Uncertainty Visualization

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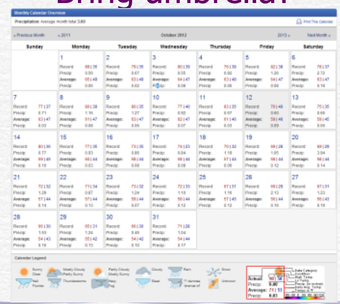
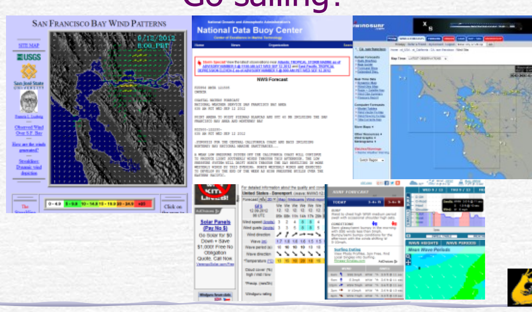
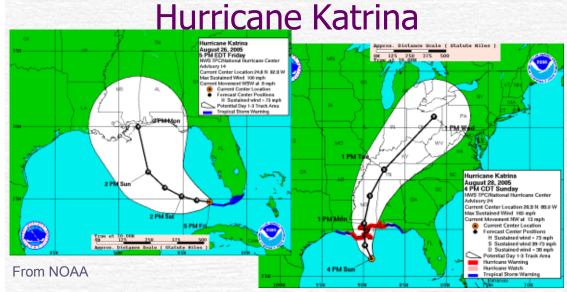
Bring umbrella?



Go sailing?

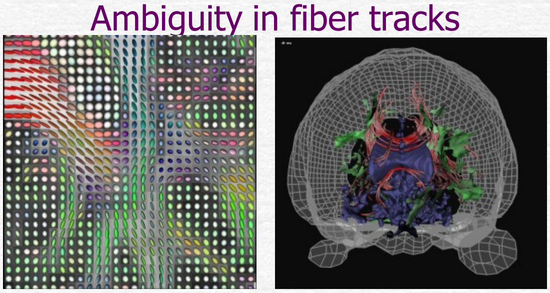


Hurricane Katrina



From NOAA

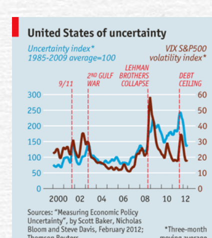
Ambiguity in fiber tracks



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

Policy & news uncertainty index

(Baker and Bloom, 2012)



Uncertainty is everywhere!

Uncertainty is Certain

Really?

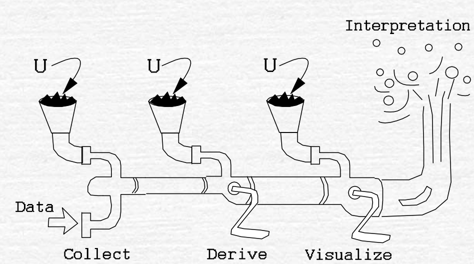
Motivation

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

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

Uncertainty in visualization pipeline



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

Requirements for End-to-End Data Understanding with Uncertainty

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

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?

Uncertainty quantification

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

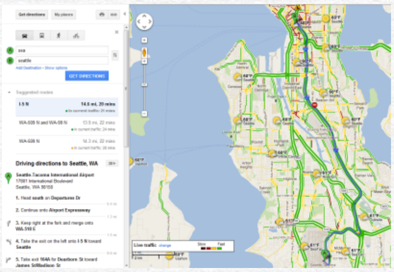
Uncertainty propagation and evolution

- Belief propagation
- Interval arithmetic
- Stochastic PDE
- Ito calculus
- Fokker Planck
- …

Uncertainty visualization

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

Map with traffic & weather

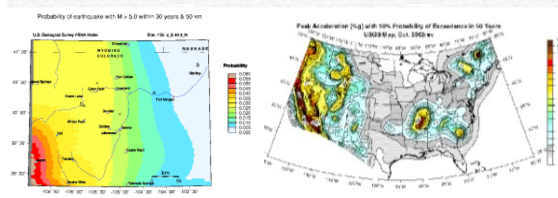


Visualizing Scalar Uncertainty

Disclaimer

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

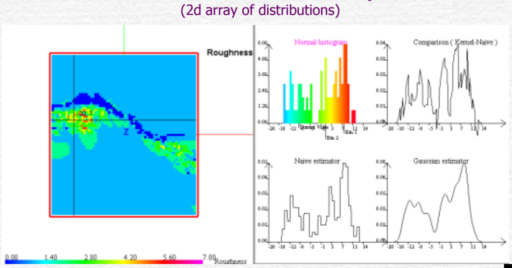
Pseudo-Color: Seismology



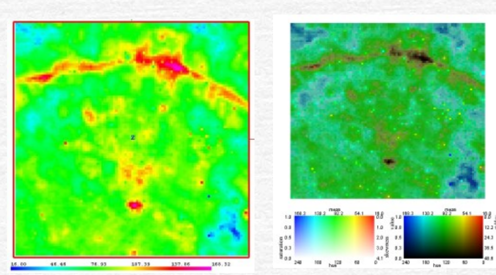
usgs.gov

Pseudo-Color : Point probe

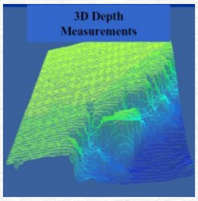
(2d array of distributions)

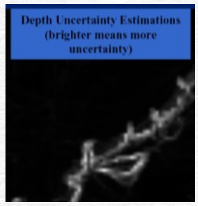


HSV : Monte Carlo

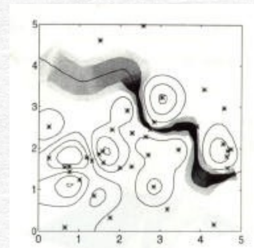


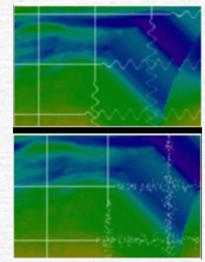
Brightness: Bathymetry from sidescan sonar





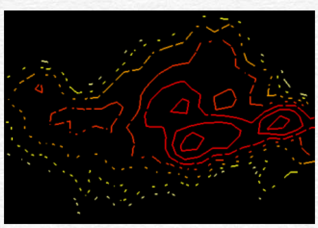
Attributes: Fat, faint, noisy lines





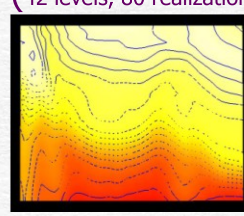
Cedilnik & Rheingans

Dashed contours



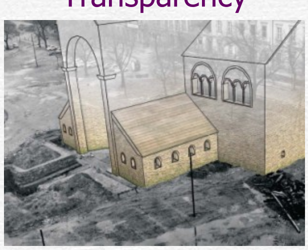
Example : Soundspeed

(42 levels, 80 realizations)



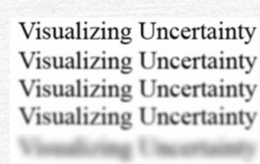
Soundspeed colored,
Standard deviation contoured.

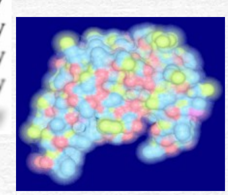
Transparency



Strothotte et al

Bluriness, fuzziness



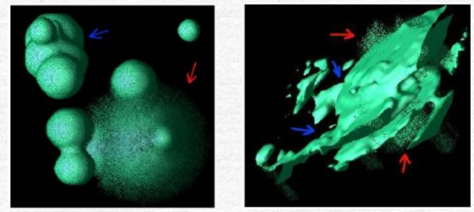


Schneiderman, Lee & Varshney

Localized fuzziness

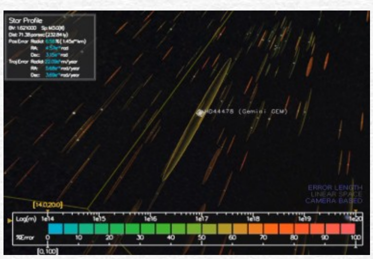
- Exploiting stereo-vision

Dust cloud

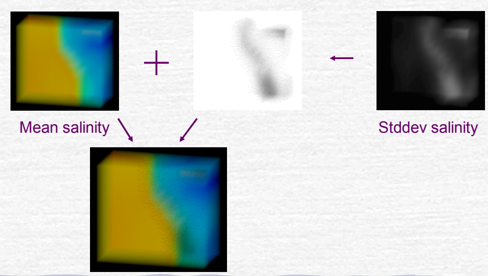


Grigoryan and Rheingans, 2002

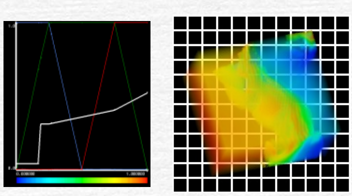
Glyphs for positional uncertainty



Direct Volume Rendering



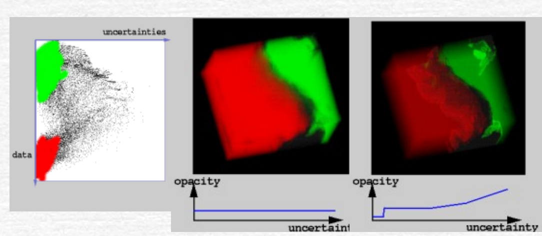
1D Transfer Function



Transfer function: Increasing opacity with uncertainty

salinity

2D Transfer Function



2D transfer function

Salinity data

Animation

Lundstrom et al., 2007

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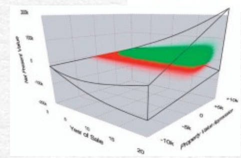
Fuzziness : Infovis

Collins et al., 2007



Streit et al., 2008

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Glyphs : Graph Comparison

Shasara et al.

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Color Coding : WikiTrust

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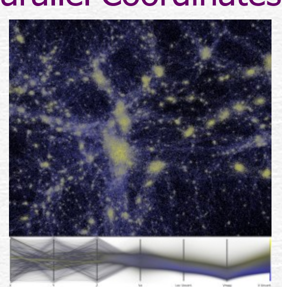
Parallel Coordinates

Haroz et al., 2008



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Visualizing Vector Uncertainty

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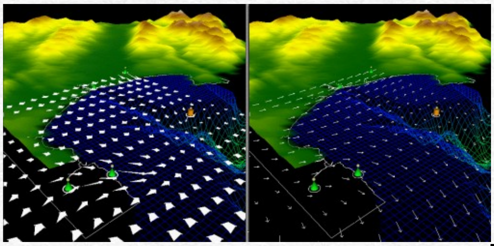
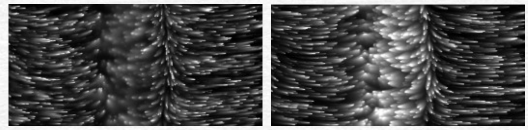
Uncertainty glyphs

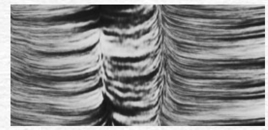


Textures

(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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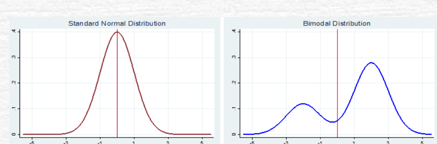
Same mean and std dev



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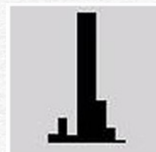
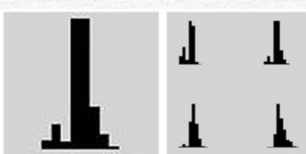
Motivation

- Limitation of traditional scalar viz

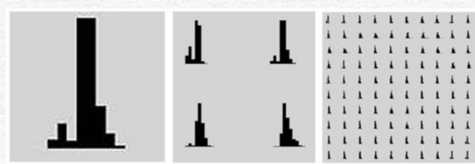
Histograms



Histograms



Histograms (cannot scalable in space)



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.

Possible Strategies

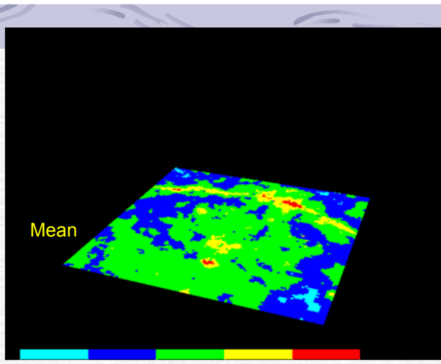
- Use an existing method e.g. histograms
- Reduce dimensionality:
  - Parametric statistics
  - Shape descriptors
- Deal with multi-value directly
  - Operator algebra
- …

Histograms and box plots

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

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



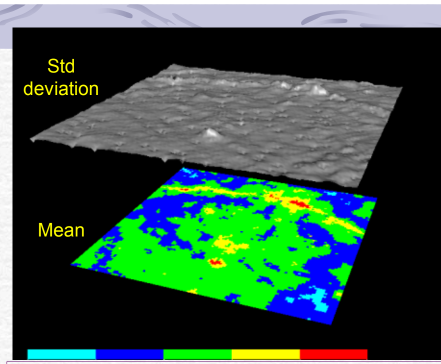
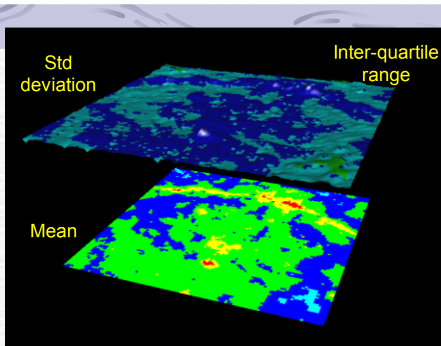
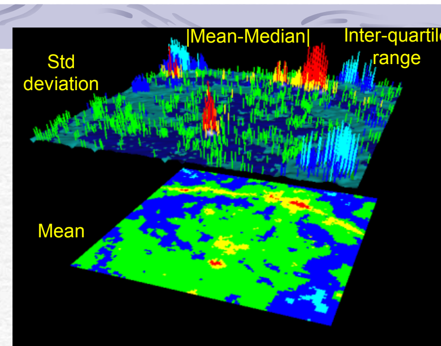


Image plane deformed by standard deviation.



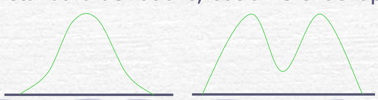
Surface graph colored by inter-quartile range.



Line glyphs indicate |mean-median| with a threshold.

Advantage/disadvantage:

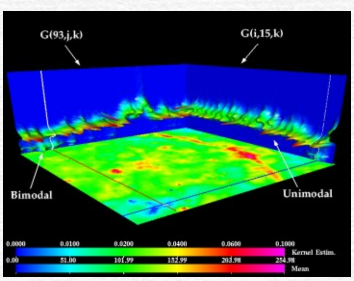
- \+ familiarity
- \- potential clutter
- \- shows summaries, not distributions
  - e.g. 2 distributions with same mean and standard deviations, but different shapes



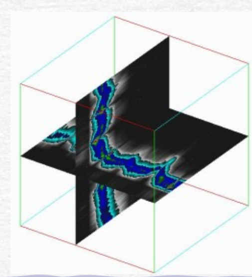
Non-parametric approach

- 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

Distribution Profiles

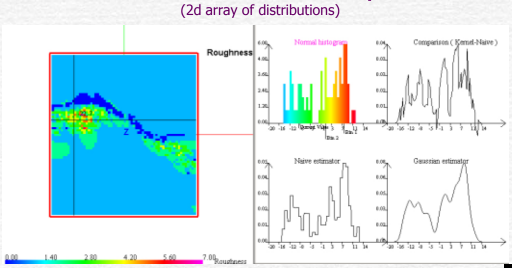


3D histogram slices



Pseudo-Color : Point probe

(2d array of distributions)



Advantage/disadvantage

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

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 = ToScalar(M)

v = ToVector(M)

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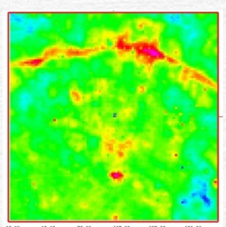
Pseudocoloring

Mean = ToScalar(M)



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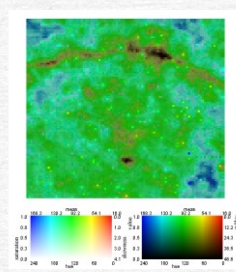
HSV Mapping



(mean, stddev, skewness) = 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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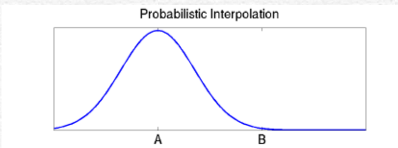


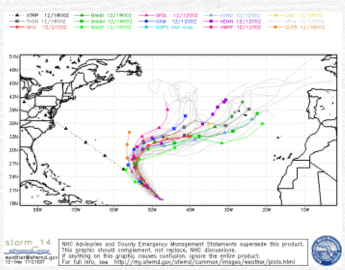
Streamlines

- Euler integration

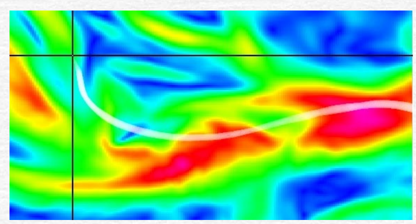
$$P_{i+1} = P_i + v\Delta t$$

- Addition of multi-values
  - Convolution addition (Gerasimov et. al)
  - Binwise addition (Gupta & Santini)
  - …

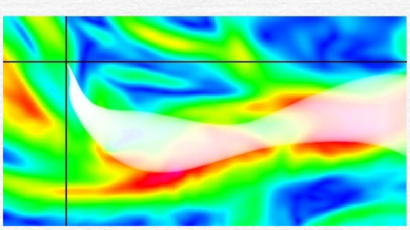
Spaghetti Plots



Streamlines with Convolution +



Streamlines with Binwise +



Comparing multi-values

- Euclidean distance:

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

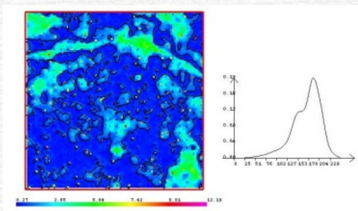
- Kullback-Leibler distance :

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

- Kolmogorov-Smirnov distance:

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

Isolines / Contour Lines



Pseudo-colored by similarity distance.

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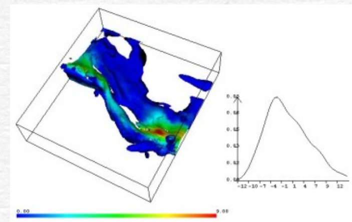
Isosurfaces



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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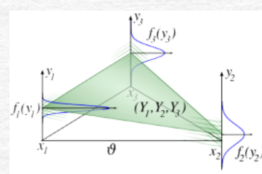
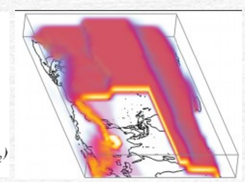
Uncertain Isocontours (2012)

(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 convery uncertainty

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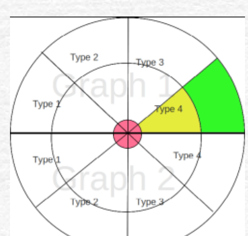
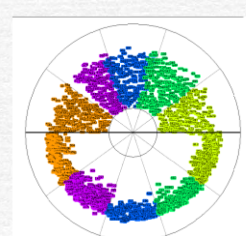
Layout : Bulls-Eye Metaphor





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Challenges

- 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

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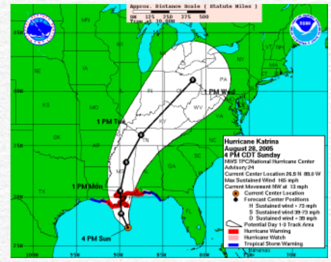
Hazards of Communicating Uncertainty



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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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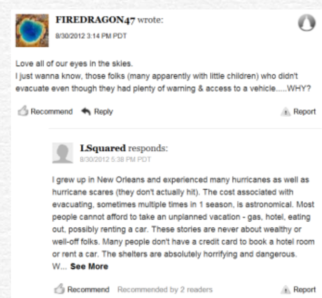
FIREDRAGON47 wrote:
8/30/2012 3:14 PM PDT

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:
8/30/2012 5:38 PM PDT

I grew up in New Orleans and experienced many hurricanes as well as hurricane scares (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 don't 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

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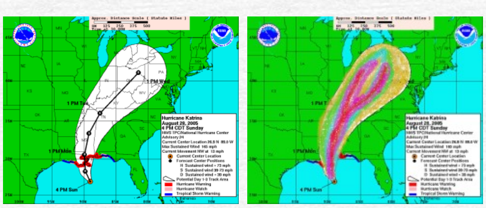
Concept



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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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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.

Questions?