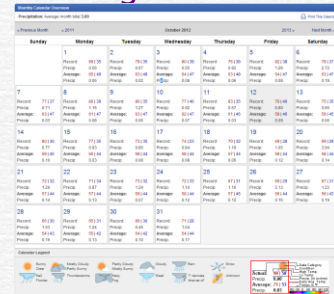


Uncertainty Visualization

Alex Pang
University of California, Santa Cruz

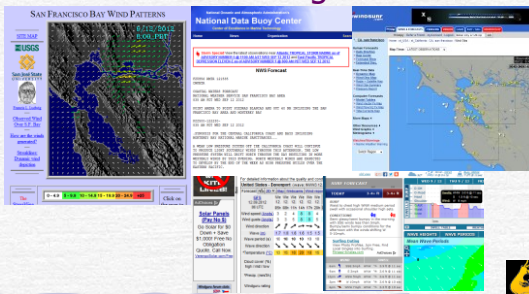
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Bring umbrella?



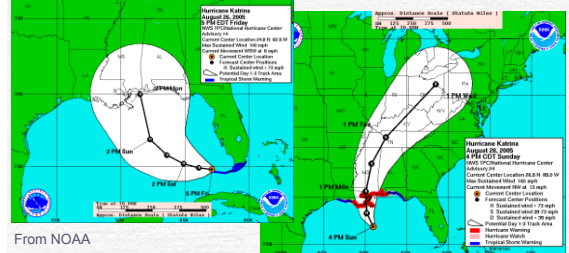
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Go sailing?



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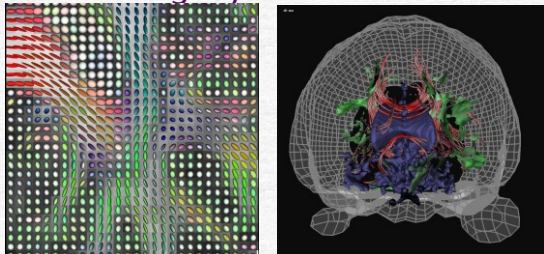
Hurricane Katrina



From NOAA

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Ambiguity in fiber tracks

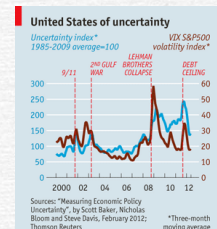


From <http://vis.cs.brown.edu/docs/pdf/Zhang-2004-DTM.pdf>

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Policy & news uncertainty index

(Baker and Bloom, 2012)



Source: "Measuring Economic Policy Uncertainty", by Scott Baker, Nicholas Bloom and Steve Davis, February 2012; Thomson Reuters.

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Uncertainty is everywhere!

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Uncertainty is Certain



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Really?



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Motivation

- Important to know about uncertainty when analyzing and understanding data
- Even more important to know about uncertainty when making decisions

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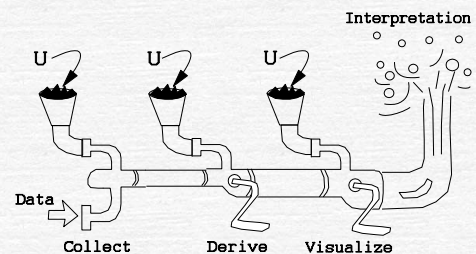
Where does uncertainty come from?

- Variability in nature
- Deficiency in instrumentations e.g. insufficient resolution, calibration drifts, ...
- Deficiency in modeling e.g. fidelity in physics, complexity, numerical imprecision, ...
- Insufficient or conflicting information
- Others e.g. introduced during visualization

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Uncertainty in visualization pipeline



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More places uncertainty is added

- ✓ Different methods of processing data
- ✓ Different rendering algorithms e.g. DVRs
- ✓ Filling in missing data
- ✓ Smoothing out high frequency data
- ✓ Filtering out outliers
- ✓ Improper use from what the visualization was originally designed for

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Requirements for End-to-End Data Understanding with Uncertainty

- ✓ Uncertainty representation
- ✓ Uncertainty quantification
- ✓ Uncertainty propagation
- ✓ Uncertainty visualization

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Uncertainty representation

- Scalar quantity e.g. confidence level, standard deviation, data quality, RMS, SNR, ...
- Pair e.g. min-max range values, mean and spread, ...
- 1D form e.g. probability density function
- 2D form e.g. covariance matrix
- Others?

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Uncertainty quantification

- ✓ Statistics and probability
- ✓ Fuzzy set theory
- ✓ Possibility theory
- ✓ Evidence theory
- ✓ Information theory
- ✓

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Uncertainty propagation and evolution

- ✓ Belief propagation
- ✓ Interval arithmetic
- ✓ Stochastic PDE
- ✓ Ito calculus
- ✓ Fokker Planck
- ✓ ...

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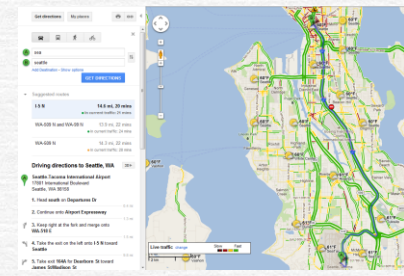
Uncertainty visualization

- ✓ Histograms
- ✓ Box plots
- ✓ Uncertainty glyphs
- ✓ Embellishments
 - Pseudo-coloring, transparency, texture
 - Fuzziness, dashed lines, dust clouds
- ✓ ...

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Map with traffic & weather



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Visualizing Scalar Uncertainty

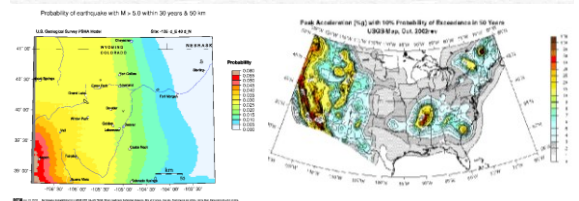
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Disclaimer

- Non-exhaustive list
- Can often swap what to highlight or to hide e.g. to emphasize or to de-emphasize uncertainty

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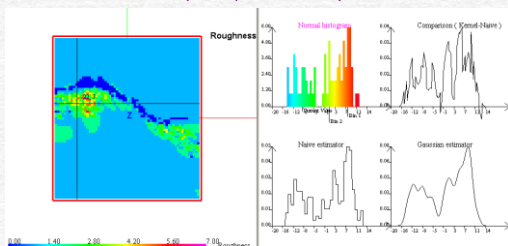
Pseudo-Color: Seismology



usgs.gov

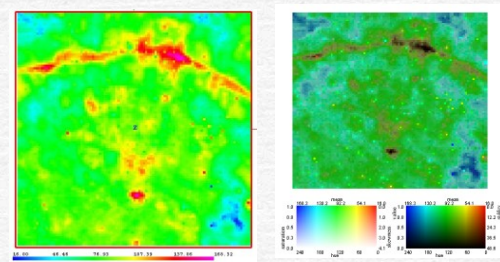
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Pseudo-Color : Point probe (2d array of distributions)



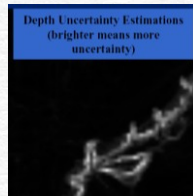
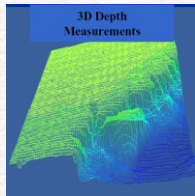
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HSV : Monte Carlo



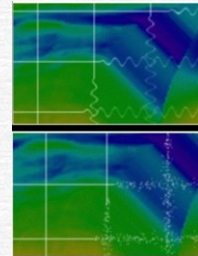
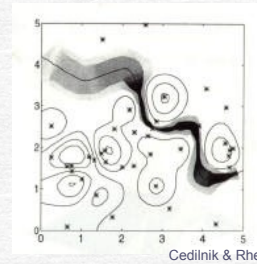
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Brightness: Bathymetry from sidescan sonar



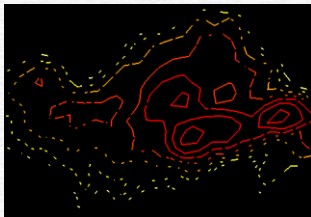
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Attributes: Fat, faint, noisy lines



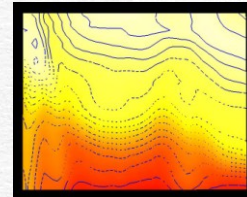
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Dashed contours



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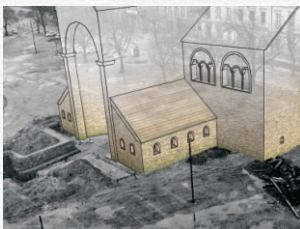
Example : Soundspeed (42 levels, 80 realizations)



Soundspeed colored,
Standard deviation contoured.

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Transparency

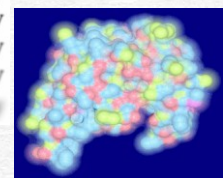


Strothotte et al

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Bluriness, fuzziness

Visualizing Uncertainty
Visualizing Uncertainty
Visualizing Uncertainty
Visualizing Uncertainty



Schneiderman, Lee & Varshney

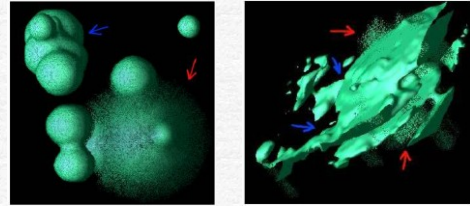
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Localized fuzziness

- Exploiting stereo-vision

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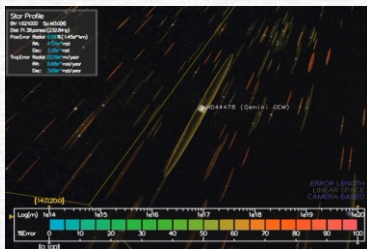
Dust cloud



Grigoryan and Rheingans, 2002

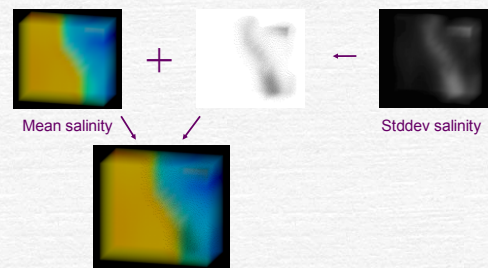
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Glyphs for positional uncertainty



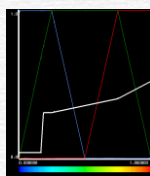
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Direct Volume Rendering

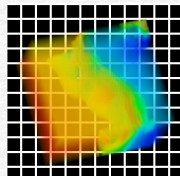


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1D Transfer Function



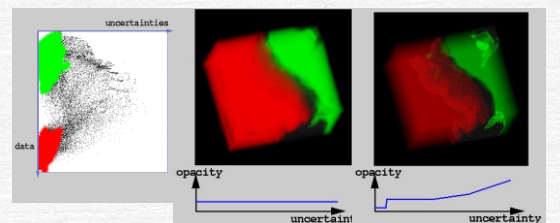
Transfer function:
Increasing opacity
with uncertainty



salinity

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2D Transfer Function



2D transfer function

Salinity data

IEEE Visualization 2012, Uncertainty and Parameter Space Analysis

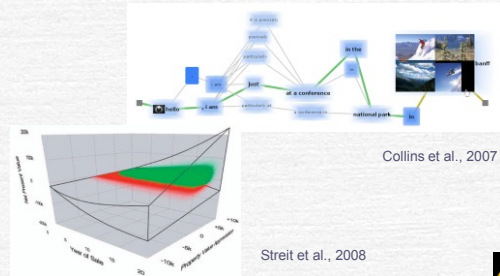
Animation



Lundstrom et al., 2007

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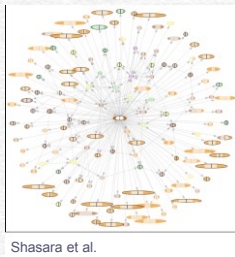
Fuzziness : Infovis



Streit et al., 2008

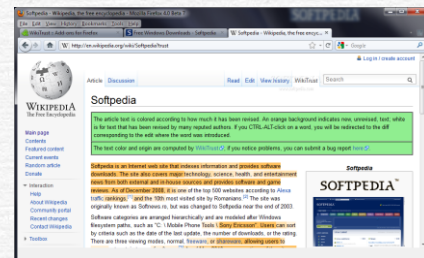
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Glyphs : Graph Comparison



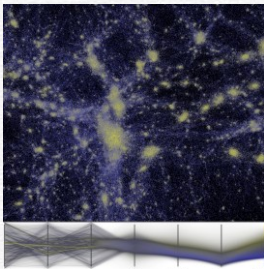
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Color Coding : WikiTrust



IEEE Visualization 2012, Uncertainty and Parameter Space Analysis

Parallel Coordinates



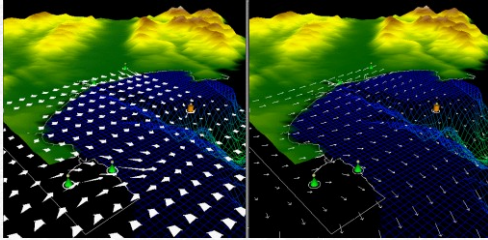
Haroz et al., 2008

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Visualizing Vector Uncertainty

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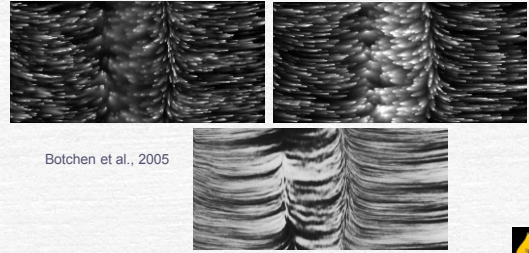
Uncertainty glyphs



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Textures

(cross advection, multi-frequency noise)

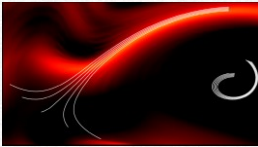


Botchen et al., 2005

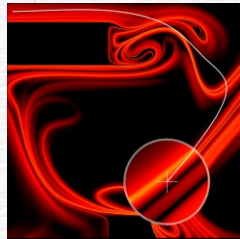
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FTLE and Predictability (2012)

(Hlawatsch et al.)



Low predictability when started in high FTLE (reddish regions)



Can be used to place seeds in finely folded ridges

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Visualizing Spatial Distributions

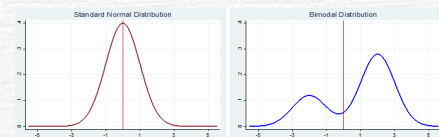
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Motivation

- Deficiency of parametric statistics

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Same mean and std dev



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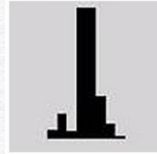
Motivation

- Limitation of traditional scalar viz

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Histograms



IEEE Visualization 2012, Uncertainty and Parameter Space Analysis



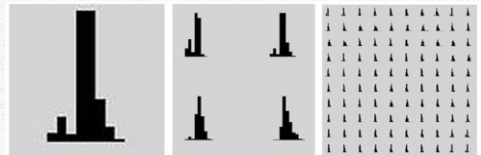
Histograms



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Histograms (cannot scalable in space)



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Motivation

- Increasing use of Monte Carlo simulations to capture uncertainty in models and parameters
- Increasing use of multiple models to form ensembles
- Results in multi-dimensional data with multiple values for the same variable at each location and time.

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Possible Strategies

- Use an existing method e.g. histograms
- Reduce dimensionality:
 - Parametric statistics
 - Shape descriptors
- Deal with multi-value directly
 - Operator algebra
- ...

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Histograms and box plots

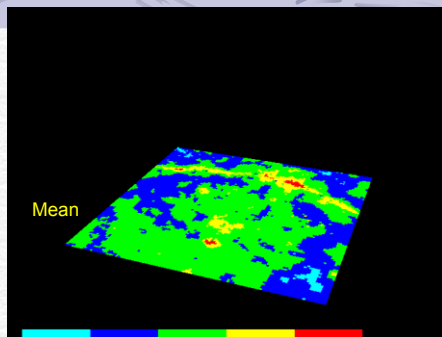
- ✓ + simplicity, familiarity
- ✓ - difficult to scale to higher spatial dimensions

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Multivariate-Parametric approach

- ✓ Collect statistics at each point
 - e.g. mean, standard deviation, skewness
 - Convert 2D array of distributions into 2D array of n-tuples
- ✓ Map n-tuples at each point to visuals
 - E.g. map statistics to color, surface height, contours, glyphs
 - Add additional layers as desired

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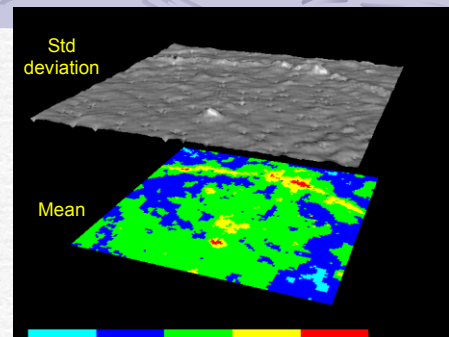
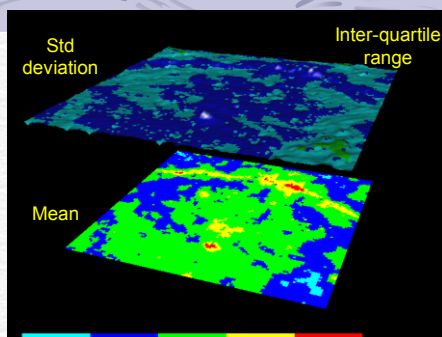


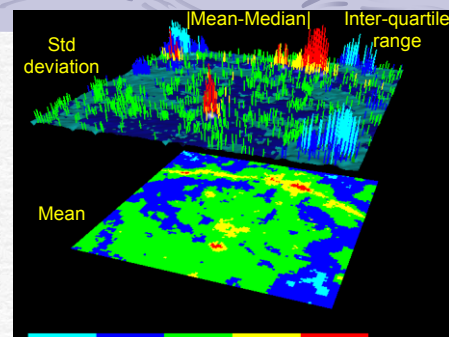
Image plane deformed by standard deviation.

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Surface graph colored by inter-quartile range.

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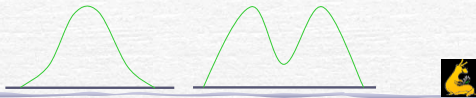


Line glyphs indicate [mean-median] with a threshold.

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Advantage/disadvantage:

- + familiarity
- potential clutter
- shows summaries, not distributions
 - e.g. 2 distributions with same mean and standard deviations, but different shapes



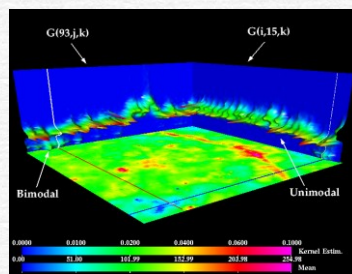
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Non-parametric approach

- Show shape of the distributions:
 - Show tiny histograms at each point
 - ▣ Does not scale with resolution and dimension
- Need other shape descriptors aside from parametric statistics

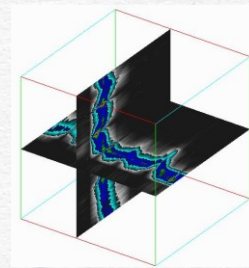
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Distribution Profiles



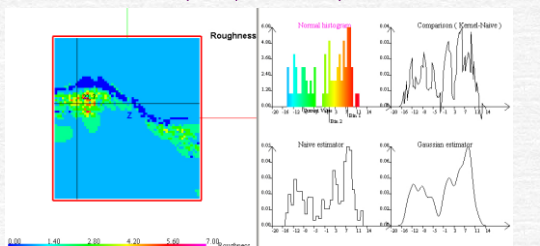
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3D histogram slices



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Pseudo-Color : Point probe (2d array of distributions)



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Advantage/disadvantage

- + more general, does not assume well-behaved distributions
- hard to extend to higher dimensions

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Operator algebra

- Provide a set of operators that specify how multi-value data can be combined with other multi-value data or data types.
- Operations can be mathematically or procedurally defined.

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Simple Operators

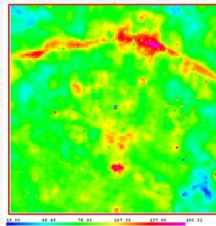
$s = \text{ToScalar}(M)$

$\mathbf{v} = \text{ToVector}(M)$

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Pseudocoloring

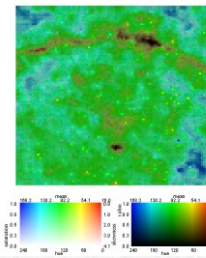
$\text{Mean} = \text{ToScalar}(M)$



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HSV Mapping

$(\text{mean}, \text{stddev}, \text{skewness}) = \text{ToVector}(M)$



Mean = hue
Skew = saturation
Stddev = value

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Arithmetic

- Combining scalars with multi-values:
 - $M' = s + M$
 - $M' = sM$
- Combining multi-values:
 - $M' = M1 + M2$
 - $M' = M1 * M2$

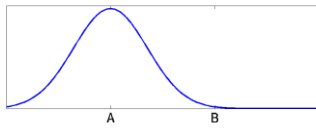
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Interpolation

- Exercise: think about how to interpolate 2 distributions – both are Gaussian with the same standard deviation, but different means.
- How does the interpolated distribution look like halfway through?

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Probabilistic Interpolation



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Streamlines

Euler integration

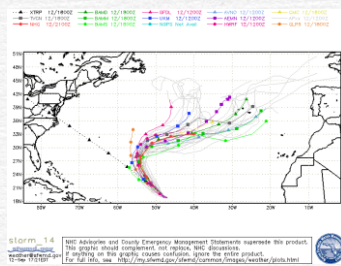
$$P_{i+1} = P_i + v \Delta t$$

Addition of multi-values

- Convolution addition (Gerasimov et. al)
- Binwise addition (Gupta & Santini)
- ...

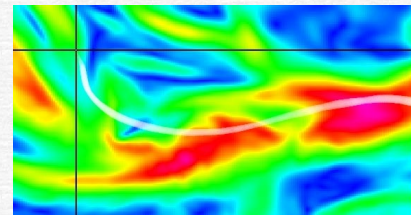
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Spaghetti Plots



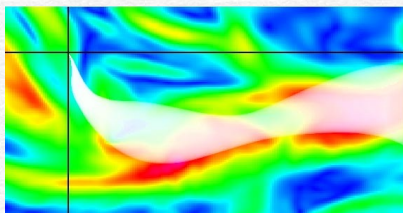
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Streamlines with Convolution +



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Streamlines with Binwise +



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Comparing multi-values

Euclidean distance:

$$ED(P, Q) = \left(\int_{-\infty}^{+\infty} (P(x) - Q(x))^2 dx \right)^{\frac{1}{2}}$$

Kullback-Leibler distance :

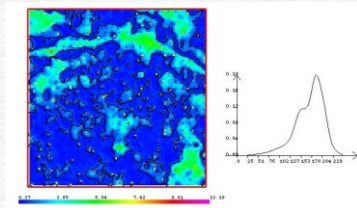
$$KL(P, Q) = \int_{-\infty}^{+\infty} P(x) \log \frac{P(x)}{Q(x)} dx$$

Kolmogorov-Smirnov distance:

$$KS(P, Q) = \max |cdf(P(x)) - cdf(Q(x))|$$

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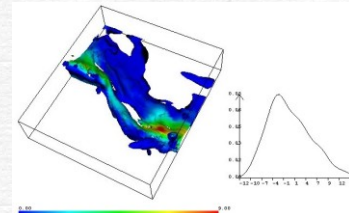
Isolines / Contour Lines



Pseudo-colored by similarity distance.

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Isosurfaces



Pseudo-colored by standard deviation.

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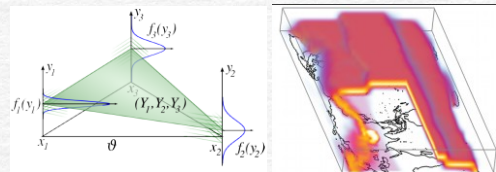
Advantage/disadvantage

- + more general approach
- + can be used for feature extraction
- +/- results vary with operators
- - learning curve for interpretation

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Uncertain Isocontours (2012)

(Pothkow et al.)



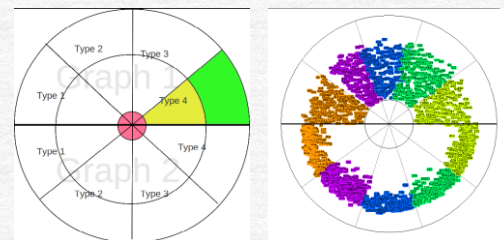
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Uncertainty in InfoVis

- Extend what we learned in SciVis to visual attributes of graph elements : node shade, color, size, etc.; edge thickness, sharpness, etc.
- Adapt techniques for UncVis e.g. Parallel coordinates
- New metaphors and layout e.g. bulls-eye that utilize layout to convey uncertainty

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Layout : Bulls-Eye Metaphor



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- End-to-end treatment of uncertainty
- Tools for data analysis and visualization of spatially dense pdfs e.g. ensembles
- Uncertainty in infovis / visual analytics
- How can we make better visualizations for decision makers

Hazards of Communicating Uncertainty

[illegible]

Cone of Uncertainty Confusing?

(w. oremus)

- Does it show the areas most likely to be affected by the storm to one degree or another, or just the areas over which the storm's eye is most likely to pass?
- The cone does not show the extent of the storm or how widespread its damages might be—just the areas over which its very center is most likely to pass.
- If you live outside of the cone entirely, what are the chances that you'll suffer a direct hit anyway?
- If you live outside of the cone entirely, you could still get hit by the eye of the storm. The chances of the storm's center straying outside the cone are about one in three.*
- Where the cone grows wider, does that mean the storm is likely to spread out and dissipate?
- Not necessarily. Where the cone grows wider, it simply means that there is more uncertainty about where exactly the storm will strike.
- Does the shape of the cone vary depending on the nature of the storm?
- No, the shape of the cone—that is, how narrow or broad it is at any given point—has nothing to do with the individual storm. It is determined prior to each hurricane season based solely on the accuracy of past predictions, and is the same for every storm that season.



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**FIREDRAGON47** wrote:
9/30/2012 3:14 PM PDT



Love all of our eyes in the skies.

I just wanna know, those folks (many apparently with little children) who didn't evacuate even though they had plenty of warning & access to a vehicle....WHY?

 **Recommend**  **Reply**

 **Report**

**LSquared** responds:
9/30/2012 5:38 PM PDT

I grew up in New Orleans and experienced many hurricanes as well as hurricane scans (they don't actually hit). The cost associated with evacuating, sometimes multiple times in 1 season, is astronomical. Most people cannot afford to take an unplanned vacation - gas, hotel, eating out, possibly renting a car. These stories are never about wealthy or well-off folks. Many people have a credit card to book a hotel room or rent a car. The shelters are absolutely horrifying and dangerous. **W... See More**

 **Recommend** **Recommended by 2 readers**

 **Report**

The IEEE logo, featuring a stylized yellow figure of a person sitting at a desk with a lamp, set against a black background.

Concept

The figure consists of two side-by-side maps of the Gulf of Mexico and surrounding regions, illustrating uncertainty analysis and parameter space analysis. Both maps show a black trajectory line starting from the Gulf of Mexico and moving towards the northeast. The left map, titled 'Uncertainty Analysis - Uncertainty Bound', shows a white uncertainty region. The right map, titled 'Uncertainty Analysis - Uncertainty Bound', shows a colored uncertainty region (yellow to red) representing different parameter values. Both maps include a legend for parameters and a scale bar.

Left Map: Uncertainty Analysis - Uncertainty Bound

Parameters:

- 1: Initial Position (km)
- 2: Initial Velocity (km/h)
- 3: Initial Acceleration (km/h²)
- 4: Initial Heading (deg)
- 5: Initial Altitude (km)
- 6: Initial Depth (km)
- 7: Initial Temperature (°C)
- 8: Initial Salinity (psu)
- 9: Initial Density (kg/m³)
- 10: Initial Pressure (hPa)
- 11: Initial Humidity (g/kg)
- 12: Initial Wind Speed (m/s)
- 13: Initial Wave Height (m)
- 14: Initial Current Speed (m/s)
- 15: Initial Tidal Current (m/s)
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Figure 1: Predicted Paths of Tropical Storms Irene and Ileana

The figure consists of two maps of the United States, each showing the predicted path of a tropical storm. The left map shows the path of Tropical Storm Irene, and the right map shows the path of Tropical Storm Ileana. Both maps include a legend for wind speed ranges and a list of potential impacts.

Legend:

- 15-30 mph
- 31-40 mph
- 41-50 mph
- 51-60 mph
- 61-70 mph
- 71-80 mph
- 81-90 mph
- 91-100 mph
- 101-110 mph
- 111-120 mph
- 121-130 mph
- 131-140 mph
- 141-150 mph
- 151-160 mph
- 161-170 mph
- 171-180 mph
- 181-190 mph
- 191-200 mph
- 201-210 mph
- 211-220 mph
- 221-230 mph
- 231-240 mph
- 241-250 mph
- 251-260 mph
- 261-270 mph
- 271-280 mph
- 281-290 mph
- 291-300 mph
- 301-310 mph
- 311-320 mph
- 321-330 mph
- 331-340 mph
- 341-350 mph
- 351-360 mph
- 361-370 mph
- 371-380 mph
- 381-390 mph
- 391-400 mph
- 401-410 mph
- 411-420 mph
- 421-430 mph
- 431-440 mph
- 441-450 mph
- 451-460 mph
- 461-470 mph
- 471-480 mph
- 481-490 mph
- 491-500 mph
- 501-510 mph
- 511-520 mph
- 521-530 mph
- 531-540 mph
- 541-550 mph
- 551-560 mph
- 561-570 mph
- 571-580 mph
- 581-590 mph
- 591-600 mph
- 601-610 mph
- 611-620 mph
- 621-630 mph
- 631-640 mph
- 641-650 mph
- 651-660 mph
- 661-670 mph
- 671-680 mph
- 681-690 mph
- 691-700 mph
- 701-710 mph
- 711-720 mph
- 721-730 mph
- 731-740 mph
- 741-750 mph
- 751-760 mph
- 761-770 mph
- 771-780 mph
- 781-790 mph
- 791-800 mph
- 801-810 mph
- 811-820 mph
- 821-830 mph
- 831-840 mph
- 841-850 mph
- 851-860 mph
- 861-870 mph
- 871-880 mph
- 881-890 mph
- 891-900 mph
- 901-910 mph
- 911-920 mph
- 921-930 mph
- 931-940 mph
- 941-950 mph
- 951-960 mph
- 961-970 mph
- 971-980 mph
- 981-990 mph
- 991-1000 mph

Potential Impacts:

- 1. Heavy Rainfall: 1-2 inches per hour
- 2. Strong Winds: 1-2 mph per hour
- 3. Storm Surge: 1-2 feet per hour
- 4. Coastal Flooding: 1-2 feet per hour
- 5. Inland Flooding: 1-2 feet per hour
- 6. Power Outages: 1-2 hours per hour
- 7. Road Closures: 1-2 hours per hour
- 8. School Closures: 1-2 hours per hour
- 9. Business Closures: 1-2 hours per hour
- 10. Evacuations: 1-2 hours per hour
- 11. Property Damage: 1-2 hours per hour
- 12. Casualties: 1-2 hours per hour

Future Research Directions

- How does one do feature extraction with multi-value data set: uncertainty in features e.g. critical point vs fuzzy critical region
- How can we retain the spatial correlation information in multi-value data sets?



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- How can we retain the spatial correlation information in multi-value data sets?

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more ...

- What's a good representation for sparse or missing data?
- How can we encode the uncertainty in graphics/visualization algorithms e.g. LODs, clustering, features, ...
- Need more research in uncertainty visualization for infovis/visual-analytics.



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Questions?



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