Comp/Phys/Mtsc 715
Multivariate & Ensemble Visualization Techniques

2/22/2012 Multivariate 1 Comp/Phys/Mtsc 715 Taylor

Preview Videos
• Vis ’97: Visualization of Music (video)
• 3D Interactive Particles (video)

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Administrative
• Be thinking about which projects you like best
  – We’ll be using HW projects for final projects
  – Send email with most favorite to least, by #
  – I’ll assign groups based on preferences
Multivariate Data Display

- At the frontier of data visualization
- More art than science
  - Several combinations can show 2-3 data sets
  - Attempting combinations beyond this is difficult
- Perceptual studies can help predict effectiveness
  - Avoiding interfering techniques gets you further
  - Still need to try it out and see
- Easier in 2D than 3D
- Several techniques shown today, some with characteristics listed

Multivariate Display Techniques

- Glyphs
- Heterogeneous Techniques
- Texture
- Layering/Subdividing
- Data Reduction
Glyphs

- Single graphical icon displaying multiple variables
  - Shape, color, other features
- Designed for discrete, non-spatial data
- Can be used to display fields
  - Scatter within 2D or 3D space
  - Display local characteristics

Classical Glyphs: Chernoff Faces

![Chernoff Faces: Different data variables are mapped to the eyes and shapes of different facial features.](image)
Glyph Techniques

- Paul Ferry, SKIGRAPH '99
  - Profile Icon, Star Icon, Stick figure Icon

- Ware
  - Probably only 3-4 distinguishable orientations
  - Don’t use parallel ones (as the figure on the right above does)
  - Varying color polarity adds more
  - Varying line width adds more

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Glyphs: Color + Size Vary

Figure 5: Particles colored by the number of neighbor links.

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Glyph: Flow Probe

Characteristics of Glyphs

• Preattentive detection rules from before apply
  – size, orientation, and color coding
• Integral vs. Separable dimensions
  – Integral dimensions are perceived holistically (upper)
  – Separable dimensions perceived independently (lower)

<table>
<thead>
<tr>
<th>Visual variable</th>
<th>Dimensionality</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial position in graph</td>
<td>3 dimensions: X, Y, Z</td>
<td></td>
</tr>
<tr>
<td>Color in graph</td>
<td>3 dimensions defined by color opponency.</td>
<td></td>
</tr>
<tr>
<td>Shape</td>
<td>2-D dimensions unknown.</td>
<td>The dimensions of shape can be manipulated independently.</td>
</tr>
<tr>
<td>Orientation</td>
<td>3 dimensions: compass (orientation) defined by primary axis.</td>
<td>Orientation is not independent of shape, the object of view varies sympathetically with author.</td>
</tr>
<tr>
<td>Surface texture</td>
<td>3 dimensions: position, roll, and contrast.</td>
<td>Not independent of shape in dimensions, may be affected by other color dimensions.</td>
</tr>
<tr>
<td>Motion coding</td>
<td>2-D dimensions largely defined by position and color.</td>
<td></td>
</tr>
<tr>
<td>Wind coding</td>
<td>Wind direction is coded on all of these.</td>
<td>1 dimension. Motion wind coding is highly independent.</td>
</tr>
</tbody>
</table>

Attributes:

• Sirens’ Song:

Number of Displayable Values

• Many dimensions not independent
  – Texture relies on at least one color difference
  – Blinking and motion coding will interfere
  – Fortunately if you can display 8-dimensional data with color, shape, spatial position (not for glyphs in space), and motion.
• Number of resolvable steps in each dimension
  – Maybe 4 values for each
  – Disallowing conjunction searches leaves 32 alternatives
• ~4 values for each of 8 channels – 6 in spatial data
  – We didn’t see more than 3 work together at high density when doing combinations of different techniques
Heterogeneous Techniques

• “Wandering in the desert”
  – “Simpleton” ideas prove their worth

• Throw a bunch of techniques together
• Hope for the best
  – Works okay for a few data sets
  – We found it hopeless for large numbers of sets

Heterogeneous 2D: Location + Width + Color
Heterogeneous 2D: Height + Texture

Heterogeneous 2D: Height + Color + Contour

Heterogeneous 2D: Color + Texture + Bump Tex
**Heterogeneous 2D**

- **Promise**
  - 1 Height dimension, 2 Color dimensions, 3+ Texture dimensions = 6+ perceptual dimensions
- **Results**
  - Luminance contrast in color confounds shape
  - High-frequency components of texture confound color
  - Multiple textures confound each other

**Heterogeneous 2D:**

- Height + Color + Glyph

- Haber, Koh, Lee
  - UIUC
- Found in
  - Keller & Keller p. 62

**Heterogeneous 3D:**

- Slice + Contour + Color + Tex.
Heterogeneous 3D: Surface + Color + Texture

- Vis 2001: Severance, Lazos, Keefe, "Wind Tunnel Data Fusion and Immersive Visualization"

Heterogeneous 3D (2D hack): Texture + Color + Animation

- Laramee, "Image Space Based Visualization of Unsteady Flow on Surfaces", Vis 2003
- Advects in 2D
- Gfx hardware
- LIC+Color
- Spot Noise + Clr

Image Space Based Visualization of Unsteady Flow on Surfaces

Robert S Laramee
Bruno Jobard
Ingrid Hoeser

VR Vis
Texture-Based Multivariate 2D

- Varying several characteristics to display data
  - Adjusting size, density, and regularity
  - Adjusting size, orientation, and density
  - Adjusting scale, orientation, and contrast
  - Spot Noise: Adjusting orientation and hue/saturation

- Varying a single characteristic to differentiate between multiple layers, intensity in each layer (both texturing and layering techniques)
  - Beyond four scalar fields in the same image
  - Oriented Slivers
  - Data-Driven Spots

Texture Dimensions

- Chris Healey
- Height = cultivation level
- Density = ground type
  - Sparse = alluvial
  - Dense = wetland
- Grayscale = vegetation
  - Dark = plains
  - Light = forest
  - White = woodland

Chris Healey:
Size, Density, Regularity, Hue

Sort of like glyphs + arrangement
Result is “texture”
Chris Healey: 
Size, Density, Orientation, Color

Dense glyphs form a texture

Texture: Spot Noise

- Invented by JJ van Wijk, SIGGRAPH 1991
- Spot orientation, spot size, hue
- Can vary scale
- Can vary shape
  - Affects texture

Quantitative Texton Sequences for Bivariate Maps (Ware)
Layer-Based Multivariate 2D

- Subdividing the surface
- Varying a single characteristic to differentiate between multiple layers, intensity in each layer (both texturing and layering technique)
  - Beyond four scalar fields in the same image
  - Oriented Slivers
  - Data Driven Spots
  - Nested and intersecting surfaces
- Layering heterogeneous techniques
  - Crawford
  - Laidlaw
  - Urness/Interrante

Attribute Blocks: Visualizing Multiple Continuously Defined Attributes (James Miller)
Multivariate Visualization on Parametric Surfaces
(James Miller)

Visualizing Multidimensional Scalar Data Using Hexagonal Tiles
(Ramachandran and Healey)

New Mexico State

Employment
Affluence
Bachelor’s degree level
Income
Oriented Slivers:
Four Tube Orientations

- Four scalar fields
  - Here, 4 orientations
  - Each mapped to displayed orientation
- Overall intensity shows total amount of material

Oriented Slivers

- Background color shows another data set
  - Reveals dark slivers
  - Shows region boundary
- Close-up of 3 data sets
Oriented Sliver Characteristics

• User study shows that 15-degree orientation difference can be easily seen
  – Enables 7+ data sets to be displayed!
• Russ claims:
  – Enables relative value estimation for all data sets at a point
  – Difficult to see boundary of a region with a particular orientation
  – Easy to see where no data sets are present

Data-Driven Spots

• 9 Scalar fields
• Each mapped to color or bump size
• Shows regions well

DDS Characteristics

• User studies show
  – At least 9 scalar fields can be shown!
  – Users can attend pairwise to data sets without interference
  – Boundaries of shapes can be seen as well as when they are drawn explicitly

• Animation of one or more data sets is very effective
  – Reveals areas with low values
  – Sweeps over entire region, showing boundaries at high resolution
  – Highlights data set(s) of interest

[Link to videos]
Evaluation of Trend Localization

• Mark Livingston, Jonathan Decker; TVCG 2011
  – Strokes (intensity, hue, orientation, width, length); DDS; Oriented slivers; Color blend; Attribute blocks tested against each other
  – Asked for region with largest trend
  – Had to compare two of the five channels

Evaluation of Trend Localization

• Mark Livingston, Jonathan Decker; TVCG 2011
  – Also compared against side-by-side ("juxtaposition")
  – County blocks provided local alignment cues

Scaled Data-Driven Spheres
(David Feng, UNC)
3D SDDS User Study

Task 2: Correlation ID Error Frequency

Average Number of Errors

<table>
<thead>
<tr>
<th>SDDS</th>
<th>SQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td></td>
</tr>
<tr>
<td>Yellow</td>
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<tr>
<td>Cyan</td>
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<td>Thic</td>
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<tr>
<td>XRoug</td>
<td></td>
</tr>
<tr>
<td>ORound</td>
<td></td>
</tr>
</tbody>
</table>

Task 2: Mean % Correct per Trial

Mean % Correct

0.0 0.2 0.4 0.6 0.8 1.0

Trial Number

SDDS Superquadrics

3D SDDS Conclusions

- Layered > Heterogeneous
- Value Estimation:
  - Spheres > Superquadrics
  - Error ~8% / ~13%
- Correlation Identification:
  - Sphere >> Superquadrics
  - Error ~20% / ~80%
- Motion seems to help

Motion SDDS

VDA: Phadke 2012
  - Nominal color by ensemble
  - Sinusoidal scale over time
  - Compares regions pairwise
Motion SDDS Video

- Can also vary shape and/or color (click movie)

Nested/Intersecting Surfaces

- Chris Weigle (UNC) dissertation
  - Inner/outer factoring
  - Transparent outer
    - Colored
    - Surface glyphs
  - Drop lines
    - Follow heat transfer

Intersecting-surface display
Nested/Intersecting User Study

Inter-surface Distance  Surface Orientation

Ensemble Display: ESS

- Ensemble Surface Slicing: VDA Alabi 2012
  - Multiple sims
  - Slice into strips
  - Color nominally
  - Animate slicing

ESS wildfire example

- Four wildfire simulations
- Same in upper left, obviously different peak
- Subtle differences in lower right
Layering 2D: Crawfis
Height + Color + Textures

Layering 2D: Laidlaw
Color + Sparse Glyphs
- Flow Visualization
- Black shadow of the geometry
- Color layer, ellipsoid layer, arrow layer
Layered 2D: Laidlaw
Color + Texture + Sparse Glyphs

- Mouse spinal cord
- Texture underlayer
- Color layer
- Glyphs
  - Ellipsoidal
  - Textured

Layered 2D: Texture + Color

- Urness & Interrante, “Effectively Visualizing Multi-Valued Flow Data using Color and Texture”
  - Color each LIC stroke
  - Saturation scale
  - Round-robin colors
  - Red, Blue, Green, Orange
  - Vis 2003

Uarness & Interrante Vis 2003 Close-up
Urness & Interrante CGA 2006

• Similar styles interact
  – UL: Two textures
  – ML: Two glyphs
  – LL: Two line-based

• Different styles separate
  – UR: Glyph + texture
  – MR: Line + glyph
  – LR: Line + texture

Layering Summary

• Layering >> Heterogeneous
• Layering >> Varying texture parameters

• Use sparse layers
• Use distinct display technique for each layer
  – Similar: discs of different color
  – Similar: Slivers of different orientation
  – Different: Ellipses, arrows
  – Different: Texture vs. line vs. glyph
Problem Reduction Techniques

- Dimensional reduction / projection
- Time and space multiplexing
  - Multiple views with different mappings
  - Mapping different fields over time
  - Dynamic Maps
  - Magic Lenses
- Adding computation
  - Smart Particles
  - Cluster analysis / Feature mapping

Dimension Reduction

- Principal-component analysis determines most significant dimensions
  - 2D to 1D shown here
- Project data onto 2D subspace of two largest principal components
  - Color or shape by others

Multiple views in Space
Multiple views in Space

- Cycle data sets through different representations
  - Animated
  - User controlled
- Overlaid on same spatial location

Multiple views in Time

- Cycle data sets through different representations
  - Animated
  - User controlled
- Overlaid on same spatial location
Dynamic Maps

- http://www.geog.le.ac.uk/argus/ICA/J.Dykes/
- Clicking on 2D (or ND) mapping highlights values
  - Column, row, or individual entries in covariance matrix show where on map
  - Map region highlights entries

Example Magic Lenses

- Local Scaling Lens
  - Adjusts geometry
  - Also could be wireframe

- Gaussian Curvature
  - Pseudo-color map
  - Numeric value overlay
Magic Lenses

- Enable viewing a subset of the data sets, and select others to be viewed in certain areas
  - Toolglass and Magic Lenses
    - Eric Bier, Maureen Stone, Ken Pier, William Buxton, Tony DeRose; Xerox Parc; SIGGRAPH 93
    - Filter the data
    - 3D magic lenses: X-ray vision

Cluster Analysis

- Map from image (left) to feature space (upper right)
  - Compute statistics on pixels (convolution with Gaussian derivatives)
  - Produces scatter plot in N-D

- Look for clusters (or ranges) in feature space (may be high dimensional space)
  - Group these clusters (here by color)
  - Map back into image space (lower right)

- "Neighbors in feature space" relationship is shown

Pattern Matching

- Julia Ebling, “Clifford Convolution And Pattern Matching On Vector Fields”, Vis 2003
  - Select canonical field shape
  - Find local best orientation
  - Dot product like sum
  - Inner product under field
Ebling Vis2003 Matching in 3D

Interactive Vector Field Feature Identification

• Joel Haniels II, Arik W. Anderson, Luis Gustavo Nonato, Claudio Silva, Utah
• http://www.youtube.com/watch?v=hodID8EfH

Conclusions

• Several example techniques
• Perceptual analysis of some of them
• Characteristics known for some of them
• Still an open area of research
References

- Texture Dimensions: Chris Healey
  (http://www.csc.ncsu.edu/faculty/healey/HTML_papers/plankton/plankton.html)
- Typhoon visualization: Chris Healey
  (http://www.csc.ncsu.edu/faculty/healey/download/tvcg.99.pdf)
- Dense Glyphs/Textons: Chris Healey
- Spot noise image: Wim de Leeuw:
  http://www.cwi.nl/~wimc/SN_intro.html
- Glyph characteristics and use for multidimensional display: Colin Ware’s book, “Information Visualization.”
- Cluster Analysis: James Coggins, UNC-CH
- Oriented Slivers: Chris Weigle, UNC-CH
- Nested/Intersecting Surfaces: Chris Weigle, UNC.
- Data-Driven Spots: Alexandra Bokinsky, UNC-CH
Run ScalarStack

- NSRG/CISMM Scalar Stack Viewer
  - C:\Program Files\CISMM\...
- Load Census data
- Show Colored Slivers
- Show DDS
- Show Oriented Slivers