Visualizing Uncertainty:
Computer Science Perspective

Ben Shneiderman, Univ of Maryland, College Park
Alex Pang, Univ of California, Santa Cruz

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Visualizing Uncertainty
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What do we mean by uncertainty?
Why is this an issue now?
Sources of uncertainty

- Measurement problems
- Ranges/Summaries
- Missing data
- Human ratings
- Potential deceptions
- Privacy protection
- Risk assessments
- Forecasts

Scientific data
- Intelligence sources
- Statistical analyses
- Medical images
- Gene expression
- Simulations
- Financial models
- Weather
- Consumer ratings
Visualizations

- Text, statistical measures…
- 1D: Lists, documents, numeric ranges…
- 2D: Geographic Info
- 3D: Scientific Visualization
- Multi-Variate: Information Visualization
- Temporal: Patient histories, web logs …
- Tree: Taxonomies, org charts, directories …
- Network: Social, communication…
Text: Statistical uncertainty

<table>
<thead>
<tr>
<th>Poll</th>
<th>Dems</th>
<th>Reps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bush</td>
<td>14%</td>
<td>81%</td>
</tr>
<tr>
<td>Kerry</td>
<td>79%</td>
<td>7%</td>
</tr>
</tbody>
</table>

Margin of error +/- 3%

<table>
<thead>
<tr>
<th>Time Variables</th>
<th>Frustration (N=372)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Lost (Incident)</td>
<td>**.293</td>
</tr>
<tr>
<td>Time to Fix (Incident)</td>
<td>**.233</td>
</tr>
<tr>
<td>Computer Years</td>
<td>-.041</td>
</tr>
<tr>
<td>Hours per Week</td>
<td>*-.124</td>
</tr>
</tbody>
</table>

* = p<.05 ** = p<.01

<table>
<thead>
<tr>
<th>Rain inches</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW</td>
<td>1.0</td>
</tr>
<tr>
<td>SE</td>
<td>1.5</td>
</tr>
<tr>
<td>NW</td>
<td>1.2</td>
</tr>
<tr>
<td>NE</td>
<td>0.8</td>
</tr>
</tbody>
</table>
Risk/Danger vs. Trust/Validity/Security

- 1D
- 2D
- 3D
- Multi-V
- Temporal
- Tree
- Network

<table>
<thead>
<tr>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Municipal Bonds</td>
</tr>
<tr>
<td>Blue Chip Stocks</td>
</tr>
<tr>
<td>Tech Stocks</td>
</tr>
<tr>
<td>Real Estate</td>
</tr>
</tbody>
</table>

Highly          About  Likely
Unlikely        Unlikely Even

NAS Workshop: Visualizing Uncertainty
1D: Ranges, variations & forecasts

- Text
- 1D
- 2D
- 3D
- Multi-V
- Temporal
- Tree
- Network

Average Completion Times (with standard deviations)

- Type 1
- Type 2
- Type 3

Record highs

Normal highs

Normal lows

Record lows
2D: Ball glyphs

Delta (observation - forecast)

- Text
- 1D
- 2D
- 3D
- Multi-V
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- Network

http://www.cse.ucsc.edu/research/slvg/assim.html
2D: Arrow glyphs (Direction & velocity)

http://www.cse.ucsc.edu/research/avis/unvis.html
2D: Box glyphs

Schmidt et al., 2004, Underwater Environmental Uncertainty, IEEE CG&A
http://csdl.computer.org/comp/mags/cg/2004/05/g5056abs.htm
2D: Grid with transparency/shading

Figure 5: Current IWEDA-like spatial display showing the cloud ceiling at one particular time over the PUMAR domain. The black stars were points of interest during the T-UAV demonstration scenario. The red, yellow, and green “pixels” were assigned based on operational T-UAV cloud ceiling sensitivities.

Figure 6: The same display as in Fig. 4, except for the application of cognitive engineering techniques to change the hue (color) and transparency of the cloud ceiling impacts based on the uncertainty of the predicted cloud ceiling.

Lefevre, Pfautz & Jones
Off-the-shelf software can give incorrect contours on data with lots of missing values.

Modifications to contouring algorithm to account for large number of missing values.
2D: Pseudocolor shows mean values

Luo, Kao & Pang, 2003, EuroVis
http://www.soe.ucsc.edu/~pang/op.pdf
2D: Darkness = uncertainty (high stddev)

Mean = hue
Skew = 1/saturation
Stddev= 1/value
2D: Separate layer

Surface Graph: Standard Deviation
Contour Color: Interquartile
Bars: |Mean - Median|

http://www.cse.ohio-state.edu/~bordoloi/Pubs/pdfCluster.pdf
2D: Streamlines with binwise +

Luo, Kao & Pang, 2003
http://www.soe.ucsc.edu/~pang/op.pdf
2D: Weather forecast

[Map of Hurricane Ivan, showing wind speed and movement]
2D: NOAA Storm Prediction Center

[Map of the United States with a tornado probability forecast]

Probability (%) of Tornado on 000506/0000

http://www.spc.noaa.gov/products/
2D: Dual views & grid lines

Dark shows pollution  
(Howard & MacEachren, 1996)

Dark shows Certainty  
(Cedlink & Rhenigas, 2000)
Dual maps for Rate and reliability

Bivariate color scheme

Double hatch shows unreliable

(MacEachren et al., 1998)
2D: Gray for missing & interpolation

Gray shows missing & interpolated value, superior to using black only


http://svs.gsfc.nasa.gov/vis/a000000/a000000/a000010/index.html
3D: Fuzzy molecular surface: HIV protease

Text
1D
2D
3D

Multi-V
Temporal
Tree
Network

Crisp molecular surface
Probe radius 1.4

Fuzzy molecular surface
Probe radius 1.4

Crisp molecular surface
Probe radius 5.0

Fuzzy molecular surface
Probe radius 5.0

Lee & Varshney (2002), UM Graphics and Visual Informatics Lab

http://www.cs.umd.edu/gvil
3D: Fuzzy molecular densities
3D: Uncertainty ‘dust’

Figure 5: Hybrid of point-based and polygonal models with transparency. Representation of uncertainty is more intuitive since uncertain regions are simply the ones which look uncertain the eye.

Figure 7: Real tumor data.

clearly see that areas pointed to by red arrows are of particularly high uncertainty while those pointed to by blue arrows are rather certain and strictly shaped. Figure 8 visualizes a larger subvolume of the same data set. Uncertainty distribution is just as intuitive as it is in Figure 3.
3D: Color & opacity
Multi-V: Database/spreadsheet tables

- Text
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Multi-V: Database/spreadsheet tables

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Temporal: Granularity of time

**Text**

- **April 14, 1865**: The Stars and Stripes is ceremoniously raised over Fort Sumter. That night, Lincoln and his wife Mary see the play "Our American Cousin" at Ford’s Theater. At 10:13 p.m., during the third act of the play, John Wilkes Booth shoots the president in the head. Doctors in the theater then move him to a house across the street. He never regains consciousness.

- **April 15, 1865**: President Abraham Lincoln dies at 7:22 in the morning. Vice President Andrew Johnson assumes the presidency.

- **April 18, 1865**: Confederate Gen. Joseph E. Johnston surrenders to Sherman near Durham in North Carolina.

- **April 26, 1865**: John Wilkes Booth is shot and killed in a tobacco barn in Virginia.

- **May 4, 1865**: Abraham Lincoln is laid to rest in Oak Ridge Cemetery, outside Springfield, Illinois.

- **In May**: Remaining Confederate forces surrender. The Nation is reunited as the Civil War ends. Over 620,000 Americans died in disease, killing twice as many as those lost in battle. 50,000 survivors return home as amputees.

**1D**

**2D**

**3D**

**Multi-V**

**Temporal**

**Tree**

**Network**
Temporal: Granularity of time

Text

1D

2D

3D

Multi-V

Temporal

Tree

Network

Using the timeline

Choose a century

- 1st century
- 1-100 AD
- 2nd century
- 100-200 AD
- 3rd century
- 200-300 AD
- 4th century
- 300-400 AD
- 5th century
- 400-500 AD
- 6th century
- 500-600 AD
- 7th century
- 600-700 AD
- 8th century
- 700-800 AD
- 9th century
- 800-900 AD
- 10th century
- 900-1000 AD
- 11th century
- 1000-1100 AD
- 12th century
- 1100-1200 AD
- 13th century
- 1200-1300 AD
- 14th century
- 1300-1400 AD
- 15th century
- 1400-1500 AD

- Roman period
- Anglo-Saxon period
- Viking Period
- Norman period
- Medieval period
- Tudor and Stuart period
- Georgian period
- Victorian period

You can use the timeline in one of the three following ways

- Chose a subject from the column on the left
- Chose a century from the column on the right
- Chose an era from below
Temporal: Granularity of time

- Text
- 1D
- 2D
- 3D
- Multi-V
- Temporal
- Tree
- Network
Temporal: Granularity of time

- Text
- 1D
- 2D
- 3D
- Multi-V
- Temporal
- Tree
- Network

[Timeline of Art History Image]
Tree: Topology, values & names

- Text
- 1D
- 2D
- 3D
- Multi-V
- Temporal
- Tree
- Network

- Gene Ontology
- Tree of Life
- Medical Subject Heading (MeSH)
- Chain of command/Org chart
Tree: Topology, values & names

- Text
- 1D
- 2D
- 3D
- Multi-V
- Temporal
- Tree
- Network
Tree: Topology, values & names

- Text
- 1D
- 2D
- 3D
- Multi-V
- Temporal
- Tree
- Network

Certainty

Hi
Med
Low

Leland or Lee

Mike or Michael

Alex or Alan

Barbara

Scott

Ben or Benjamin

Diane or Di

Ed or Edward or Eddie
Network: Social relationship

- Text
- 1D
- 2D
- 3D
- Multi-V
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- Network

prefuse demos: radial layout

http://prefuse.sourceforge.net/demos-radial.html
Network: Communication capacity
Network: Node & edge uncertainty

- Text
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- 2D
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Next steps

Explore novel approaches to:

- Text: standard terms, percent, probabilities
- Box plots, whiskers, ranges
- Uncertainty glyphs, isoclines,…
- Contours, surfaces, volume rendering
- Hue, saturation, value, focus, haze, dust,…
- Dual views, probes
- Animation, blinking, shaking, flipping,…
- Sound, haptics,…
Next steps

- Heighten awareness of the problem among public, professionals, researchers & developers
- Support multi-valued data representation standards
- Explore techniques for each data type
- Develop guidelines for implementers:
  - Data formats
  - Interactive interfaces
  - Visual presentations
- Develop human performance evaluation methods
- Publish benchmark datasets & evaluation metrics
- Form guidelines for how to propagate/integrate uncertainty markers