Patterns, Gestalt, Perceived contours, Transparency, Motion, Uncertainty

Example Videos

• Vis 2010: Van Pelt: file245-3 avi
  – Illustrative methods for flow visualization

• Vis 2010: Tikhonov: file290-2 mov
  – Proxy-based ambient occlusion and relighting

Patterns

• Investigation is often about finding patterns
  – That were previously unknown, or
  – That depart from the norm.
• Finding such patterns can lead to key insights
  – One of the most compelling reasons for visualization
• Today we look at
  – What does it take for us to see a group?
  – How is 2D space divided into distinct regions?
  – When are patterns recognized as similar?
  – When do different display elements appear related?
Object Perception Stages

- **Stage 1: Parallel, fast extraction**
  - Form, motion, texture, color, stereo depth
  - Contrast sensitivity, edge detection, as studied before

- **Stage 2: Pattern Perception**
  - Contours and boundaries form perceptually distinct regions

- **Stage 3: Object Identification**
  - Slower, serial identification of objects within the scene
  - Comparisons with working memory
Object Perception Stages

• There is feedback!
  – Linear model is a simplification
  – Later stage intentions affect earlier stage responses

Pattern Perception: Gestalt “Laws”

• Gestalt = “pattern”
  – School formed by Max Westheimer, Kurt Koffka, and Wolfgang Kohler
• Robust rules easily translate into design principles
  – * Proximity
  – * Symmetry
  – * Continuity (and Connectedness)
  – * Closure
  – Similarity
  – Relative Size
  – Figure and Ground

Proximity

• Things that are close are grouped together
  – One of the most powerful perceptual organizing principles
  – We perceptually group regions of similar density
  – Design Principle: Place related entities nearby
Symmetry (1/2)

- Bilateral symmetry stronger than parallelism
- Symmetric shapes seen as more likely

Symmetry (2/2)

- Design principle: Make use of symmetry to enable user to extract similarity

Continuity

- Good continuity of elements
- Easier with smooth curves than abrupt changes
- Design principle: Connector and crossing linear elements should be smooth, without sharp bends
Connectedness

- Palmer and Rock (1994) argue that this is more fundamental than continuity.
- Design principle: Positive and negative statement:
  - Connecting two objects can group them even when they are not otherwise similar.
  - Unrelated objects should not be connected, or they will appear to be grouped no matter what.

Closure (1/2)

- A closed contour is seen as an object.
- Perceptual system will close gaps in contours.

Closure (2/2)

- Contour separates world into “inside” and “outside”:
  - Stronger than proximity
  - Venn diagrams from set theory
  - Closure and continuity both help
- Closed rectangles strongly segment visual field:
  - Provide frames of reference
- Design Principle:
  - Partial obscuration may be okay
  - Especially for symmetric objects
Similarity

- Color or shape similarity groups by row
- Separable dimensions enable alternate perception
- Design Principle: Items to be grouped should share similar characteristics

Relative Size

- The smaller components of a pattern tend to be perceived as the object
  - Black propeller on white background
- Horizontal and vertical tend to be seen as objects
- Plays into figure/ground principle
- Design principle
  - Make dots the object rather than “cheese grater”

Figure and Ground

- The fundamental perceptual act in object identification according to Gestalt school
- What is foreground, what is background?
- All other principles help determine this
Figure/Ground Illusions from SPAM

Contours

- Perceived continuous boundary between regions
  - Line (sharp change on both sides in intensity)
  - Boundary between regions of two colors
  - Stereoscopic depth
  - Patterns of motion
  - Texture
  - Illusory (continuity & closure):
When do contours jump gaps?

• When a smooth curve can be drawn over gaps
  – Straight lines are easiest
  – Quite wiggly is possible

• Principle: Line up to jump gaps
Transparency (1/2)

- Attempting to present multiple data layers
- Many perceptual pitfalls
  - "WARNING, WARNING, DANGER Will Robinson!"
  - Different layers interfere with each other to some extent
  - Sometimes layers will fuse perceptually into one
  - Patterns similar in color, frequency, motion, etc. interfere more
- Design principle:
  - Make layers differ in at least one significant dimension
  - Try before you buy

Transparency (2/2)

- Need good continuity and correct color relationship
- Switch to sparse, distinguishable patterns
Form and Contour in Motion

- Contours can be seen in moving dot fields by motion alone
  - Rival static contour detection
- Phase of the motion seems most salient
  - Compared to frequency and amplitude
- Patterns of dots moving in synchrony group together

• Click for app →

• Design Principle:
  - Consider animation for association of groups
  - Works great for data-driven spots (even linear motion)!

Frames in Motion

- Rectangular frame forms strong context

- Groups of dots moving together form frame
Motion Design Principles

• Use motion as strong cue for grouping
• Add frame around group of related particles
• Speed around a few cm per second
  – Speed up things that are much slower than this
    (Show video of beads, use arrows and hide left then play)
  – Slow down things that are much faster
    (See next slide)

Slow Down Fast Objects

Other Motion Information

• Motion can express causality
  – Launching
  – Delayed Launching
  – Triggering
• Motion of dots on human limbs is immediately recognizable as such
• Motion patterns can express emotion or behavior
  – Happy triangle, excited square, sad circle
Sources of Uncertainty

- Wittenbrink et al., TVCG 2(3), 1996

The Taxonomy of Uncertainty

Error Bars vs Ambiguation

• Olston and Mackinlay, InfoVis 2002
• There is a difference between statistical uncertainty and bounded uncertainty
  – Statistical: has an expected value and distribution extends to infinity
  – Bounded: no preferred value, just a range of possible values
• Use ambiguation for bounded uncertainty

Three Views on Uncertainty Visualization

• View 1
  – Uncertainty is just another data set
  – Apply techniques for multivariate visualization
  – Show “correlation” between data and uncertainty
• View 2
  – Uncertain data may take on a range of values
  – Show possible range of data
• View 3
  – Uncertain data should intentionally be obscured
  – Actively prevent users from making judgements about uncertain data

Two Classes of Uncertainty Visualization Techniques

• Intrinsic
  – Vary visualization technique properties to show uncertainty
  – Transparency, Color maps, texture properties, etc.
• Extrinsic
  – Additional visualization techniques to show uncertainty
  – Glyphs, annotations, volume rendering, animation
Intrinsic Uncertainty Visualization Methods

- Scalar data
  - Color maps
  - Contour line modification
  - Data removal
  - Transparency
  - Animated color maps
- Vector data
  - Glyph modification
- Info vis
  - Parallel coordinates modification

Fuzzy Spectral Signatures

- Bastin et al., Computers & Geosciences 28 (2002), pp. 337-350
- Showing fuzzy classifications of multi-spectral imagery
- Graph show thick lines of probability that a land cover type produces specific reflectivity in each band
- Mean reflectivity shown as dark line

Showing Uncertainty with Standard 2D Scalar Techniques

- Dungan et al., IGRSS 2002
- Use standard 2D scalar techniques for showing statistical information in remote sensing applications
- Shows uncertainty from different estimates of forest cover
Saturation as an Indicator of Uncertainty
• Tomislav Hengl, GeoComputation, 2003
• Map data to color map, uncertainty to saturation

RGB Color Mapping
• Cliburn et al., Computers & Graphics 26, 2002, pp. 931-949
• Temperature, soil, and precipitation encoded as intensities of red, green, and blue, respectively according to how much each contributes to uncertainty in water balance model

Isosurface Uncertainty
• Kindlmann et al., IEEE Vis 2003
• Color map shows uncertainty
Transparency to Hide Uncertain Data

- Cliburn et al., Computers & Graphics 26, 2002, pp. 931-949
- Water balance model uncertainty
- Goals: don’t want users to make decisions affecting locations where uncertainty is high
- Make uncertain regions transparent

Volume Rendering of Uncertainty Data

- Djurcilov et al., Data Visualization 2001

Animation Showing Uncertainty in Remotely Sensed Imagery

- Bastin et al., Computers & Geosciences 28 (2002), pp. 337-350
- Sources of uncertainty:
  - Spectral confusion of land cover types
  - Spatial mis-registration
  - Topographic and atmospheric effects
  - Sensor biases
- Pixels randomly change between land cover types over time according to probability distribution
Probabilistic Animation in Volume Rendering
- Lundstrom et al., TVCG 13(6)

Broken Contour Lines
- Alex Pang, "Visualizing Uncertainty in Geospatial Data", prepared for Computer Science and Telecommunications Board, 2001
- Broken-ness of lines indicates uncertainty in location of contours

Kernel-Density Uncertainty
- Feng 2010
- Blurring lines by uncertainty removes false negative to indicate correlations
Kernel-Density Uncertainty (2)

- Feng 2010
- Blurring lines by uncertainty removes false positive to indicate no useful data in cluster

Kernel-Density Uncertainty (3)

- Feng 2010
- Blurring points by uncertainty removes false positive to indicate no outlier
- Adding center-highlighting shows samples

Uncertain Regions in AFM Surface Reconstructions

- Accounting for uncertain surface reconstruction in atomic force microscopy
- Shows uncertainty by making parts of reconstructed surface black (zero height)
Displaying Uncertainty in Astrophysical Data

• H. Li et al., IEEE Vis 2007

Fig. 5: Left: An example model showing trajectory uncertainty of a star frame. Right: The trajectory uncertainty of a star in 50,000 years, where the color represents the percentage error and the trajectory data is from a paper. The color scale is from white to red. The error of the star at a later time is shown in green and blue. The uncertainty of the star's trajectory is shown in yellow and orange.

Where is Betelgeuse? Where will a star be in 50,000 years?

Approaches to Visualizing Vector Uncertainty

• Wittenbrink et al., TVCG 2(3), 1996
• Table of glyphs potentially used for showing uncertainty
• Attempt to convey magnitude and angular uncertainty

Wittenbrink Uncertainty Glyphs

• Wittenbrink et al., TVCG 2(3), 1996

Fig. 5: An example of a glyph used to show vector uncertainty. The glyph consists of a line with a small arrow indicating the direction and magnitude of the uncertainty. The glyph is used to show the uncertainty of a vector in a specific frame.
Display of Uncertainty with Glyphs
- Johnson and Sanderson, CG&A Sept/Oct 2003
  - Images from Alex Pang

2004 Sanderson, Johnson, Kirby

Error in Vector Fields
- Botchen et al., IEEE Vis 2005
Error in Vector Fields
- Botchen et al., IEEE Vis 2005
  - Note: draws attention to uncertain regions!

Extrinsic Uncertainty Visualization Methods
- Scalar data
  - Confusion image
  - Uncertainty annotations
  - Glyphs
- Surfaces
  - Point-based surface
  - Volume rendering
  - Texture
  - Animation
- Vector data
  - Color maps
  - Widgets
- Molecular visualization
  - Transparency
  - Volume rendering

Positional Uncertainty in Molecules
- Rheingans and Joshi, Data Visualization 1999
- Conveying uncertainty in atom positions in molecules
Metastable Molecular Visualization

- Schmidt-Ehrenberg, IEEE Vis 2002
- What is the space of possible molecular confirmations?
  - Shows confirmation density
  - Similar to notion of electron density

Showing Fuzzy Classification


Vibrating Surfaces (3D)

- R. Brown, “Animated visual vibrations as an uncertainty visualization technique”, 2004
Vibrating Colors

Line Glyphs for Showing Uncertainty (1/2)
- Ciliburn et al., Computers & Graphics 26, 2002, pp. 931-949
- Separate lines for each variable drawn at each sample point with different color
- Size of line indicates magnitude of uncertainty

Line Glyphs for Showing Uncertainty (2/2)
- Dungan et al., IGRSS 2002
- Four statistics summarizing variance in elevation data
Box Glyphs for Showing Uncertainty

- Schmidt et al., Visual Analytics, Sept./Oct. 2004

Point-based Surfaces

- Grigoryan and Rheingans, TVCG 10(5), 2004
- Render geometry as points
- Uncertainty conveyed by random displacement along normal
  - Higher uncertainty = higher range of displacements

Isosurface Uncertainty

- Johnson and Sanderson, CG&A Sept/Oct 2003
**Adding Texture to Express Uncertainty**

- Djurcilov et al., Data Visualization 2001
- Speckles show areas of uncertainty

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**Risk-based Classification (2D)**

- Kniss et al., IEEE Vis 2005
- Delays material classification until rendering
- Importance is inversely proportional to penalty for misclassifying materials in volume

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**Risk-based Classification in Volume Rendering**

Figure 5: Effect of varying the importance term for white matter in a classified brain dataset visualization.
Vibrating Textures (2D)

- Draw attention to uncertain areas.
- Top: bad
- Bottom: good?

Color Maps Indicating Glyph Uncertainty

- Pang et al., The Visual Computer, 13, pp. 370-390, 1997

Glyphs Glyphs Glyphs(1)
Uncertainty displayed with same channel as data.

Figure 10: Surface patches are translated in or out of their original positions to highlight differences.

Figure 11: Surface patches are rotated instead of translated giving a similar effect.

Figure 12: Altering diffuse coefficients according to different.

Figure 13: Altering specular coefficients according to different.
Uncertainty Annotations

- Cedilnik and Rheingans, IEEE Vis 2000
- Idea: overlay annotations on top of data and distort according to uncertainty

Uncertainty in Vector Fields (1)

- Lodha et al., UFLOW, 1996

Uncertainty in Vector Fields (2)

- Lodha et al., UFLOW, 1996
Uncertainty in Vector Fields (3)

• Lodha et al., UFLOW, 1996

Sonification

• LISTEN library by Lodha et al., IEEE Vis 1996
• Use sound to express uncertainty
  – Use another perceptual channel besides visual
  – Uncertainty of data at probe mapped to pitch which can "show" more values than color map
  – Uses different timbres to display multiple variables
• Auditory perception and processing not understood well
• Good mappings to sound are unknown

Multivariate 3D Uncertainty (1)

• Feng 2010: Coupled to abstract vis
Multivariate 3D Uncertainty (2)

• Feng 2010: Transparency removed depth

Multivariate 3D Uncertainty (3)

• Feng 2010: Screen-door cluttered image

Uncertainty + Parallel Coordinates

• Shiping Huang, master’s thesis, Worcester Polytechnic Institute, 2005
• Show uncertainty by displacement in 3rd dimension
• Problems:
  – Occlusion
  – Parallel lines no longer parallel in projection
  – Non-parallel lines may become parallel in projection
Visual Grammar of Maps

• Well-known grammar
• Developed over time

• Does it fit your problem?
  – Use wholesale if so
  – Consider adding animation

<table>
<thead>
<tr>
<th>Geometric Code</th>
<th>Visual Notation</th>
<th>Semantics</th>
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<tbody>
<tr>
<td>1. Ellipse</td>
<td>Geometric region</td>
<td></td>
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<tr>
<td>2. Circle</td>
<td>Geometric region</td>
<td></td>
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<tr>
<td>3. Line</td>
<td>Geometric region</td>
<td></td>
</tr>
<tr>
<td>4. Text</td>
<td>Geometric region</td>
<td></td>
</tr>
</tbody>
</table>

References:

• Edge completion, More perceptual illusions: Penny Rheingans
• The rest of the lecture: Colin Ware, “Information Visualization,” chapter 6.

Extra readings


Credits

• Annotation: Gitta Domik
• Protein Models: UNC GRIP project, F.P. Brooks, Jr. Pl.
Credits

• Parallel Coordinates: Fua, InfoVis ’99; Wong, Visualization ’96
• ConeTree: Robertson, CHI ’91; Card, InfoVis ’97

Credits

• Intrinsic/extrinsic discussion