Variability in Visualization

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"The use of computer-supported, interactive, visual representations of (abstract) data to amplify cognition"

Data is increasing in complexity and variability

Data Complexity and Variability

- Challenges
  - New imaging modalities, data sources
  - Very large data sets, across scales
  - High-dimensional, multi-valued, multi-modal, heterogeneous
  - Time varying data
  - Uncertainties, errors, variations, ensembles, longitudinal studies, populations

How to cope with increased data variability??

Visual Steering to Support Decision Making in Visdom

J. Waser, R. Fuchs, H. Ribilić, Ch. Hirsch, B. Schindler, G. Blöschl, E. Gröller

Flood emergency assistance

- New Orleans 2005: 17th canal levee breach

Evaluation of breach-closure techniques in a laboratory model

Flood emergency assistance

- Testing sandbag configurations in a virtual environment

Motivation – Interactive decision making

- Complex problem can only be solved by posing a series of ‘What if’ questions.

Motivation – Interactive decision making

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Solution: World Lines

Control

Solution: World Lines

Knowledge

Multi-View
System

Multi-View
System
Video: World Lines - Basics

Robustness Analysis
- Task: Find robust sandbag arrangement

Robustness Analysis
- Local expert proposes 3 different solutions to be tested

Robustness Analysis
- For each solution, we create a parameter study with respect to levee-breach location

Nodes on Ropes
- Data flow: horizontally ↔ Control flow: vertically

Robustness Analysis
- Robustness Analyzers to visualize results per output

a) $\sigma < 0.1$

b) $0.1 \leq \sigma < 0.5$
Robustness Analysis

- Robustness Analyzers to visualize results per output

\[ 0.5 \leq \sigma < 0.8 \]

Video: Robustness Analysis

- Video: Real-World Example - Innsbruck

Joint system project of VRVis + ETH Zürich

- Client-Server System
  - Meta-flow on client
  - Data-flow on server
  - GPU-based simulation, rendering and analysis
  - Future vision: Mobile decision support

http://visdom.at

Uncertainty-Aware Exploration of Continuous Parameter Spaces Using Multivariate Prediction

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Pointwise Navigation and Prediction

User-defined focal point
- Specifies values for all parameters
- Coordinates multiple views

Real-time prediction of associated targets
- Uses surrogates for the more complex real functions
  - Regression models
  - K-nearest neighbor estimators

Contribution

Local Analysis

Parameter Space

Target Space

Guided Navigation

- Varies the parameters defined by current focal point
- Indicates target ranges within reach
- Enables quick navigation to interesting points
**Guided Navigation**

- **Parameter Space**
- **Target Space**
- **Focal Point**
- **Variations**

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**Guided Navigation**

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- **Focal Point**
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**Contribution**

- **Parameter Space**
- **Target Space**
- **Local Analysis**

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**Contribution**

- **Parameter Space**
- **Target Space**
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**Guided Navigation**

- **Parameter Space**
- **Target Space**
- **Map Neighborhood**

- Visualizes neighborhoods around the prediction at the focal point.
- Indicates gradients of the targets around predictions at the focal point.
- Conveys the sensitivity of multiple targets

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**Guided Navigation**

- **Parameter Space**
- **Target Space**
- **Area shape**

- **5% decrease**
- **Target 1**
- **5% increase**
- **Constant prediction**
- **Low sensitivity**

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Uncertainty of Predictions

### Parameter Space
- Regression models
  - Potentially insufficient complexity
- Nearest-neighbor predictors
  - Depend on the local sampling density

### Target Space
- Uncertainty at focal point

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Uncertainty of Predictions

- Regression models
  - Distribution of prediction residuals near the focal point
- Nearest neighbor predictors
  - Distribution of the used target values

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Application Background

- Development process of car designs by means of 1D-CFD multi-run simulations
- Parameter Space
  - Design choices of the engineers (e.g., fuel injection timing)
  - Conditions varying during operation (e.g., engine speed)
- Target Space
  - Simulated behavior (e.g., torque, fuel consumption)
- Goals
  - Studying the complex interactions between car components
  - Optimizing design choices

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Application Example

**Application Example:**

Optimize the design of a real-world turbo-charged car engine

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User Feedback

- Increased interaction between multiple complex car components
- Immediate prediction helps to convey dynamics of the investigated systems
- Guided navigation helpful to quickly navigate to interesting points
- Uncertainty of predictions a crucial information to justify expensive simulation runs

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Coping with Complexity and Variability

- Reducing data complexity well established
  - Sub-setting
  - Slicing
  - Projection
  - Dimension reduction
  - Clustering

- Reducing visual complexity ??
  - Integrated views
  - Comparative visualization
  - Fuzzy visualization
  - ...

Reducing visual complexity ??

Integrated Views


Views - Linked Views - Integrated Views

- Separate views
  + Remove overload
  - Loss of context

- Linked views
  + Re-establish context
  - Scalability??

- Integrated views

Views - Linked Views - Integrated Views

Side-by-side view

Volume Rendering

Hierarchical Layout

Balloon layout
**Integrated View**

**Integrated Visualization and Interaction**

**Dataset Series**

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<th>Dataset Resolution</th>
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<th>Series Size</th>
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</table>

**Comparative Slice View**

- Viewing two datasets on a single screen
- Viewing multiple datasets on a single screen

**Comparative Visualization**

Visualization (Multi-image View)
- Each slice shows part of each dataset

Comparative Slice View (Multi-image View)
- Direct density visualization
- Relative density visualization

Video: Comparative Visualization - Interaction

Fuzzy Visualization

Curvature Based Selective Application
If principal curvature is not positive then contours are bluish

Semantic Layers for Illustrative Volume Rendering (1)
- Mapping volumetric attributes to visual styles
- Use natural language of domain expert (rules)
- Rules evaluated with fuzzy logic arithmetics

[Rautek et al. 2007]
Semantics exist

- volumetric attributes
  - density: low – … – high
  - curvature: negative – zero – positive
  - etc.

Illustrative styles
- contour style
- transparent
- black
- red
- etc.

Curvature:
- negative
- zero
- positive

Membership Functions

- if-part: semantics for volume attributes
  - attribute
  - close to zero
  - positive

- then-part: semantics for visual appearance

Rule Base

- if (principal curvature is negative and density is high and gradient magnitude is high or distance to user focus is low)

- then contour style is red

Fuzzy Logic Inside the Black Box

- attribute semantics
- illustration semantics
- parameters for styles

Fuzzy Logic as a Black Box

- attribute semantics
- style semantics
- fuzzy logic
- parameters for styles

Semantics Driven Illustrative Rendering

- video1
- video2
- video3

Make use of semantics!
Variability in Visualization – Quo Vadis? (1)

- Image collections: comput. photography → large data collections: comput. vis. ???
- Integrated views/interaction
- Comparative visualization
- Comparative navigation
- Difference visualization
- Contradictory visualization
- Information theory → fuzzy visualization
- Sparsification of visual representations

Variability in Visualization – Quo Vadis? (2)

- Parameter space analysis
  - Local (stability), global (boundaries, basins)
  - Topology of parameter spaces
  - Automatic parameter tuning
- Interaction sensitivity
- Interval arithmetics → distribution arithmetics in visualization (uncertainty visualization)
- Algorithmic centric → data/image centric
- Imperative → declarative approaches

Variability in Visualization – Quo Vadis? (3)

- Frameless rendering → algorithmless rendering
- Program verification → image verification
  - Algorithms on demand
  - Each pixel/voxel gets its own algorithm
- Publishing in visualization
  - More stability/robustness analyses in future?
  - Executable Paper Grand Challenge

Thank You for Your Attention

Questions?

Doubt is not a pleasant condition, but certainty is absurd. [Voltaire]

Variability in Visualization

- Abstract: Data Visualization uses computer-supported, interactive, visual representations of (abstract) data to amplify cognition. In recent years data complexity and variability has increased considerably. This is due to the availability of uncertainty, error and tolerance information. The talk discusses visual steering to support decision making in the presence of alternative scenarios. Multiple, related simulation runs are explored through branching operations. To account for uncertain knowledge about the input parameters, visual reasoning employs entire parameter distributions. This can lead to an uncertainty-aware exploration of (continuous) parameter spaces. Coping with the heightened visual complexity and variability requires advanced strategies like comparative visualization, integrated views and inclusion of fuzzy sets in the visualization process.

Related links:

- http://www.cg.tuwien.ac.at/research/publications/2010/malik-2010-cvp/