A Topology Based Visualization for Exploring Data with Uncertainty

Keqin Wu, 10/24/2011
Mississippi state University

Outline

- Introduction
- Related Work
- Method
  - Contour Tree Layout and Tree View Graph Design
  - Contour Tree-Based Uncertainty Visualization
  - User Interface Design
- Experimental results
- Conclusion & Future Plans

Introduction

Why topology based visualization for uncertainty?

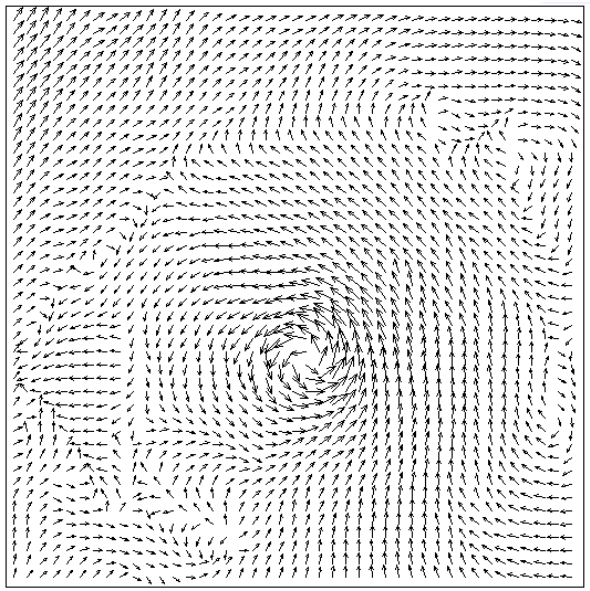
The challenges of handling 3D data with uncertainty

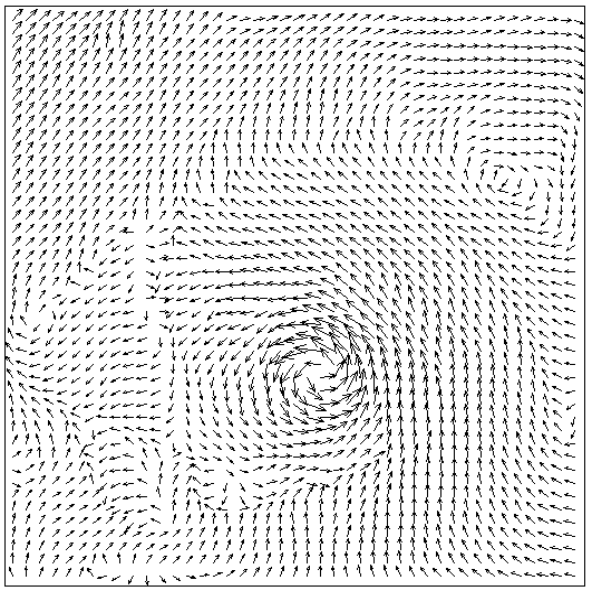
- Qualification
- Representation
- Interaction

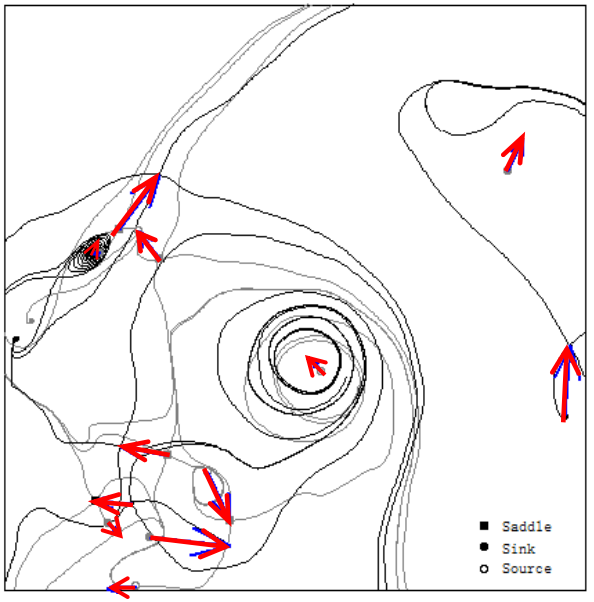
Challenges of handling uncertainty of 3D Data

Quantification

Data-level uncertainty: the uncertain numerical values of a data
Feature-level error: the uncertain deviations of a feature, e. g., a sink or a source, a maximum or a minimum, in the data
The gap between data-level uncertainty and feature-level uncertainty …



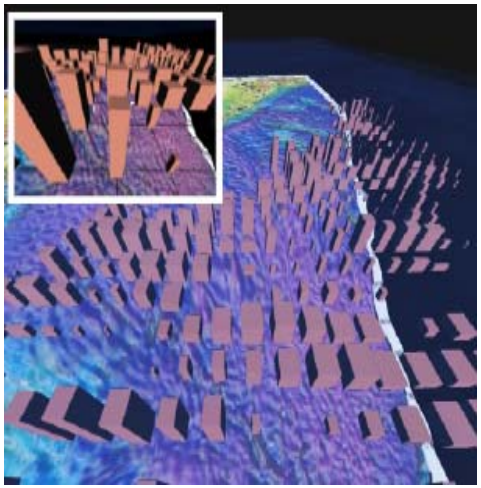




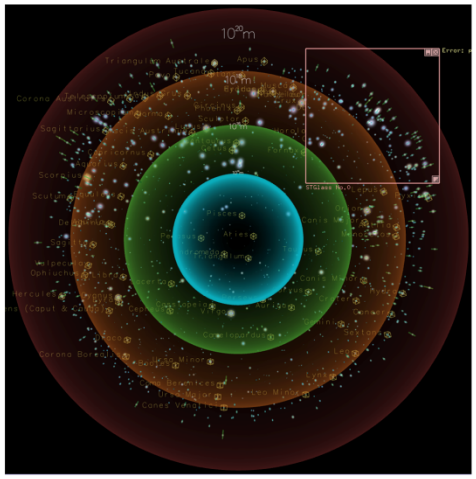
Challenges of handling uncertainty of 3D data

Representation

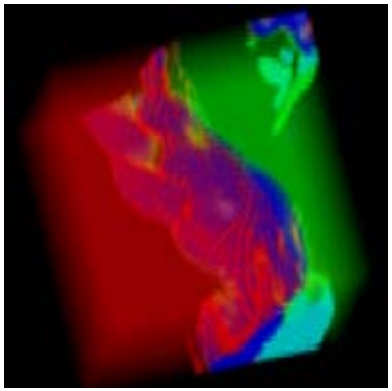
- Information overload
- Cluttered display
- Occlusion



Box glyphs
Schmidt, 2004



Uncertainty Volume Rendering
S. Djurcilov, 2001



Positional uncertainty of stars with error bars, H. Li, 2007

Challenges of handling uncertainty of 3D Data

Interaction

- Geometry bandwidth bottle neck
- Depth perception, cluttering, and occlusion
- Interaction inconvenience with 3D objects

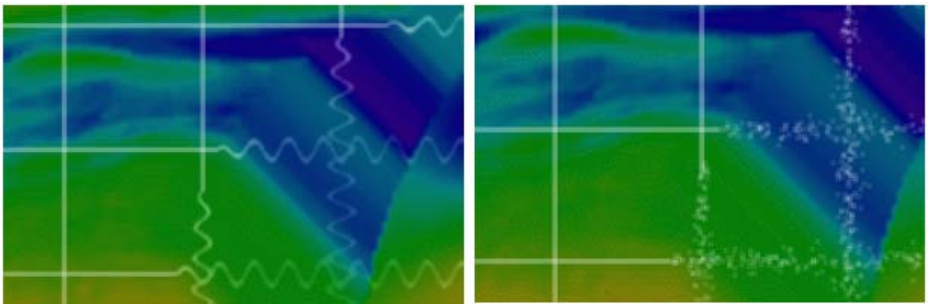
The integrated visualization of both data and uncertainty information intensifies these issues!

Related Work

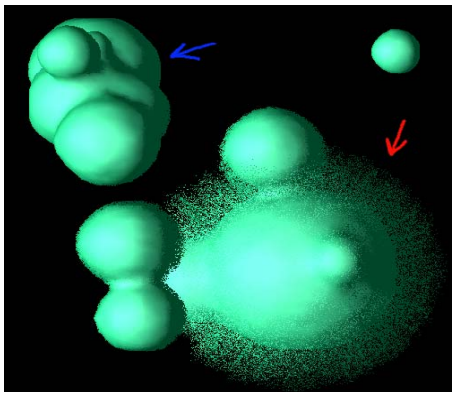
- General Uncertainty visualizations
- Contour uncertainty visualizations
- Contour tree and its applications

Uncertainty Visualization

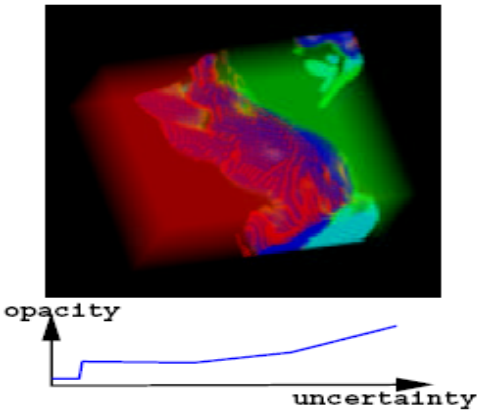
- **Visual blurring**



Procedural Annotation [Cedilnik 1997]

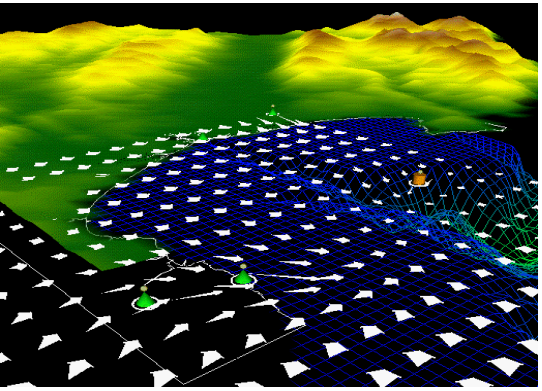


Point-based uncertainty model [Grigoryan 02]

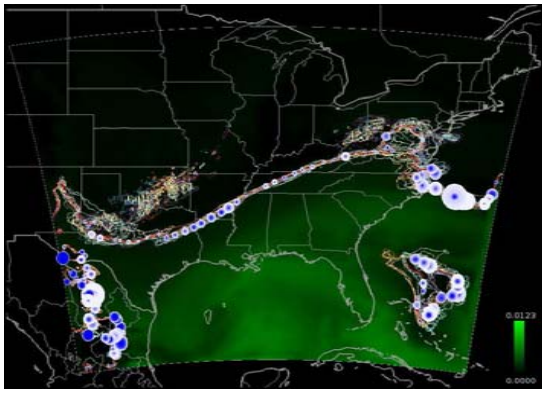


Uncertainty Volume Rendering [Djurcilov 01]

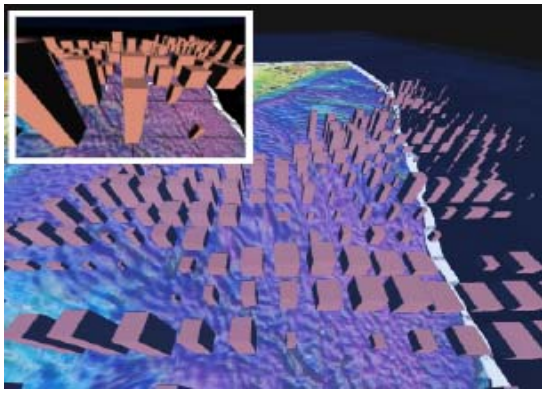
- **Quantitative glyph**



Vector glyph [Wittenbrink 96]



Graduated glyph [sanyal 2010]



Box glyphs [Schmidt 2004]

- **Animation, sonification, psycho-visual approaches, etc**

Uncertainty about contours

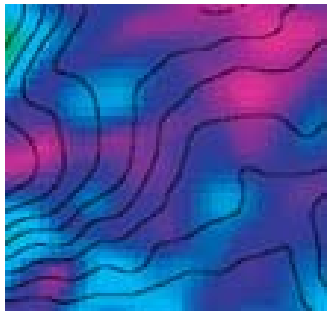
Probabilistic Iso-surface: random variable F at each data point with density function f(z)

Ken Brodlie, et al. 2008

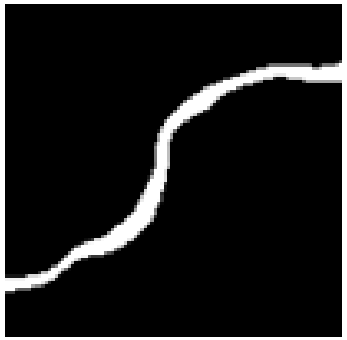
Measurement errors:
Normal distribution

Rounding errors:
Uniform distribution

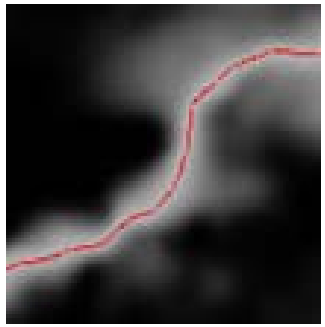
Ensemble computing:
Distribution derived from data



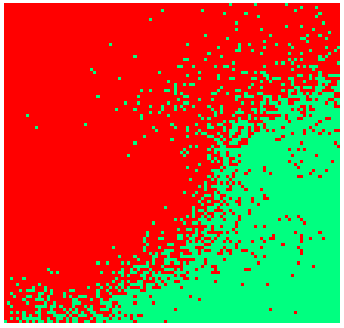
RMS error



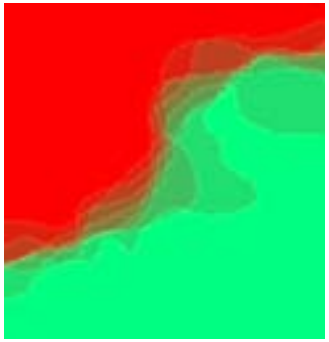
Contour bond



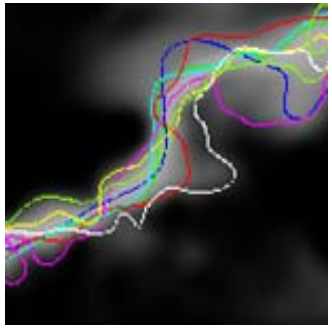
Fuzzy Contour



Probabilistic Model



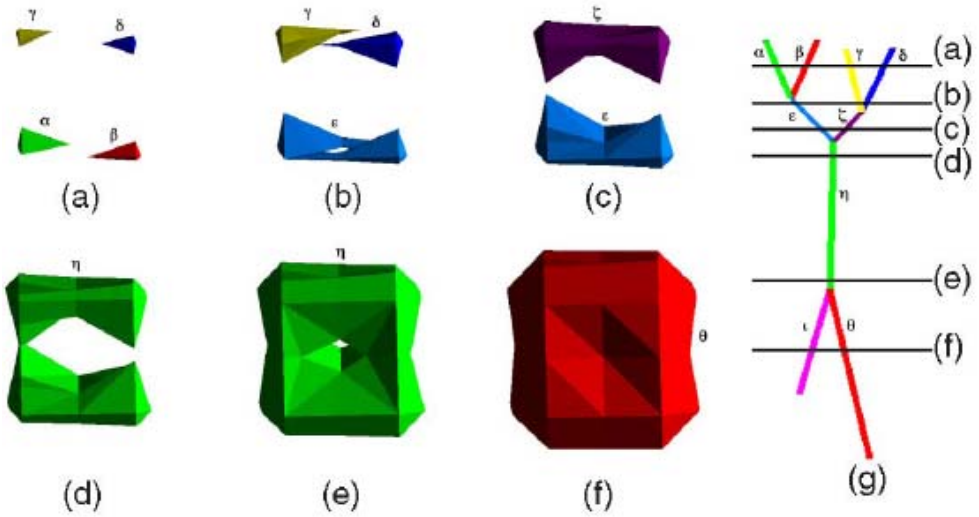
Over lapping



Spaghetti plots looking at each model

Contour Tree

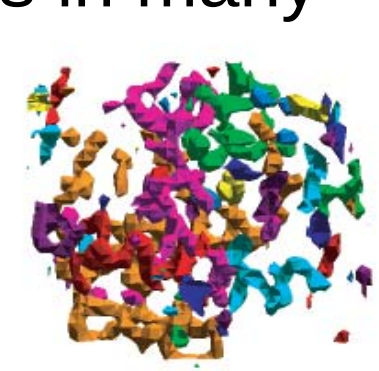
- A Contour Tree (CT):
  - A graph that tracks the evolution of contours in a scalar function
  - Each edge represents a set of adjacent and uniform contours
  - Each node represents a critical point where contours appear, disappear, or merge as the function value increases.
  - One-one mapping from points in the tree to the contours of a scalar field

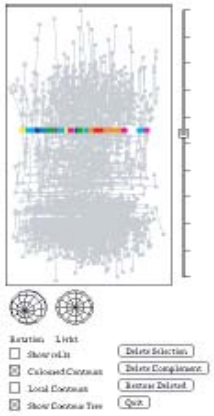


A scalar field (left) and its contour tree (right)

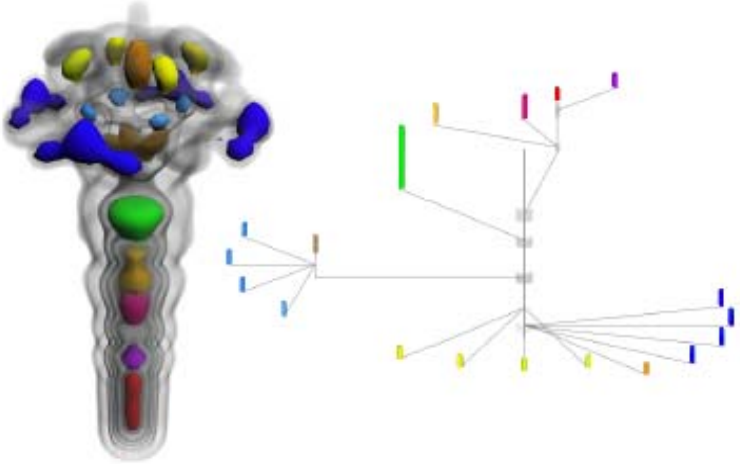
Contour Tree

- Contour tree provide effective tools in many applications
  - Iso-value selection
  - Transfer function design
  - Hierarchical representation

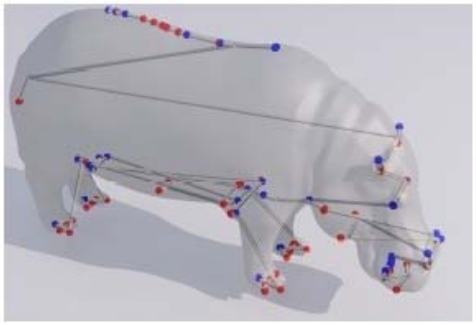


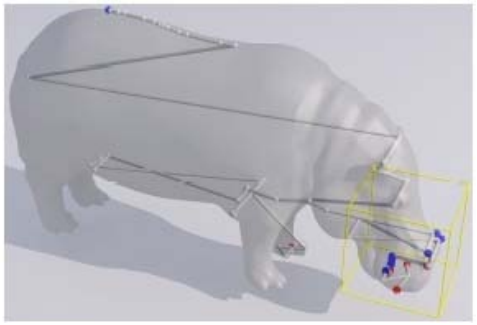


Contour selection for a molecule
H. Carr, 2003



Transfer function design using contour tree, S. Dilard, 2007





Hierarchical contour tree
V. Pascucci, 2004

Method

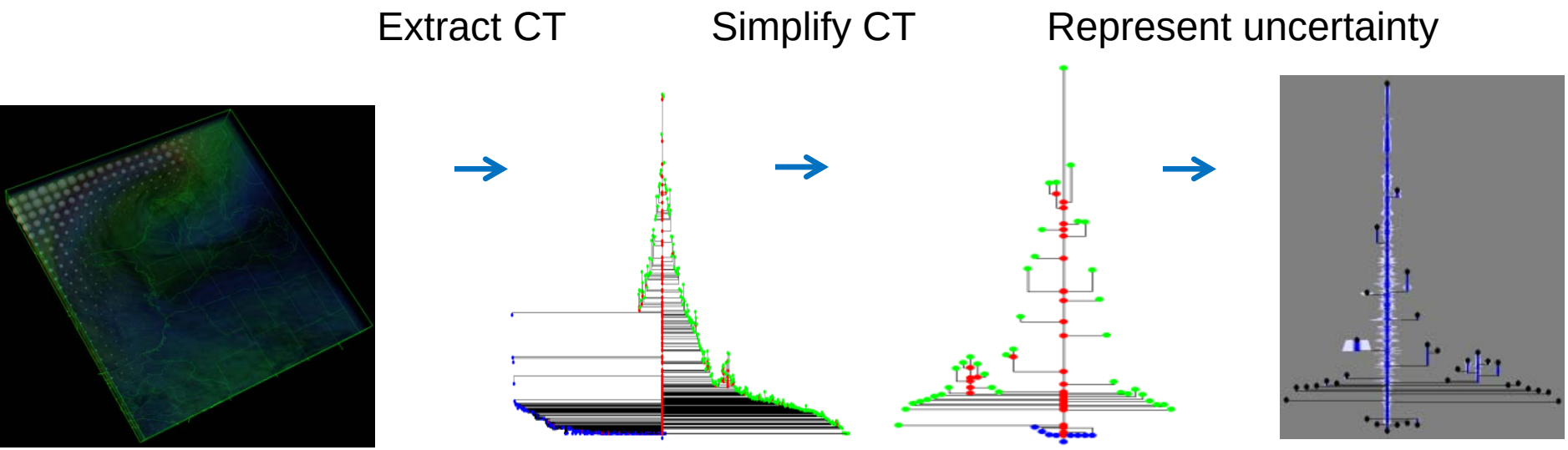
- Method Overview
- Contour Tree Layout and Tree View Graph Design
- Contour Tree-Based Uncertainty Visualization
- User Interface Design

Method Overview

- Our goal:
  - Develop interactive tool to explore uncertain data
  - Fully explore uncertainty in data-level, contour-level, and topology level with intuitive uncertainty representation

Method Overview

- Method Components
  - Contour tree extraction [Carr et al. 2003]
  - Contour tree simplification, layout, and interaction
  - Contour tree-based uncertainty representation
  - User interface
- Method Pipeline



Contour Tree simplification, Layout, and Interaction

- Contour tree simplification
- Contour tree layout
- Tree View Graph interaction design

Contour Tree Simplification

- Introduced to help represent and interact with large CTs
- Usually cancel edges repeatedly with increasing importance

Cancel a CT edge

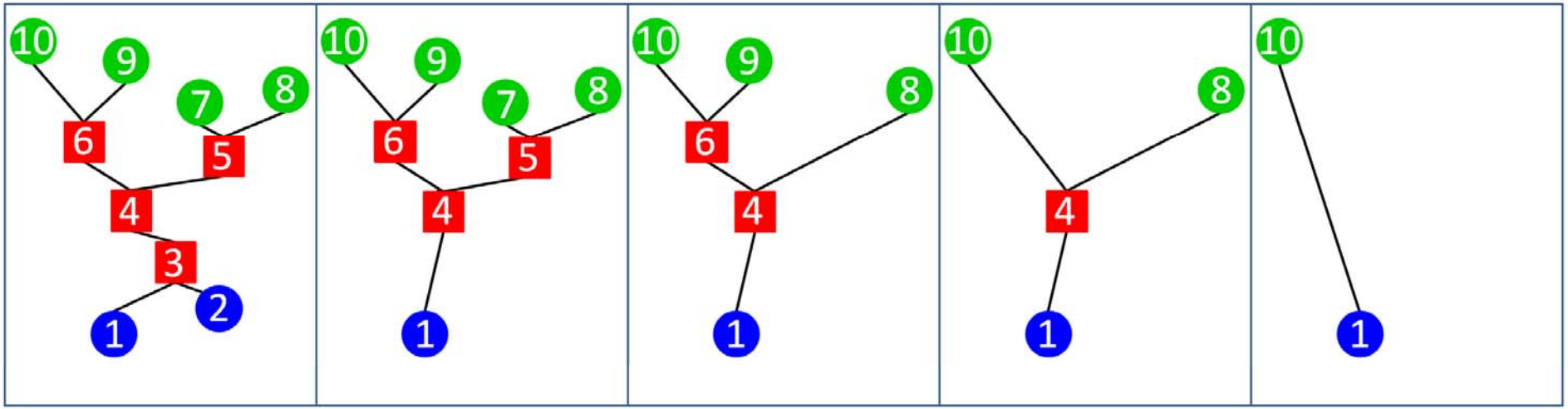
Persistence: the absolute difference in function value spanned by the two end points of a edge

CT Simplification, Layout, and Interaction

Contour Tree Simplification

- Introduced to help represent and interact with large CTs
- Usually cancel edges repeatedly with increasing importance

Traditional bottom-up simplification



Contour Tree Simplification

New Top-down Contour Tree Simplification

- Find edges in decreasing persistence
- How it works?

The idea: Find reversed edge cancelation order of a bottom-up simplification

Two new lemmas:

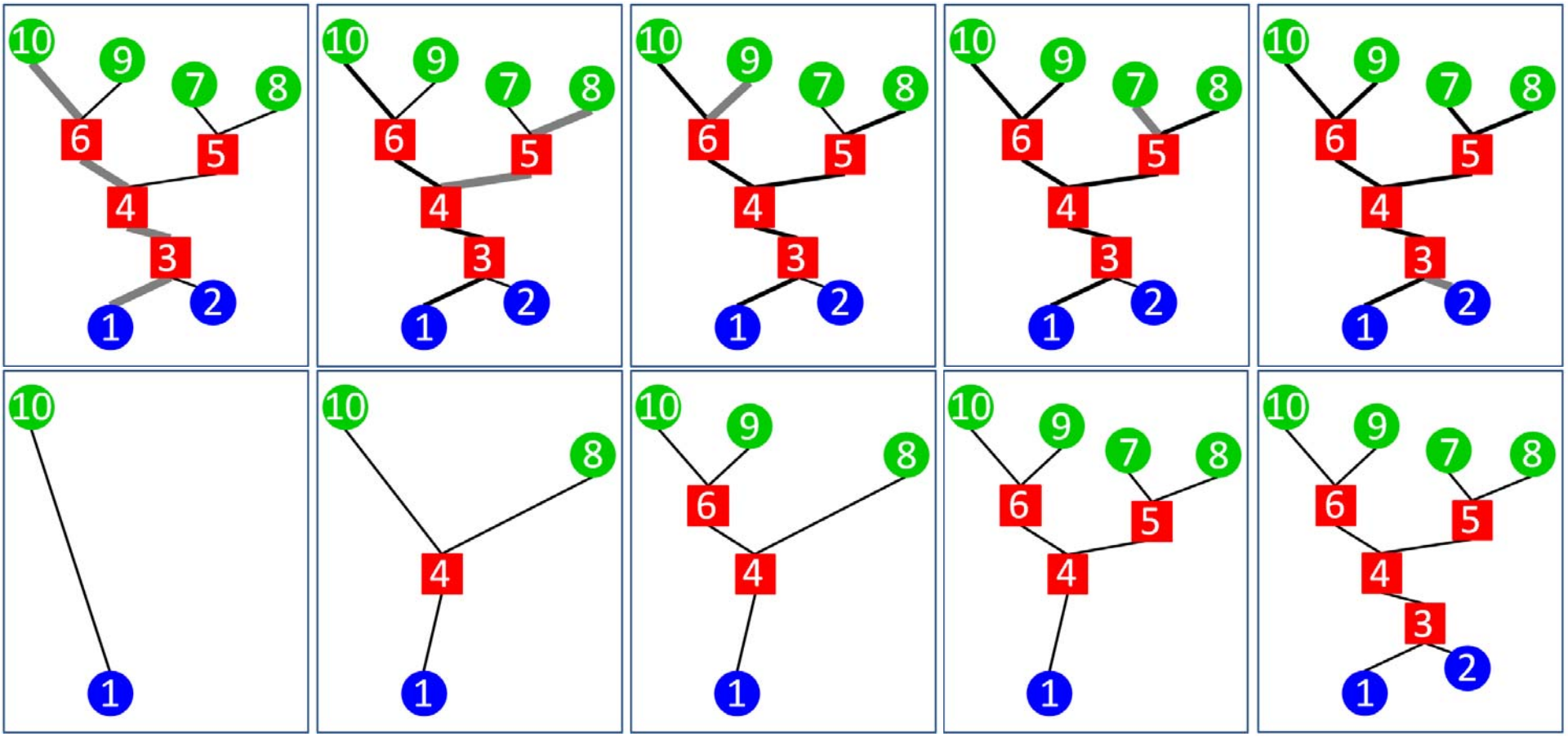
Lemma 1 The last cancelled pair in a bottom-up simplification is the pair of lowest minimum and the highest maximum that is searchable through a monotone path of CT.

Lemma 2 The *n+1* th cancelled pair in a bottom-up simplification is the pair with the highest persistence among all the child branches in the simplified CT after cancelling *n pairs.*

Contour Tree Simplification

New Top-down Algorithm

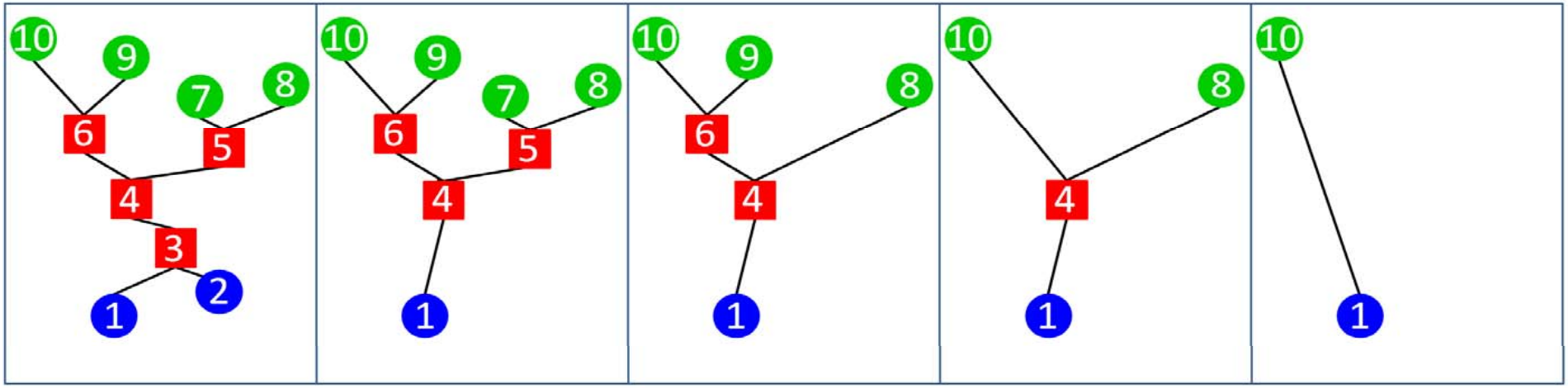
Top-down contour tree simplification



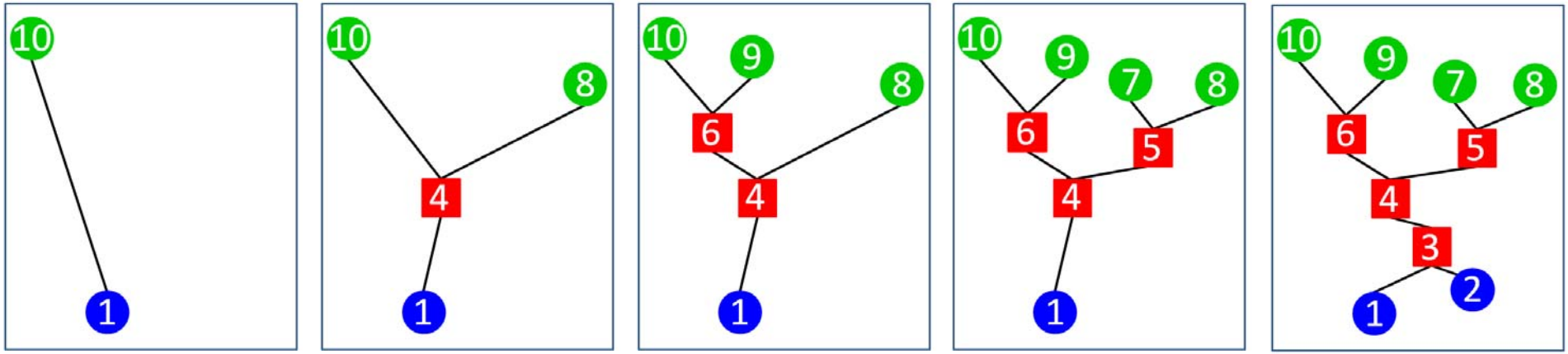
Contour Tree Simplification

Top-down Simplification VS Bottom-up Simplification

Bottom-up simplification - faster when the contour tree is small



Top-down simplification - faster when the contour tree is large

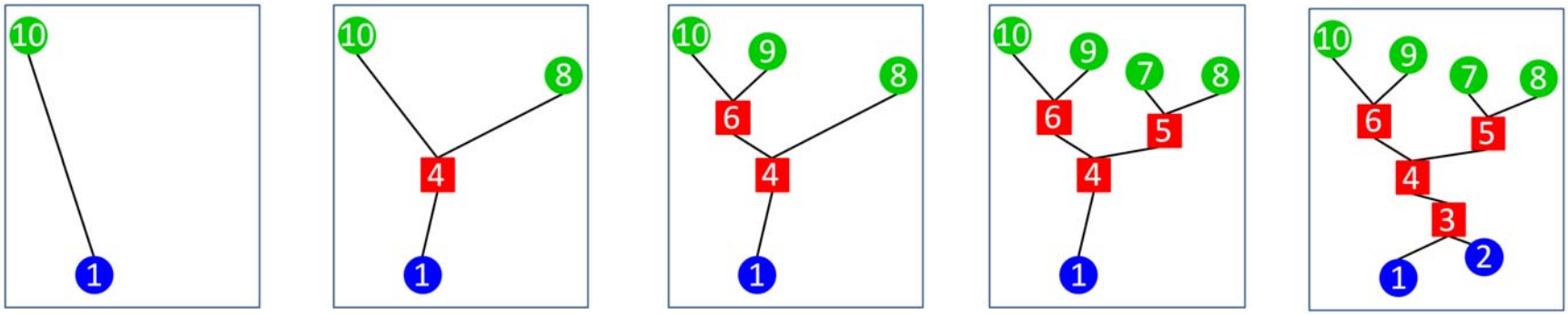


CT Simplification, Layout, and Interaction

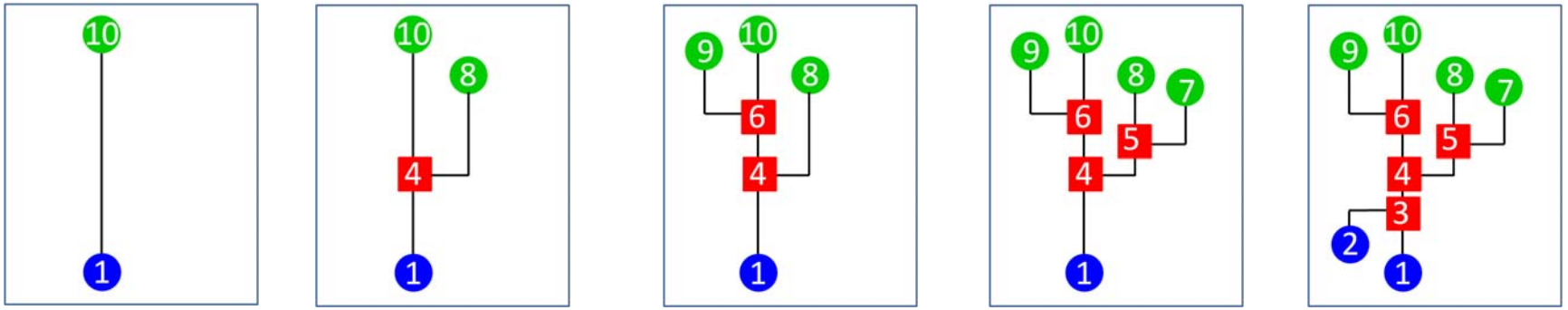
Contour Tree Layout Design

- The idea:
  - Recursively assign vertical slots to the branches of a CT
  - Driven by the top-down simplification

Grow …



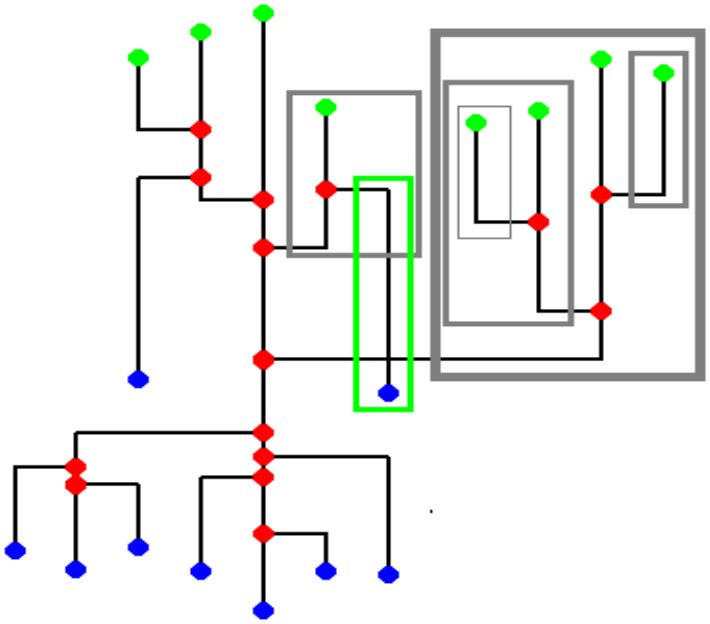
Display …



CT Simplification, Layout, and Interaction

Contour Tree Layout Design

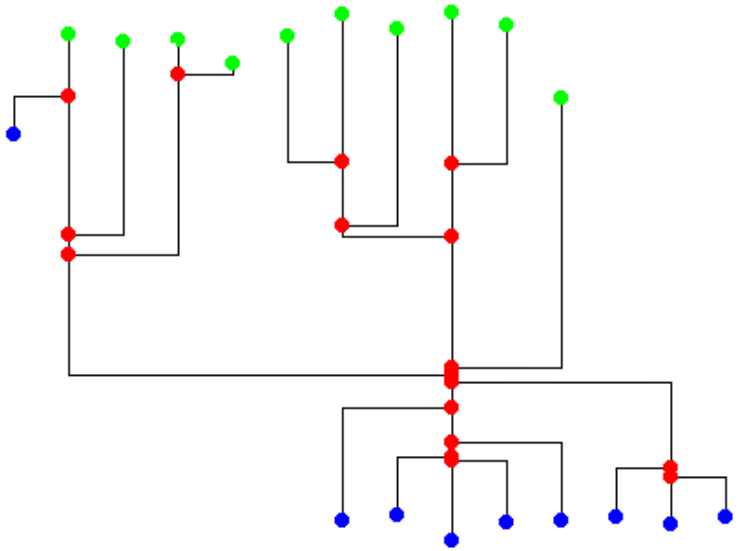
- The idea:
  - Recursively assign vertical slots to the branches of a CT
  - Driven by the top-down simplification



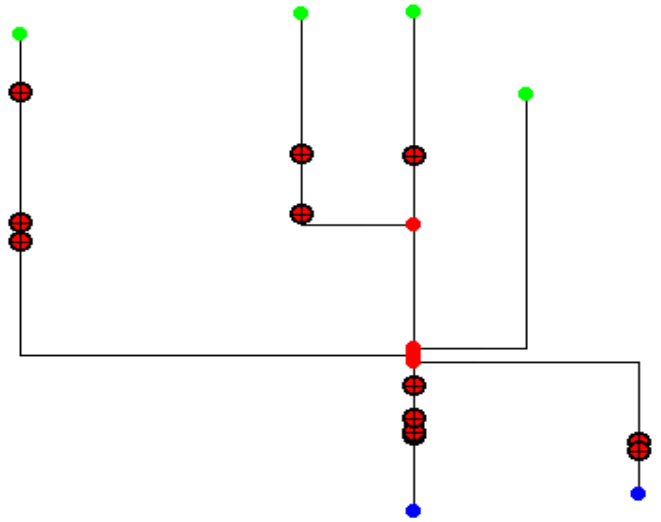
CT Simplification, Layout, and Interaction

Interact with CT - Tree View Graph

- The idea:
  - Adopt the intuitive tree view graph
  - Users can collapse (or expand) a particular sub-tree to hide (or show) the items included in that sub-tree.



Original CT displayed with the new planar layout



Interactively simplified CT after user clicked on several nodes

CT-Based Uncertainty Visualization

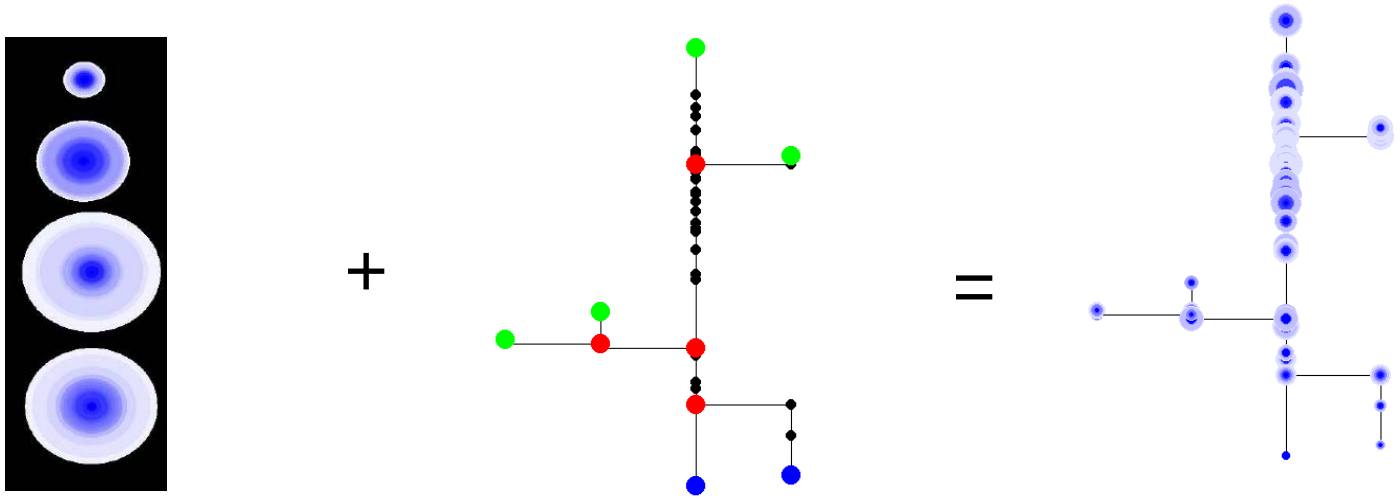
- **Data-Level Uncertainty**
- **Contour-Level Uncertainty**
- **Topology-Level Uncertainty**

Data-level Uncertainty Visualization based on CT

- What is it?
  - The data-level uncertainty measures how uncertain the numerical values of data are along the contours
  - Measured by standard deviation (SD), inter-quartile range (IQR), and the confidence intervals (CI)
- Why visualize data-level uncertainty based on CT?
  - Avoid the issues when visualizing uncertainty within volume data (limited glyph resolution, cluttering, and occlusion)

Data-level uncertainty Visualization based on CT

- How to visualize data-level uncertainty based on CT?
  - Attach uncertainty glyphs to a fully augmented CT
  - Avoid the visual cluttering and occlusion of viewing uncertainty within volume data



Circular graduated glyphs
Sanyal, 2010

A fully augmented CT
(with all the vertices of the data)

CT with uncertainty glyph

Contour-level uncertainty visualization based on CT

- What is it?
  - Contour-level uncertainty measures the positional uncertainty of a contour
- Why visualize contour-level uncertainty?
  - Users are interested in the most stable or unstable contours
  - Users' estimates tend to be inaccurate due to the randomness of the contour shape and length

Contour-level uncertainty visualization based on CT

- How to visualize contour-level uncertainty based on CT?

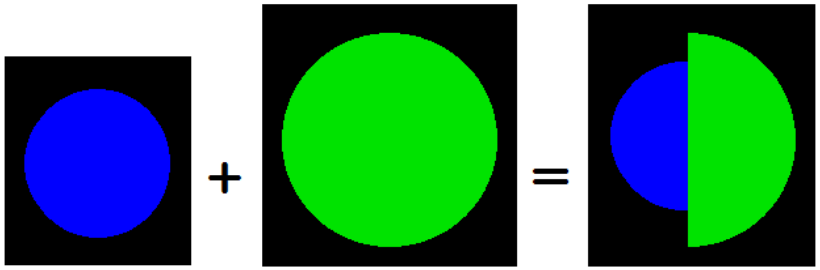
  Let a contour of the ensemble mean be C , and corresponding contours of individual ensemble be Ci, i=1, …, k.

  Two uncertainty metrics:

  (1) Average distance among contours of individual ensemble members:

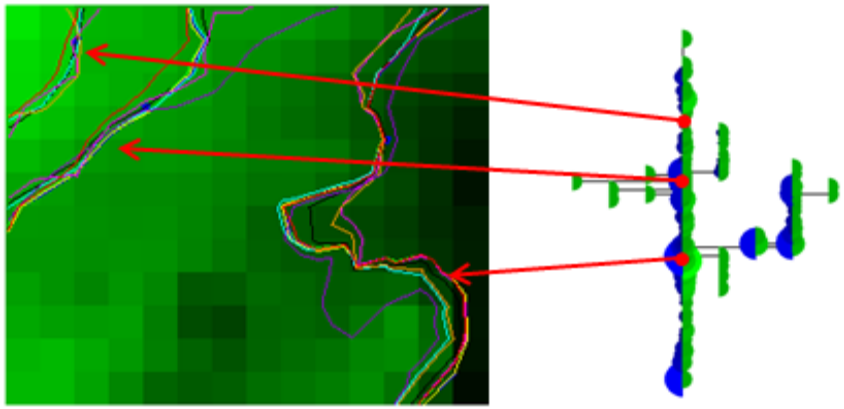
$$mean = \sum dis\tan ce(C, C_i) / k$$

  (2) Variance: $$va = \frac{\sum (difference(C, C_i) - mean)^2}{k}$$



mean distance variance combined glyph

Contour-level uncertainty glyph design



Each glyph on CT indicates uncertainty of a corresponding contour

Topology-level uncertainty visualization based on CT

- What is it?
  - Topology-Level Uncertainty measures uncertainty concerning the difference of Contour Tree among the ensemble members
- Why visualize topology-level uncertainty based on CT?
  - Contour tree summarize the topology of contours
  - A key to uncover how uncertain the topology is

CT-Based Uncertainty Visualization

Topology-level uncertainty visualization based on CT

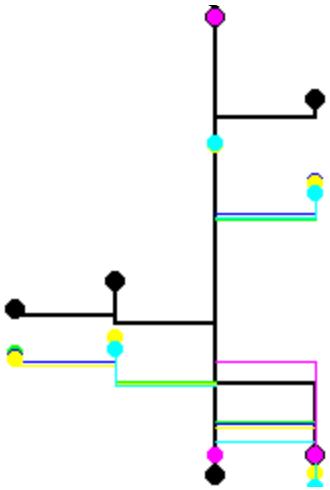
- How to visualize topology-level uncertainty based on CT?

  The idea: Overlay the CTs of different ensemble members and the ensemble mean

  Repeat for branches from high to low hierarchy:

  Step 1: measure the distance between branches (sa , ua) in CTa and (sb , ub) in CTb at the same CT hierarchy $|f(s_a)-f(s_b)|+|f(u_a)-f(u_b)|$

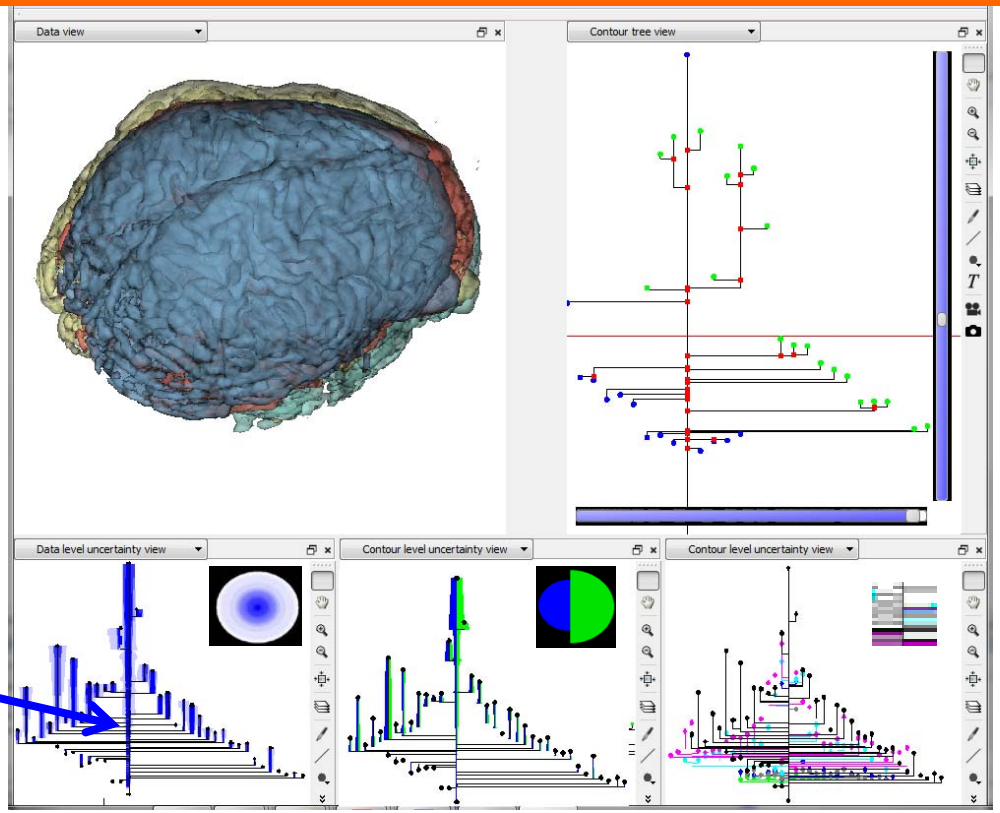
  Step 2: Render the best matched branches (with minimum distance) of different CTs with the same horizontal location



All the matched branches are drawn with same x-coordinate

User Interface

Contours of the same iso-value in different ensemble members

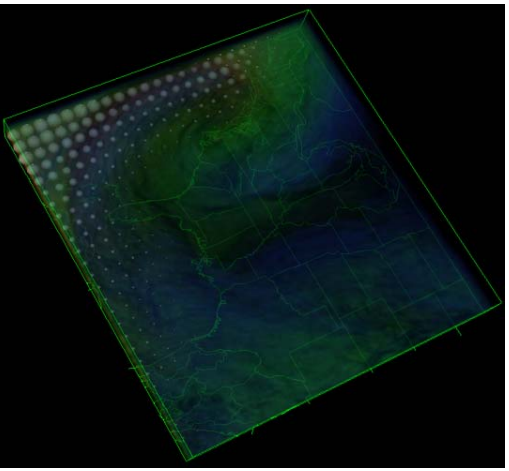


(1) Use a horizontal slider on the bottom of the CT display to decide how many branches to be shown
(2) Work on the tree view graph to remove the unwanted sub-trees
(3) Select contours to display by double-clicking on the CT based on the quantified uncertainty information attached in the CT

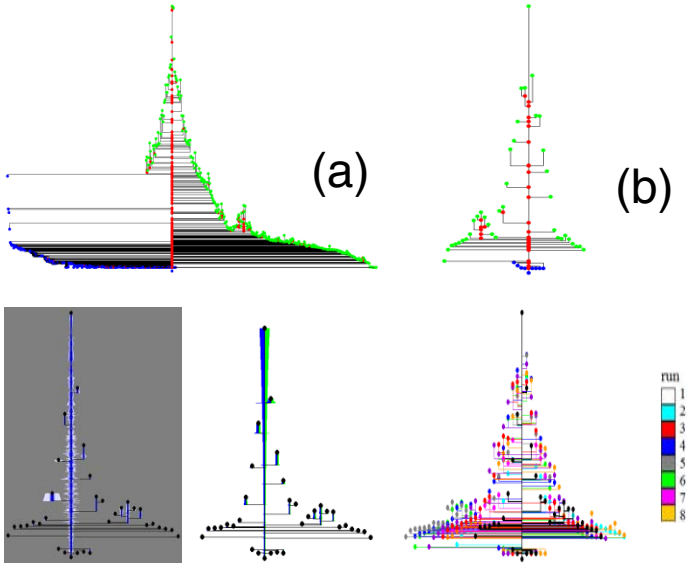
Experiments

- WRF simulated data ensembles
- Volumetric medical data

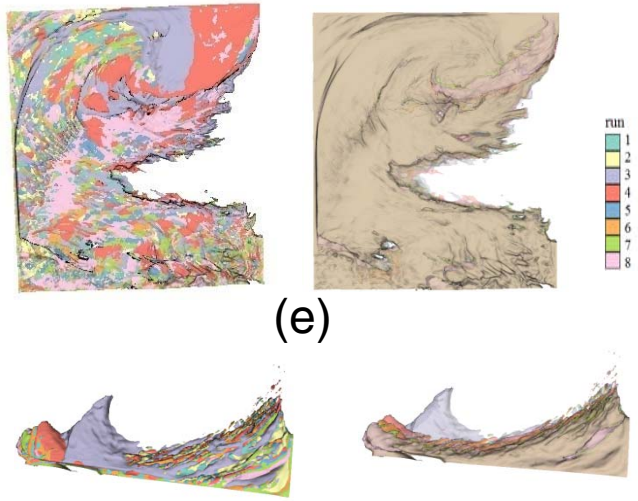
WRF Weather ensembles



(d)



(c)

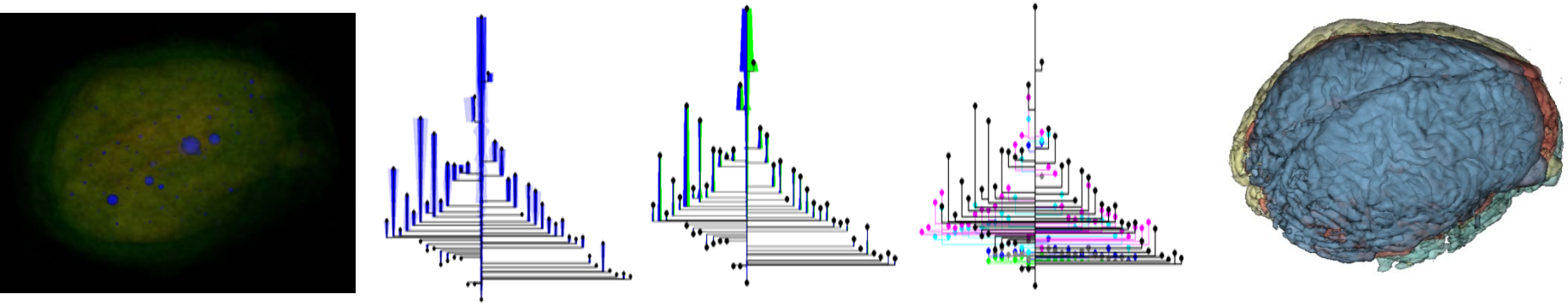


(e)

(f)

Weather data application. (a) Original contour tree. (b) Simplified contour tree. (c) Left to right: data-level uncertainty, contour-level uncertainty, and topology-level uncertainty shown in the simplified contour tree. (d) Volume rendering with uncertainty glyphs. (e) A set of contours with high data-level uncertainty. (f) A set of contours with high contour-level uncertainty. Both non-transparent and transparent iso-surfaces are shown.

Volumetric human brain



(a) (b) (c)

Medical data. (a) Volume rendering with uncertainty glyphs. (b) Three level of uncertainties shown in simplified contour tree. (c) A contours (of the same iso-value in different data)

Conclusion & future plan

- Contributions:
  - An efficient CT top-down simplification
  - A planar CT layout with low self-intersections and tree view graph interaction
  - A new paradigm of visualizing uncertainty based on CT with data-level, contour-level, and topology-level of
  - An interactive CT-based visualization for exploring 3D data guided by quantified uncertainty information

Conclusion & future plan

- Future Plan
  - Perfect uncertainty measurement, visualization effect, and interface design
  - Domain expert evaluation

Acknowledgments

This work has been supported in part by NSF1117871. The authors wish to thank Jibonananda Sanyal for providing the WRF data and helping us to design interface with Qt.

Question & Suggestion