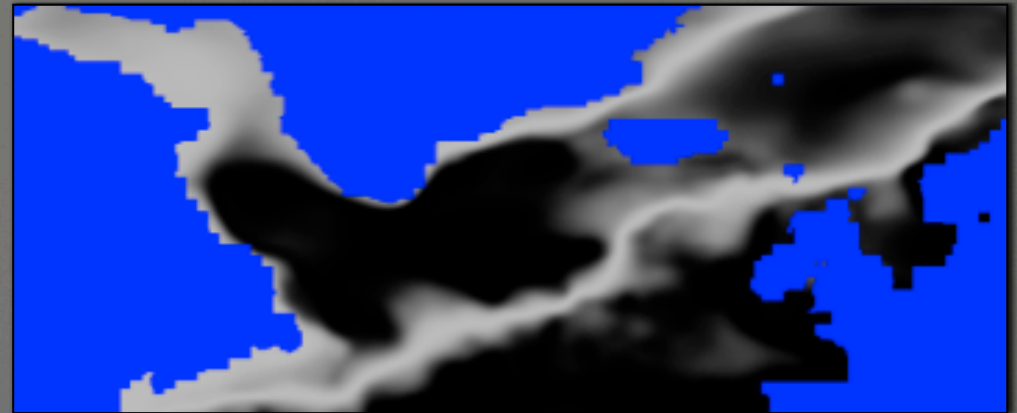
2D Annotation

- Modulate annotation lines or glyphs with uncertainty
- Minimal interference
- U n c e r t a i n t y n o t
e m p h a s i z e d

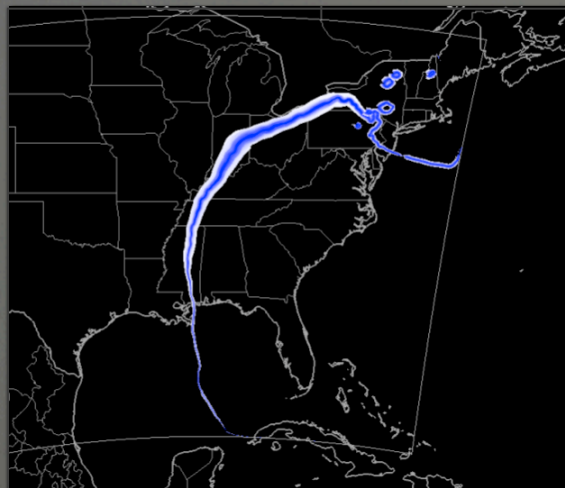


Contouring

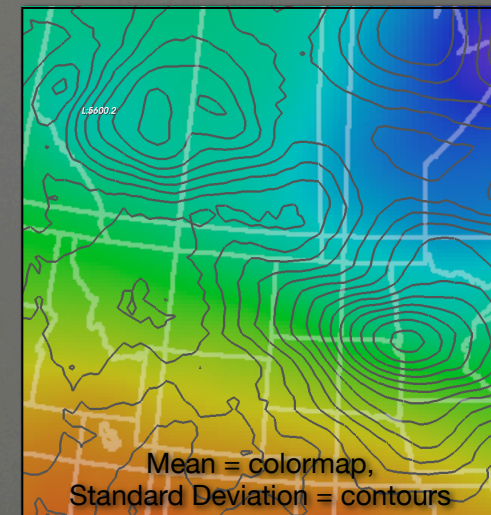
- Contours follow the line of a specific data value (ex. terrain map)
- Standard Deviation
- Fuzzy contours
- Graduated contours



R.S. Allendes Osorio, K.W. Brodlie.
Contouring with Uncertainty.
In Theory and Practice of Computer Graphics Conf, 2008.



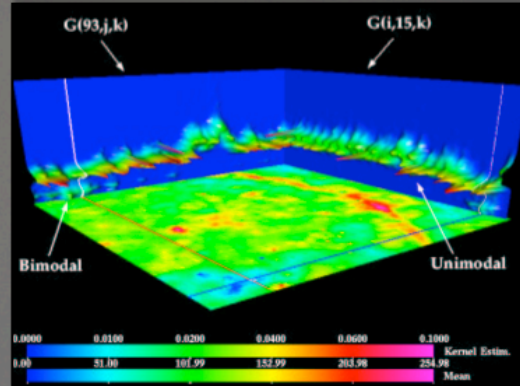
J. Sanyal, S. Zhang, J. Dyer, A. Mercer, P. Amburn.
Noodles: A Tool for Visualization of Numerical Weather Model Ensemble Uncertainty
In Proc IEEE Vis, 2010.



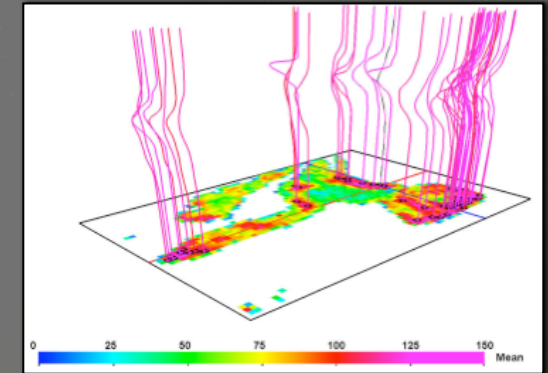
K. Potter, et al.
Ensemble-Vis: A Framework for the Statistical
Visualization of Ensemble Data.
In IEEE ICDM Workshop on Knowledge
Discovery from Climate Data: Prediction, 2009.

Ensembles / 2D Distributions

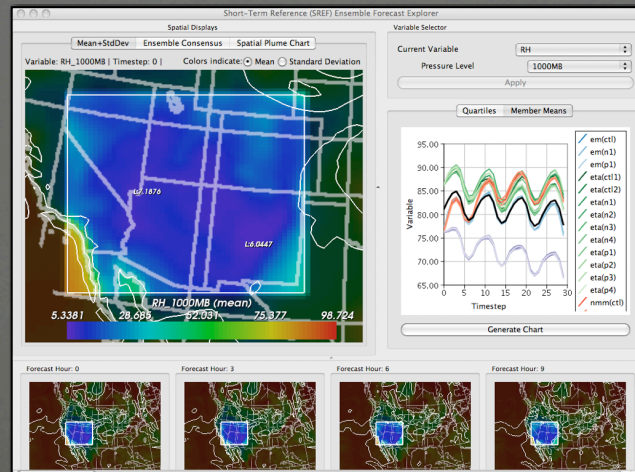
- Multi-run/model simulations
- Distribution of data at every pt
- Mean/std dev may not be appropriate



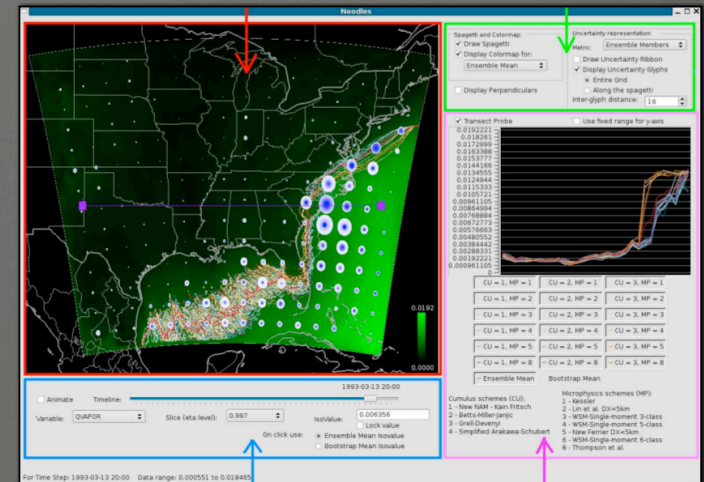
D. Kao, A. Luo, J. Dungan, A. Pang.
Visualizing Spatially Varying Distribution Data.
In Proc Information Visualisation, 2002.



D. Kao, M. Kramer, A. Luo, J. Dungan, A. Pang.
Visualizing Distributions from Multi-Return Lidar
Data to Understand Forest Structure.
In The Cartographic Journal, 42(1), 2005.



K. Potter, et al.
Ensemble-Vis: A Framework for the Statistical
Visualization of Ensemble Data.
In IEEE ICDM Workshop on Knowledge
Discovery from Climate Data: Prediction, 2009.

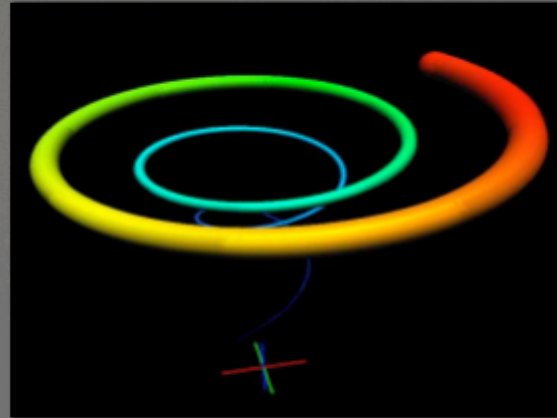


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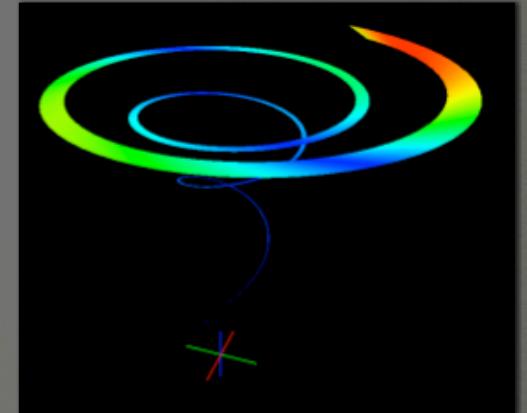
Streamlines

Differences between 2 streamlines

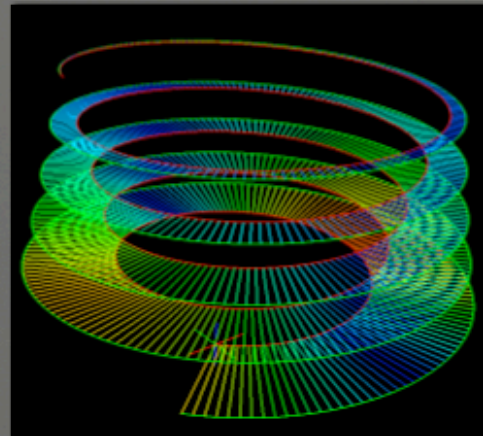
- Uncertainty from numerical algs for particle tracing in fluid flow
- Highlight sensitivity of algorithm choice - particularly near critical pts



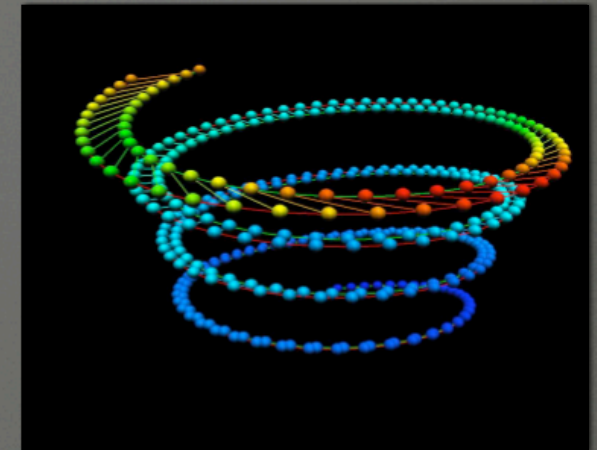
Tube



Ribbon



Lines



Balls + lines

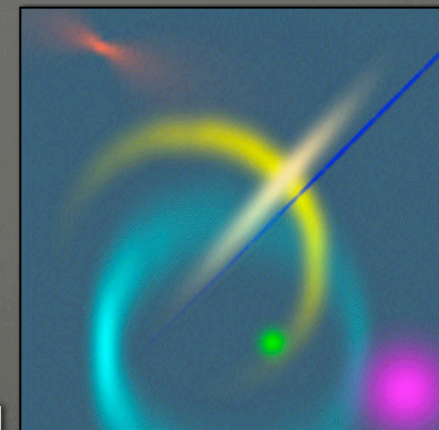
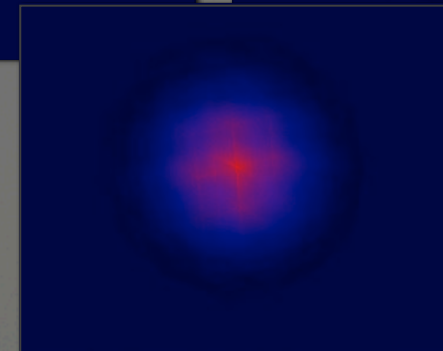
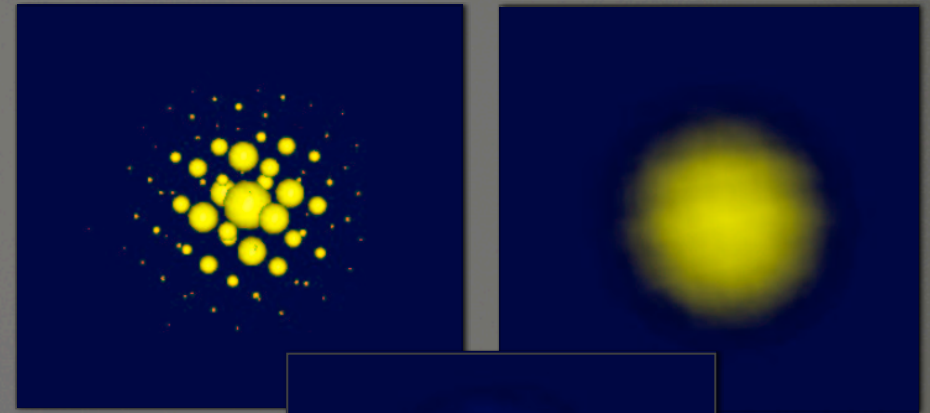
S. Lodha, A. Pang, R. Sheehan, C. Wittenbrink.
UFLOW: visualizing uncertainty in fluid flow.
In Proc IEEE Vis, 1996.

* S. Lodha, C. Wilson, R. Sheehan.
"LISTEN: sounding uncertainty visualization".
In Proceedings Visualization '96, pp. 189--195, 1996.

* Modulate pitch based on uncertainty.

Particle Movement

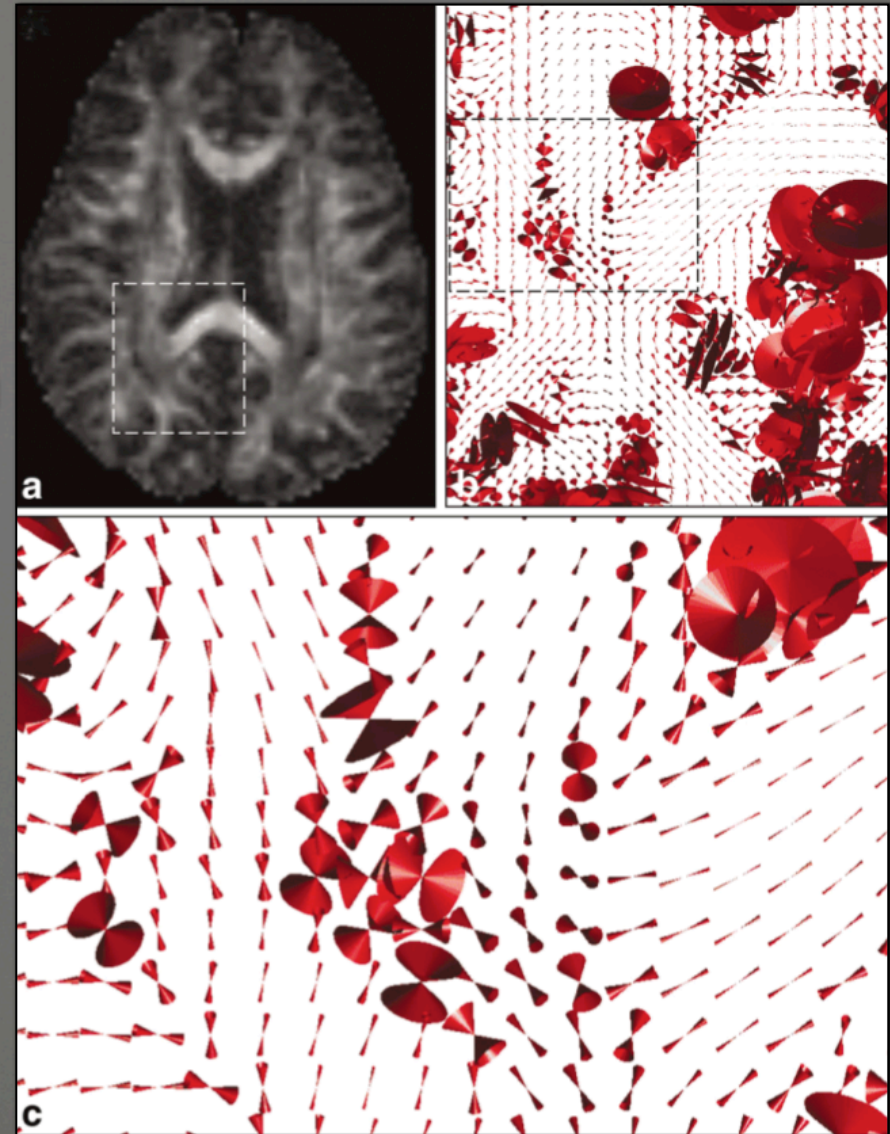
- PDFs to characterize initial position, speed, and direction of the particle
- Location of particle position visualized as a probability cloud
- Sphere glyphs, transparency, and transparency + color



7 Particles using
transparency + color

DT-MRI

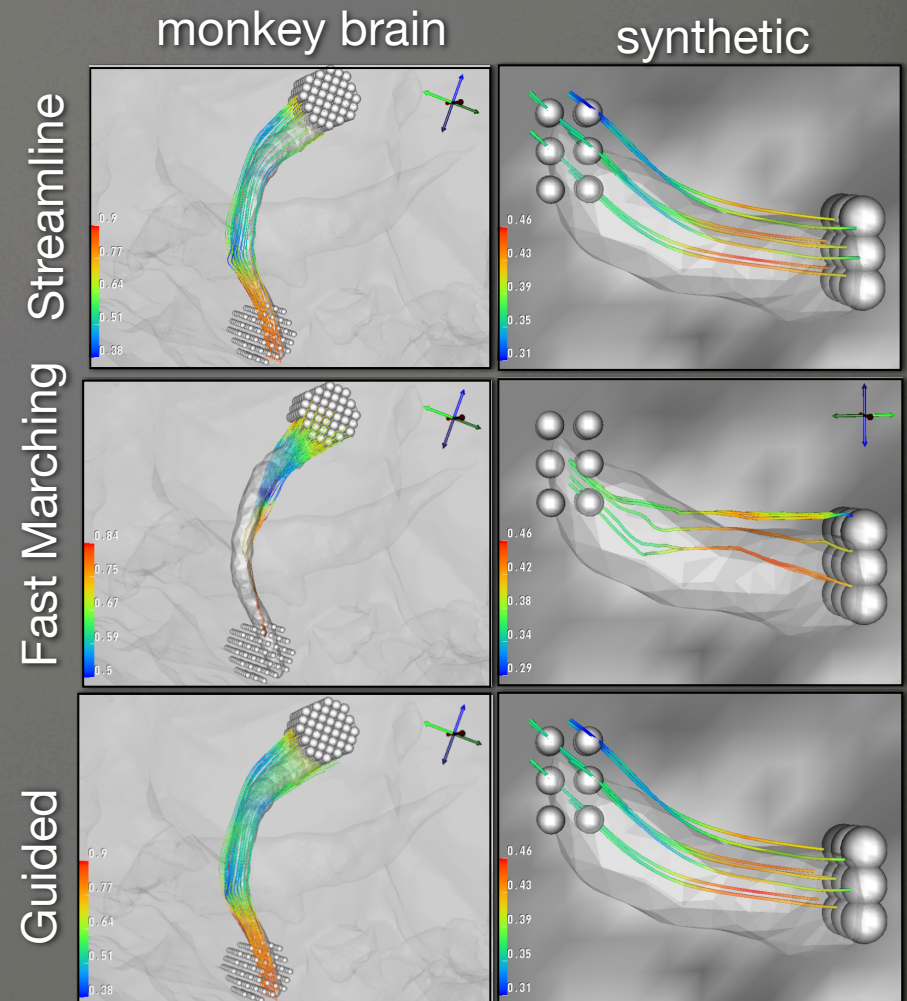
- Determine dominant orientation of structured tissue
- Uncertainty associate with eigenvector estimation
- Confidence intervals on fiber orientation
- “Cones of uncertainty” show orientation & uncertainty



D. Jones.
Determining and visualizing uncertainty in estimates of fiber orientation from diffusion tensor MRI.
In Magnetic Resonance in Medicine, vol. 49, 2003.

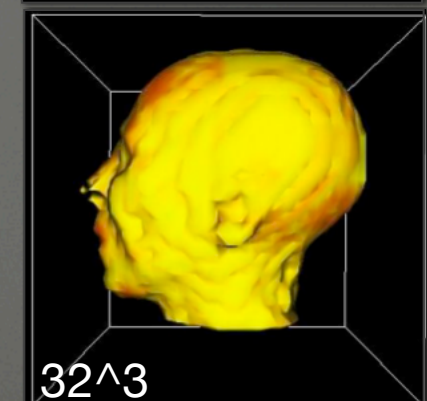
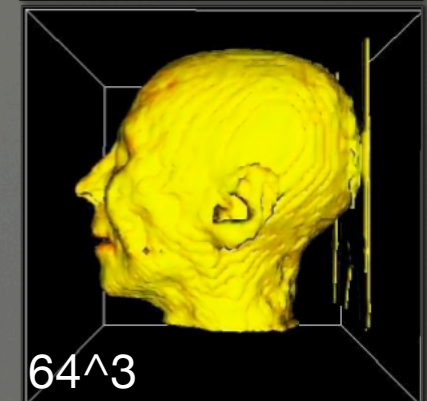
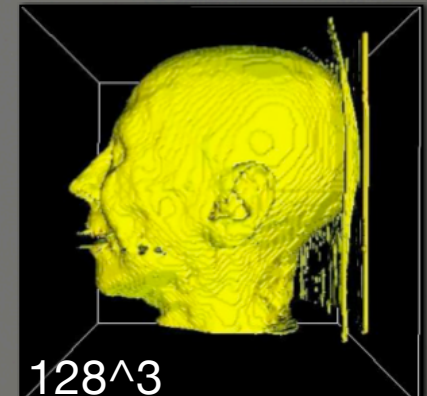
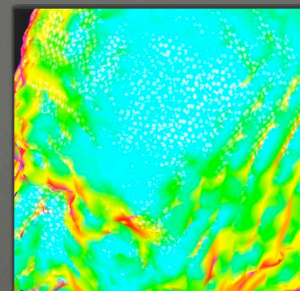
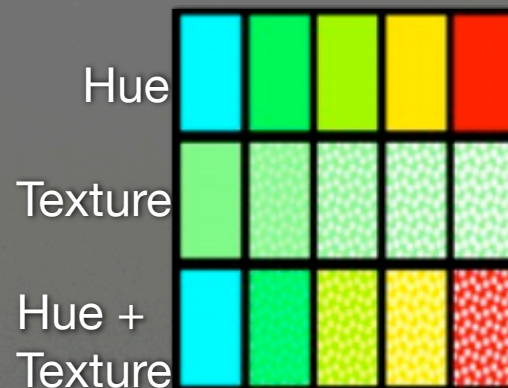
DTI Fiber Tracking

- Metrics to quantify differences in fiber tracking algorithms
 - Area between corresponding fibers of each bundle
 - Earth Mover's Distance between two fiber bundle volumes
 - Current distance between two fiber bundle volumes



Volumetric Data - Isosurfacing

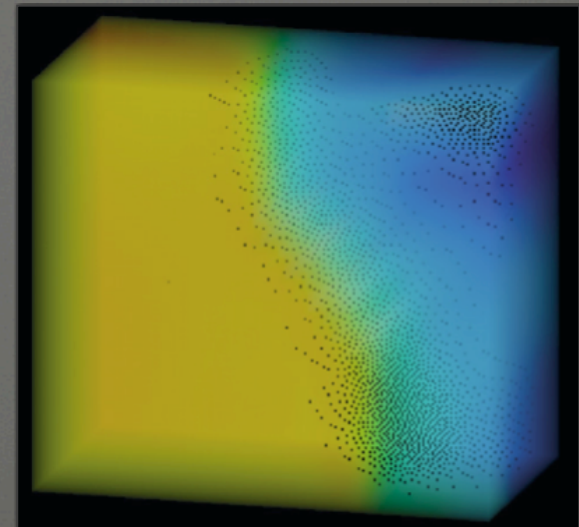
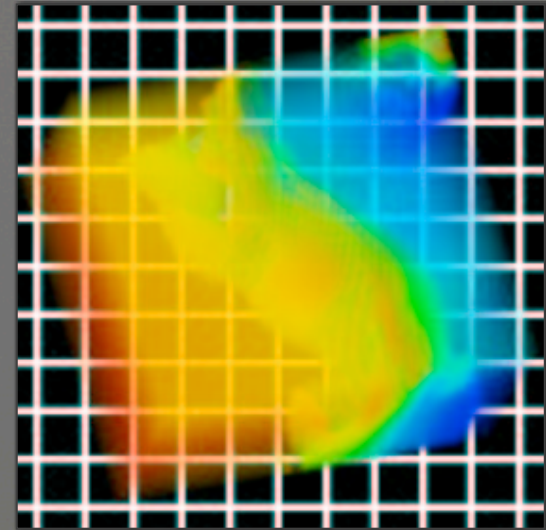
- Isosurfaces show where a volumetric data value lies in space
- Map uncertainties to:
 - hue, saturation, brightness
 - texture mapping
- Isovalue eases display



Isovalue = 0.185

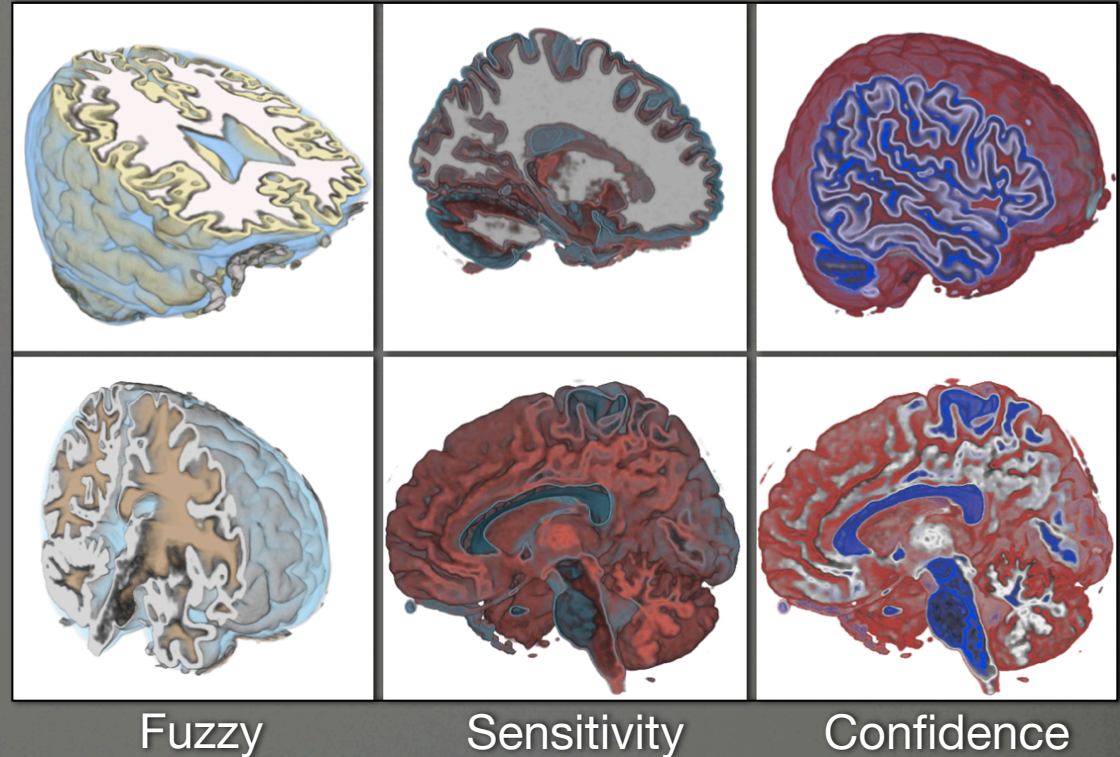
Volumetric Data-Volume Rendering

- Show data with high or low uncertainty
- Map data to color & uncertainty to opacity
- Add discontinuities to regions of high uncertainty (speckles, noise)

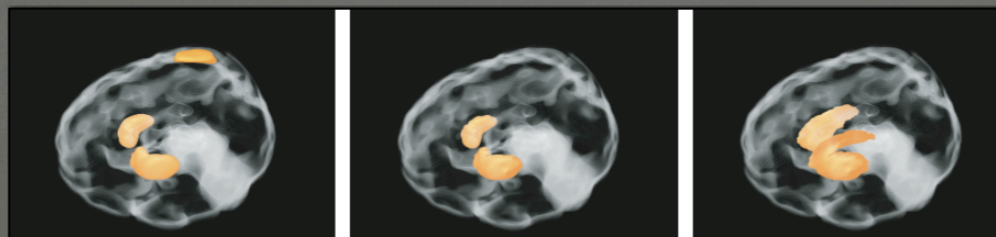


Fuzzy Classification - Volume Rendering

- Transfer function to segment data into structures
- Border between structures is fuzzy
- Statistically quantify this boundary



J. Kniss, R. Van Uiter, A. Stephens, G. Li, T. Tasdizen, C. Hansen.
"Statistically Quantitative Volume Visualization".
In IEEE Vis, 2005.

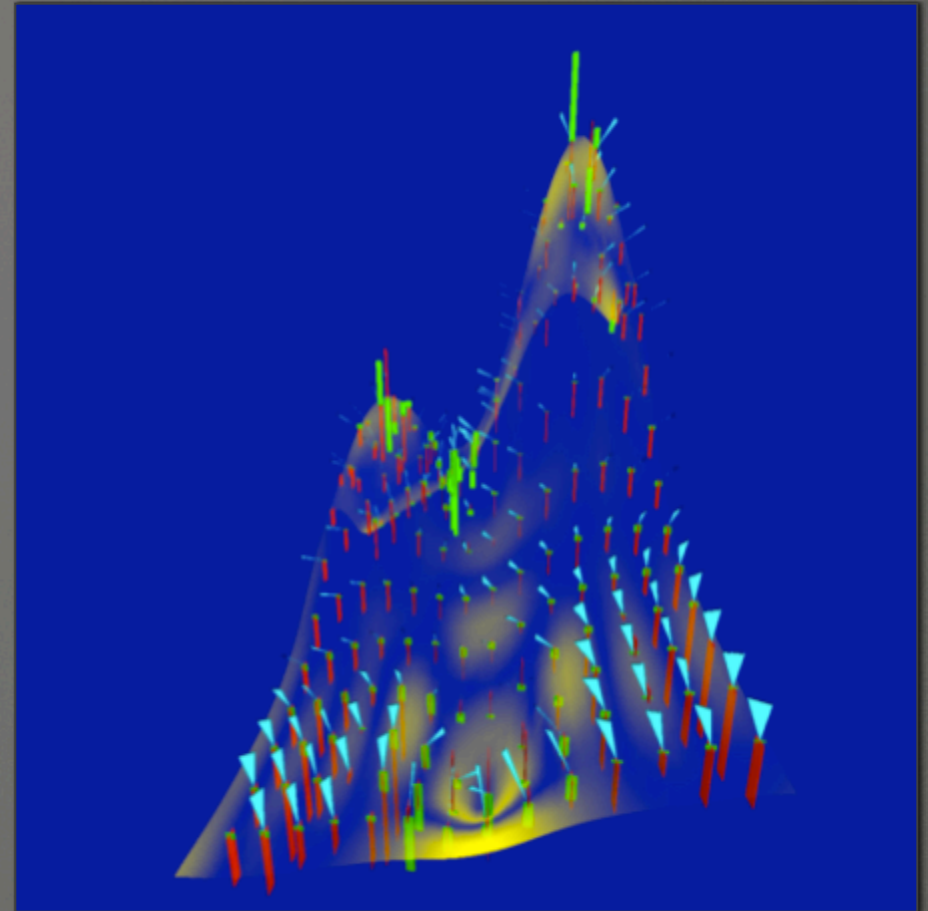


Tissue segmentation based on shape prior

A. Saad, G. Hamarneh, T. Möller
"Exploration and Visualization of Segmentation Uncertainty Using Shape and Appearance Prior Information"
In IEEE Vis, 2010.

Surface Interpolants

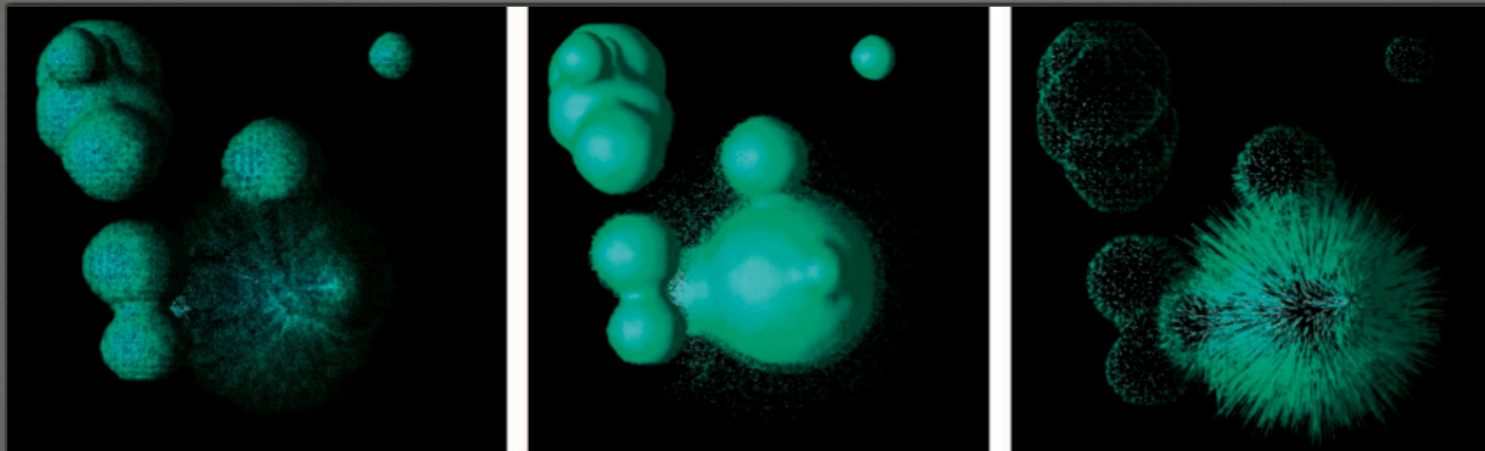
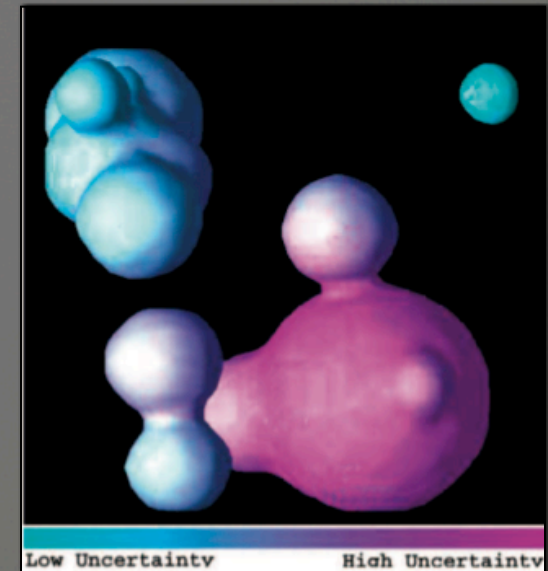
- Geometric uncertainty/
interpolation error
 - differences in position, normals, principal curvatures and directions, and mean and Gaussian curvatures
 - bilinear, C0 linear, C2 bicubic B-spline, multiquadrics, inverse multiquadrics and thin plate splines



S. Lodha, B. Sheehan, A. Pang, C. Wittenbrink.
Visualizing geometric uncertainty of surface interpolants.
In Proc Conference on Graphics Interface, 1996.

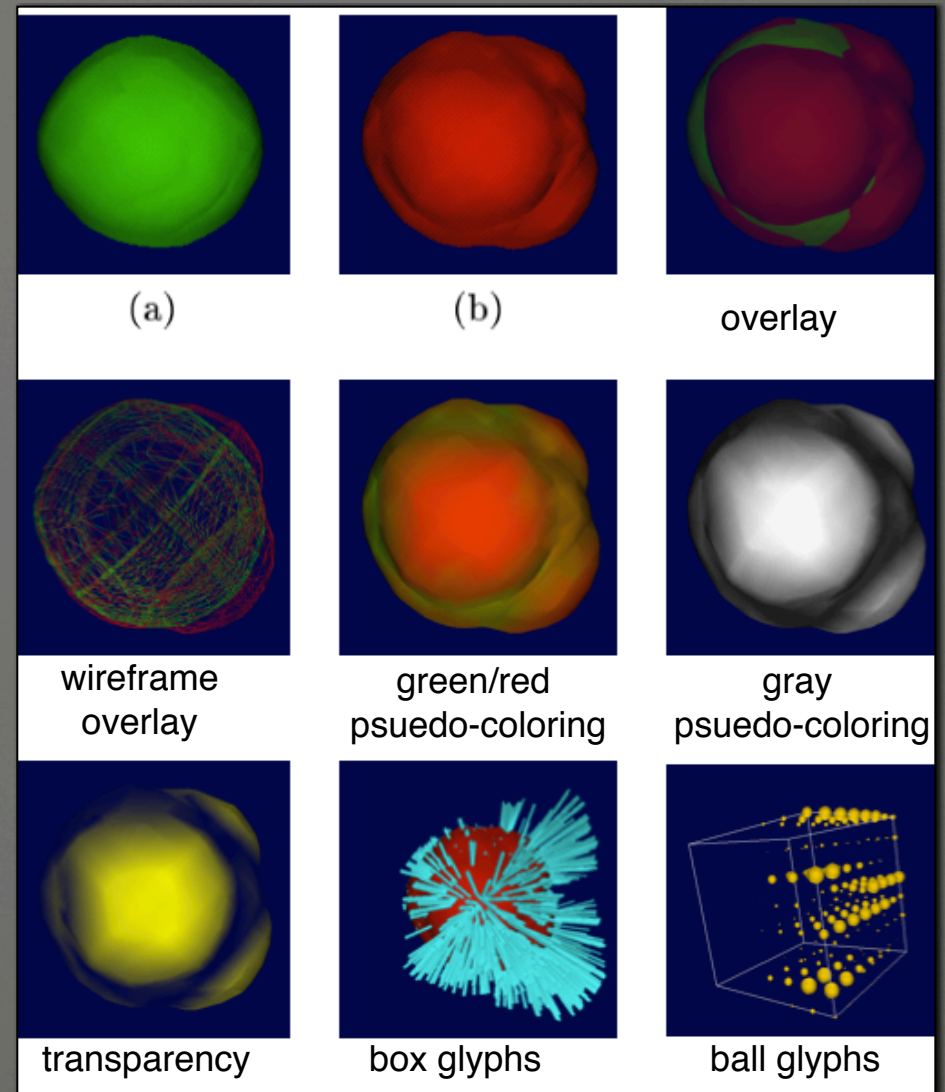
Surface Uncertainty

- Uncertainty in position of data
- Points as primitives, displace pts with uncertainty



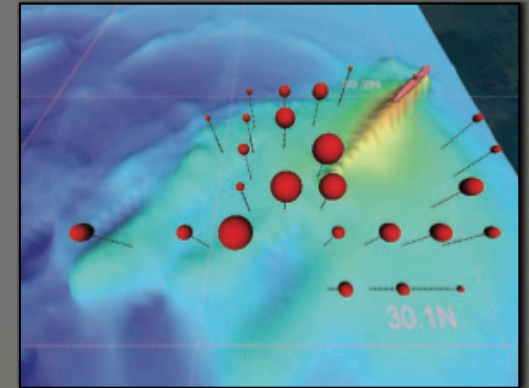
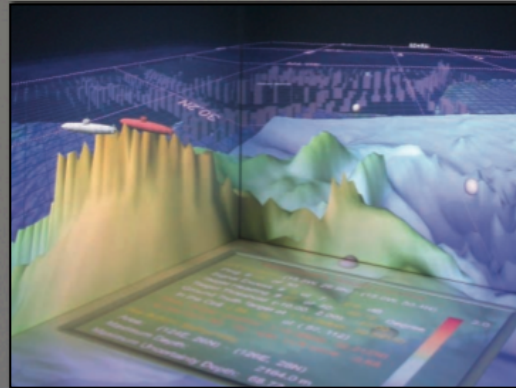
Visualization Uncertainties - Isosurfaces

- Uncertainty from differences in isosurface creation
- Compare
 - marching cubes & marching cubes with ambiguous cell correction
 - interpolation schemes

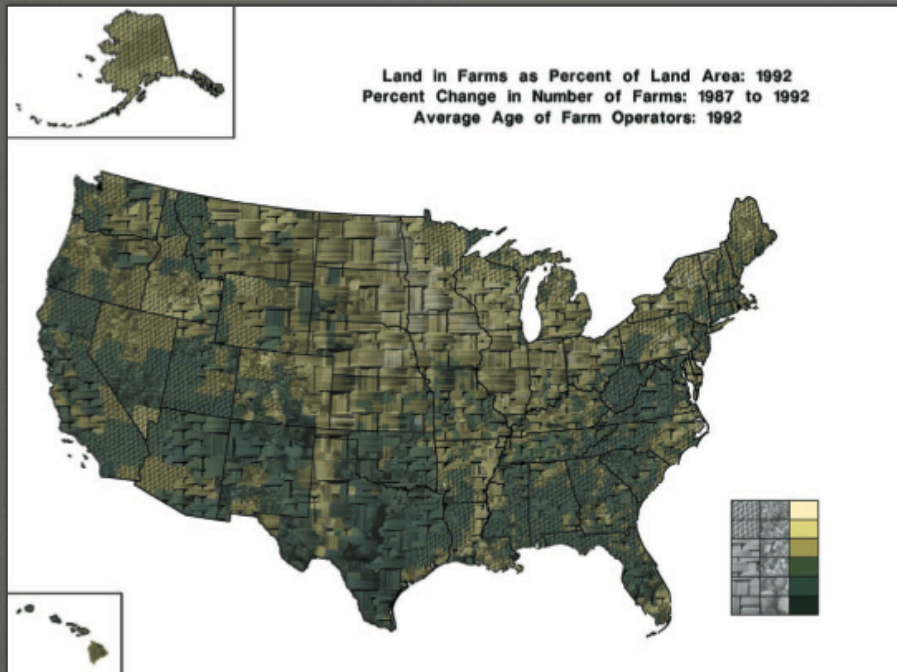


N-Dimensional Uncertainty

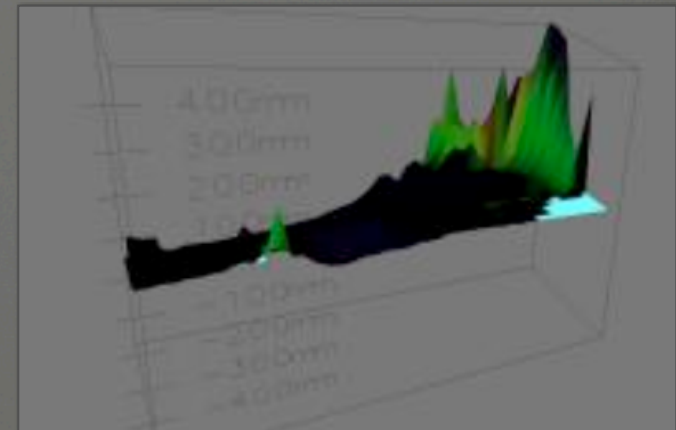
- Multidimensional & multivariate
- Often found in earth sciences data



G. Schmidt, S. Chen, A. Bryden, M. Livingston, L. Rosenblum, B. Osborn.
Multidimensional visual representations for underwater environmental uncertainty.
In IEEE CG&A, 24(5), 2004.



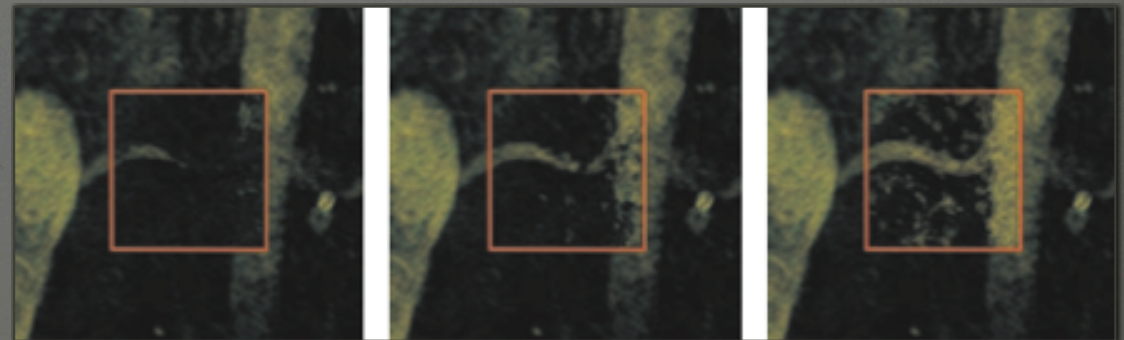
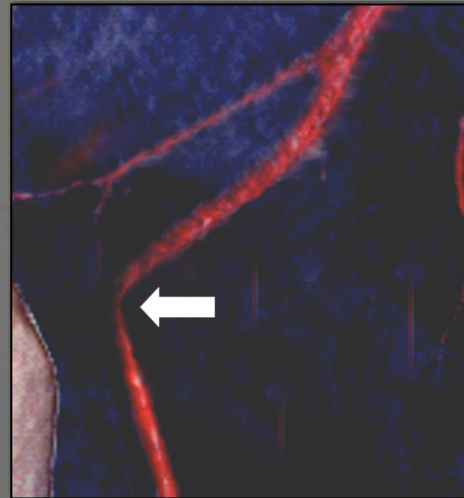
Victoria Interrante.
Harnessing Natural Textures for Multivariate Visualization.
In IEEE CG&A, 20(6), 2000.



J. Miller, D. Cliburn, J. Feddema, T. Slocum.
Modeling and Visualizing Uncertainty in a Global Water Balance Model.
In Proceedings of the 2003 ACM symposium on Applied computing, 2003.

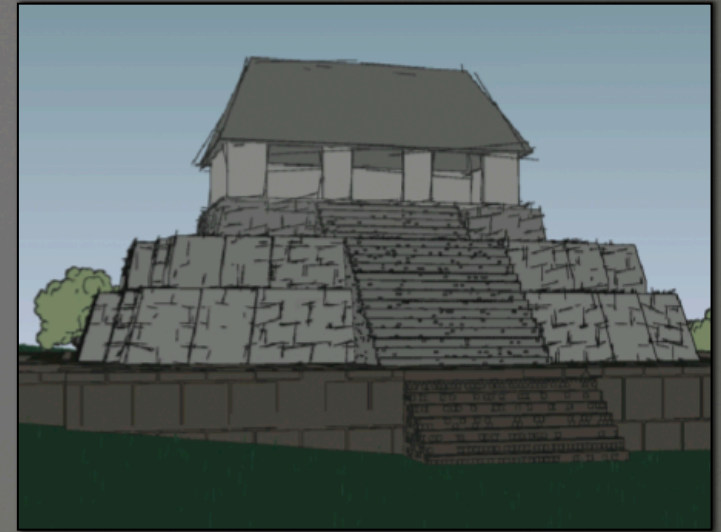
Visualization Uncertainties - DVR

- Direct volume rendering
 - transfer function defines mapping to color & opacity
- Sensitivity lens
 - UI animates region of interest

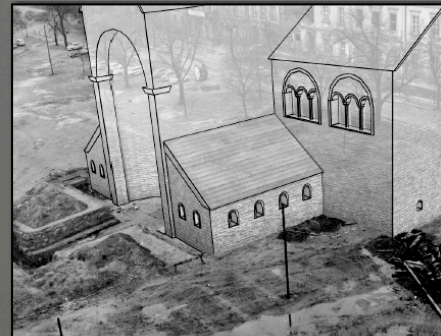
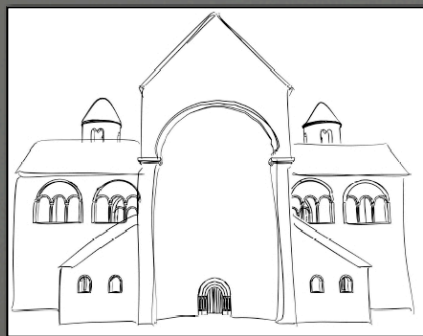


Architectural Uncertainties

- Confidence of 3D reconstruction
- Position, materials, arch details are unknowns
- Shiny pictures, solid lines indicate truth



K. Potter, et al.
Resolution Independent NPR-Style 3D Line Textures.
In CGF, 28(1), 2009.



T. Strothotte, M. Masuch, T. Isenberg.
Visualizing Knowledge about Virtual Reconstructions of Ancient Architecture.
In Proc of Computer Graphics International, 1999.

Summary/Conclusion

- Uncertainty vis becoming a hot topic in the vis community
- Many (most?) obvious solutions have been tried
- Increasing visual complexity main challenge

Thanks!

Surveys

J. Thomson, B. Hetzlera, A. MacEachren, M. Gaheganb, M. Pavel.
"A Typology for Visualizing Uncertainty".
In Proceedings of SPIE. Vol. SPIE-5669, p.146--157, 2005.

H. Griethe, H. Schumann.
"The Visualization of Uncertain Data: Methods and Problems".
In Proceedings of SimVis '06, 2006.

A. Pang, C. Wittenbrink, S. Lodha.
"Approaches to Uncertainty Visualization".
In The Visual Computer, 13(8), p. 370-390, 1997.

A. MacEachren, A. Robinson, S. Hopper, S. Gardner, R. Murray, M. Gahegan, E. Hetzler.
"Visualizing Geospatial Information Uncertainty: What We Know and What We Need to Know".
In Cartography and Geographic Information Science, 32(3), p. 139-160, 2005.