Data Visualization (CSCI 490/680)

Review

Dr. David Koop
Fields in Visualization

Scalar Fields
(Order-0 Tensor Fields)

Vector Fields
(Order-1 Tensor Fields)

Tensor Fields
(Order-2+)

Each point in space has an associated...

Scalar

\[ s_0 \]

Vector

\[
\begin{bmatrix}
  v_0 \\
  v_1 \\
  v_2
\end{bmatrix}
\]

Tensor

\[
\begin{bmatrix}
  \sigma_{00} & \sigma_{01} & \sigma_{02} \\
  \sigma_{10} & \sigma_{11} & \sigma_{12} \\
  \sigma_{20} & \sigma_{21} & \sigma_{22}
\end{bmatrix}
\]
Streamlines & Variants

- Steady vs. **Unsteady** flows
  - In unsteady flows, the vector field **changes** over time
- Variants: **Pathlines** and **Streaklines**

---

**Pathlines & Streaklines**

- In unsteady flows, the vector field changes over time.
- Variants: Pathlines and Streaklines.
Streamlines & Variants

- **Steady vs. Unsteady flows**
  - In unsteady flows, the vector field *changes* over time
- **Variants:** Pathlines and Streaklines

All are identical in steady flows!

[T. Möller]
Streamlines vs. Pathlines

Streamlines

Pathlines

[Weinkauf & Theisel, 2010]
Streamline Variants

**Streaklines** [NASA]

**Stream Ribbons** [Weiskopf/Machiraju/Möller]

**Stream Tubes** [Weiskopf/Machiraju/Möller]
Line Integral Convolution

- Goal: provide a global view of a steady vector field while avoiding issues with clutter, seeds, etc.
- Remember convolution?
- Start with random noise texture
- Smear according to the vector field
- Need structured data

[Weiskopf/Machiraju/Möller]
Key developments in topological data analysis (TDA):
1. Abstraction of the data: topological structures and their combinatorial representations
2. Separate features from noise: persistent homology

Scalar Field Topology

2D Scalar function

Reeb Graph/Contour Tree/Merge Tree

Morse-Smale Complex

[via Levine]
Vector Field Topology

- Instead of “guessing” correct seed points for streamlines to understand the field, try to identify structure (topology) of the field.

*Figure 7.1* A phase portrait.
Critical Points

- **Repelling Focus**
  - \( R_1, R_2 > 0 \)
  - \( I_1, I_2 \neq 0 \)

- **Saddle Point**
  - \( R_1 \cdot R_2 < 0 \)
  - \( I_1, I_2 = 0 \)

- **Repelling Node**
  - \( R_1, R_2 > 0 \)
  - \( I_1, I_2 = 0 \)

- **Attracting Focus**
  - \( R_1, R_2 < 0 \)
  - \( I_1, I_2 \neq 0 \)

- **Center**
  - \( R_1, R_2 = 0 \)
  - \( I_1, I_2 = 0 \)

- **Attracting Node**
  - \( R_1, R_2 < 0 \)
  - \( I_1, I_2 = 0 \)

[Helman & Hesselink]
Text Visualization

• Why visualize text? Text is already visual, right?
• How much text? What granularity? (What is an item?)
  - Single string
  - Words/lines
  - One document
  - Multiple documents (corpus)
• Considerations:
  - Legibility
  - Variable length
  - Locality
  - Occurrence
Tag Cloud (One Document)

- Derived data: number of occurrences of words
- Channel: Font size
- Potential problem: Think about ink…

[Scray, CC-BY-SA-3.0]
that

one day

this nation will rise up and live out the true meaning of its creed. "We hold these truths to be self-evident,
on the red hills of Georgia the sons of former slaves and the sons of former slave owners will be able to sit down
even the state of Mississippi, a state sweltering with the heat of injustice, sweltering with the heat of oppression
down in Alabama, with its vicious racists, with its governor having his lips dripping with the words of interposition:
every valley shall be exalted, and every hill and mountain shall be made low, the rough places will be made plain
my four little children will one day live in a nation where they will not be judged by the color of their skin but by the
today. i have a dream that one day

down in Alabama, with its vicious racists, with its governor having his lips dripping with the words of interposition:
every valley shall be exalted, and every hill and mountain shall be made low, the rough places will be made plain

[Wattenberg & Viegas, 2007]
On the other hand, applying different expressions to the same text can reveal a series of interrelated conceptual networks. The phrase nets of Jane Austen’s novel *Pride and Prejudice* illustrate this. Matching “X and Y” shows a network of concepts and people. The main characters appear neatly organized in two clusters: Jane, Elizabeth, Lydia, Kitty, Catherine, and Mr. Bingley form a central cluster, whereas “mother,” “aunt,” and “uncle” keep some distance. Positive attributes such as “sense,” “disposition,” “humour,” “kindness” cluster together while less flattering qualities such as “pride,” “conceit,” “vanity,” “folly,” and “ignorance” form a group of their own. Perhaps most interesting, to those familiar with the novel, is that “Darcy” does not appear in the network—in a certain sense he is the most solitary major character.

If we analyze the same text with the pattern “X at Y” we obtain an entirely different network that reveals the set of locations inhabited by the characters in the novel and the events that take place at those locations. In a sense, the user can direct exploration towards a particular dimension of the text by intelligently choosing the pattern to match for.

Figure 1 shows the result of another targeted pattern. Here we have analyzed the whole bible using the pattern “X begat Y,” a specific formulation from the King James Bible indicating a parent-child relationship. The resulting graph illustrates the lengthy genealogies that are recorded by many different books in the bible. The network also uncovers a number of defining aspects of these lineages, such as the importance of Abraham.

### 4.2 Regular expressions and matching

The patterns we have shown so far are of the form “X <connector> Y”, where the connector is either a separate word or a phrase. However, regular expressions also allow us to specify patterns that match for specific pre- and postfixes to X and Y. Previously, the authors worked with a humanities scholar to analyze a set of 7,000 British novel titles between 1740 and 1850—in fact, much of the motivation behind building phrase net comes from this collaboration. This scholar was interested in how the use of simple syntactic constructions such as “X of the Y” reflected changes in literary style over the centuries.
ally similar to the connected lists view of Jigsaw [28], however PTCs use size-weighting of words in the display. Shneiderman and Aris [26] have previously explored the contents of a faceted legal document databases using matrix-based visualizations to reveal the number and type of data items matching each facet value. Our work differs in that we seek to aggregate and visualize the contents of the data items, not only their presence or absence. A matrix visualization approach would not be appropriate as our word-selection method, described later, seeks to maximize the differences between corpus subsets. Rather than the single vertical column of words that a words ⇴ facets matrix would contain, our approach allows the entire space to be filled with a wide variety of words. VisGets, or visualization widgets, have been used to explore faceted collections of web-based streaming data [5]. Facets are filtered using scented visual widgets [34] appropriate for the data type, providing both an overview of the available data items and a method to drill down along several facets simultaneously. A tag cloud VisGet consists of a traditional tag cloud summarizing all available documents — text differentiation along a facet is only achieved through interactive brushing. The goal of VisGets is to provide coordinated overview and navigation tools in a faceted information space, where our work is customized to providing meaningful differentiating overviews across facets within large amounts of textual data.

Finally, the Authorlines visualization [31] provides an overview of individual messages using arrays of circles, sized according to message length. We borrow this visual encoding and extend it to small multiples of bar charts in the document browser coordinated view, linked to the PTC.

2.2 U.S. Circuit Court Decisions

"Jargon serves lawyers as a bond of union: it serves them, at every word, to remind them of that common interest, by which they are made friends to one another, enemies to the rest of mankind."

Jeremy Bentham [2, 292]

Figure 2: US Court Circuits are multi-state regions.

The words of the iconoclast Bentham were not the last written on the topic of legal language. Law and language meet in many academic ways: forensic linguists help solve crimes, judges make semantic rulings on unclear contract wording, and social scholars take a high-level view, studying the language of lawyers and judges [29]. By analyzing the written decisions of the US Circuit Courts of Appeal, we hope to shed light on thematic and potentially linguistic differences between subsets of the data. Differences in word usage between courts has been previously studied using legal databases as a source for historical lexicography [8]. However, in that work, text-based searches provided information on particular words of interest. Through text mining and visualization, we select words of interest and provide a broad overview as an entry point to deeper analysis. The US Circuit Courts of Appeal are made up of 12 regionally-based court divisions (numbered First through Eleventh, plus the DC Circuit) and the Federal Circuit, which hears cases of national relevance, such as patent-related appeals (see Fig. 2). This data contains 628,000 court decisions, each labeled by circuit. The judgments are faceted, because they can be organized along several dimensions, such as the lead authoring judge, the decision length, the date of the decision, or whether the lower court was upheld or overturned.
Project

• Presentations on **Thursday**:  
  - Turn in code for the visualization to **Blackboard** by **Dec. 4 at 11:59pm**  
  - **5 minutes** per presenter  
  - Showcase the visualization (not slides)  
    • Brief introduction to your data and questions  
    • Discuss design decisions  
    • Demonstrate the interactive features of your project  
  - Should run in a web browser so we will use my laptop  
  - Have until Dec. 6 to turn in final code and report
Final Exam

- Thursday, Dec. 12, **10-11:50am**
- Covers all topics but emphasizes second half of the course
- Similar format as Midterm (multiple choice, free response)
- As with the Midterm, 680 students will have a few questions related to the research papers
“Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively.”

— T. Munzner
Dataset Types

- **Tables**
  - Attributes (columns)
  - Items (rows)
  - Cell containing value

- **Networks**
  - Link
  - Node (item)

- **Fields (Continuous)**
  - Grid of positions
  - Cell
  - Attributes (columns)
  - Value in cell

- **Geometry (Spatial)**
  - Position

- **Multidimensional Table**
  - Key 1
  - Key 2
  - Attributes
  - Value in cell

- **Trees**
  - + Sets
  - + Text

[Munzner (ill. Maguire), 2014]
Tasks

**Why?**

<table>
<thead>
<tr>
<th>Actions</th>
<th>Targets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyze</td>
<td>All Data</td>
</tr>
<tr>
<td>→ Consume</td>
<td>→ Trends</td>
</tr>
<tr>
<td>→ Discover</td>
<td>→ Outliers</td>
</tr>
<tr>
<td>→ Present</td>
<td>→ Features</td>
</tr>
<tr>
<td>→ Enjoy</td>
<td>Attributes</td>
</tr>
<tr>
<td>→ Produce</td>
<td>→ One</td>
</tr>
<tr>
<td>→ Annotate</td>
<td>→ Many</td>
</tr>
<tr>
<td>→ Record</td>
<td>→ Distribution</td>
</tr>
<tr>
<td>→ Derive</td>
<td>→ Dependency</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Search</th>
<th>Network Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Topology</td>
</tr>
<tr>
<td>Target known</td>
<td>→ Paths</td>
</tr>
<tr>
<td>Location known</td>
<td>→ Extremes</td>
</tr>
<tr>
<td>→ Lookup</td>
<td>→ Correlation</td>
</tr>
<tr>
<td>→ Browse</td>
<td>→ Similarity</td>
</tr>
<tr>
<td>Location unknown</td>
<td>→ Explore</td>
</tr>
<tr>
<td>→ Locate</td>
<td>Spatial Data</td>
</tr>
<tr>
<td></td>
<td>→ Shape</td>
</tr>
</tbody>
</table>

[Muñzner (ill. Maguire), 2014]
How do we do visualization?

<table>
<thead>
<tr>
<th>How?</th>
<th>How?</th>
<th>Facet</th>
<th>Reduce</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Encode</strong></td>
<td><strong>Manipulate</strong></td>
<td><strong>Facet</strong></td>
<td><strong>Reduce</strong></td>
</tr>
<tr>
<td>Arrange</td>
<td>Change</td>
<td>Juxtapose</td>
<td>Filter</td>
</tr>
<tr>
<td>Express</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Order</td>
<td>Select</td>
<td>Partition</td>
<td>Aggregate</td>
</tr>
<tr>
<td>Use</td>
<td>Navigate</td>
<td>Superimpose</td>
<td>Embed</td>
</tr>
<tr>
<td>Map from categorical and ordered attributes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Color</td>
<td>Change</td>
<td>Juxtapose</td>
<td>Filter</td>
</tr>
<tr>
<td>Hue</td>
<td>Color</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saturation</td>
<td>Select</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Luminance</td>
<td>Navigate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size, Angle, Curvature, ...</td>
<td>Shape</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shape</td>
<td>Motion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direction, Rate, Frequency, ...</td>
<td>Motion</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

[Muñzner (ill. Maguire), 2014]
Nested Visualization Design

- **Domain situation**
  You misunderstood their needs

- **Data/task abstraction**
  You’re showing them the wrong thing

- **Visual encoding/interaction idiom**
  The way you show it doesn’t work

- **Algorithm**
  Your code is too slow

[Munzner (ill. Maguire), 2014]
Visual Encoding

Gapminder, Wealth & Health of Nations
Visual Encoding

- **Marks** are the basic graphical elements in a visualization
- **Channels** are ways to control the appearance of the marks

**Marks classified by dimensionality:**

- Points
- Lines
- Areas

- Also can have surfaces, volumes
- Think of marks as a mathematical definition, or if familiar with tools like Adobe
Channels by Effectiveness

Channels: Expressiveness Types and Effectiveness Ranks

**Magnitude Channels: Ordered Attributes**
- Position on common scale
- Position on unaligned scale
- Length (1D size)
- Tilt/angle
- Area (2D size)
- Depth (3D position)
- Color luminance
- Color saturation
- Curvature
- Volume (3D size)

**Identity Channels: Categorical Attributes**
- Spatial region
- Color hue
- Motion
- Shape

[Munzner (ill. Maguire), 2014]
D3

- [http://d3js.org/](http://d3js.org/)
- Supports data as a core piece of Web elements
  - **Correspondence** between data and DOM elements
  - Dealing with changing data (joins, enter/update/exit)
  - Data drives the marks and channels
- Selections (similar to CSS) that allow greater manipulation
- Integrated layout algorithms, axes calculations, etc.
- Focus on interaction support
  - Straightforward support for transitions
  - Event handling support for user-initiated changes
Arrange Tables

Express Values

Separate, Order, Align Regions

Separate

Order

Align

1 Key
List

2 Keys
Matrix

3 Keys
Volume

Many Keys
Recursive Subdivision

Axis Orientation

Rectilinear

Parallel

Radial

[Munzner (ill. Maguire), 2014]
Categorical Map
This map removes mostly uninhabited areas, revealing Mr. Bush’s suburban and rural support in the East and South.

* Areas with less than three people per square mile.
Rectangular Cartogram

1860 Presidential Election

<table>
<thead>
<tr>
<th>CANDIDATE</th>
<th>PARTY</th>
<th>ELECTORAL VOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abraham Lincoln</td>
<td>Republican</td>
<td>180</td>
</tr>
<tr>
<td>John C. Breckinridge</td>
<td>Southern Democratic</td>
<td>72</td>
</tr>
<tr>
<td>John Bell</td>
<td>Constitutional Union</td>
<td>39</td>
</tr>
<tr>
<td>Stephen A. Douglas</td>
<td>Northern Democratic</td>
<td>12</td>
</tr>
</tbody>
</table>

Each state is sized by the number of electoral votes it had in 1860.

[New York Times]
Arrange Networks and Trees

- **Node–Link Diagrams**
  Connection Marks
  - ✔ NETWORKS
  - ✔ TREES

- **Adjacency Matrix**
  Derived Table
  - ✔ NETWORKS
  - ✔ TREES

- **Enclosure**
  Containment Marks
  - ✗ NETWORKS
  - ✔ TREES

[Munzner (ill. Maguire), 2014]
Tree Visualizations

A variety of graphical representations are available for depicting tree structures (Figure 1), from "classical" node-link diagrams [23, 7], to treemaps [14, 26, 6, 30], concentric circles [2, 27, 31], and many others. Some have been augmented to numerically show the "size" attribute of each node. (Although not shown in the figure, the labels could also be augmented to show the "weight" attribute if desired, but even they still result in much whitespace around certain labels, suggesting that a more space-efficient (in terms of label size) representation might be possible.

Quantifying the Space-Efficiency

A mathematical evaluation and comparison of the space-efficiency of various 2D graphical representations of tree structures (including all the forms in Figure 1) is introduced that quantifies the distribution of area across nodes in a tree representation, and that can be applied to a broad range of different representations of trees. Several accepted standard sets of metrics for evaluating area, aspect ratio, label size, or other measures. However, there is no fair comparison of them. Space-efficiency might be described in terms of the relative sizes of nodes in Figures 2A and 2C, an unfortunate side effect of making the node labels line up. Similarly, icicle diagrams also allow for a weighted partitioning of area, and performs the first rigorous analysis and comparison of the space-efficiency of these representations. Assuming the representation is bound within a 1 square, both have a total area of 1, but also because they allow for the relative sizes, an alternative approach would be to give equal weight to the relative sizes of nodes (i.e. the leaf nodes) in the representation, in addition to on the nodes, some times called a "tree list," and sometimes augmented to show the "size" attribute of each node. In Figure 2, both have a total area of \( \pi \times \frac{1}{4} \approx 0.785 \) (the area of a circle of diameter 1), and are also equally efficient according to the metric of total area. However, experience suggests that the representations within each of these pairs do not scale equally well with larger, deeper trees. This is introduced that quantifies the distribution of area, and incidentally have no need for margins between the labels, suggesting that a more space-efficient (in terms of label size) representation might be possible.

Figure 2 shows that icicle diagrams also allow for a weighted partitioning of area, and performs the first rigorous analysis and comparison of the space-efficiency of these representations. Assuming the representation is bound within a 1 square, both have a total area of 1, but also because they allow for the relative sizes, an alternative approach would be to give equal weight to the relative sizes of nodes (i.e. the leaf nodes) in the representation, in addition to on the nodes, some times called a "tree list," and sometimes augmented to show the "size" attribute of each node. In Figure 2, both have a total area of \( \pi \times \frac{1}{4} \approx 0.785 \) (the area of a circle of diameter 1), and are also equally efficient according to the metric of total area. However, experience suggests that the representations within each of these pairs do not scale equally well with larger, deeper trees. This is introduced that quantifies the distribution of area, and incidentally have no need for margins between the labels, suggesting that a more space-efficient (in terms of label size) representation might be possible.

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Human Color Perception

Metamerism: same three responses == same color

[via M. Meyer]
Avoid Rainbow Colormaps!

[Borland & Taylor, 2007]
Colormaps

[Munzner (ill. Maguire), 2014]
Interaction Overview

- **Change over Time**

- **Select**

- **Navigate**
  - **Item Reduction**
    - Zoom
      - Geometric or Semantic
    - Pan/Translate
    - Constrained
  - **Attribute Reduction**
    - Slice
    - Cut
    - Project

[Munzner (ill. Maguire), 2014]
Staged Animated Transitions

[M. Bostock]
Staged Animated Transitions
Multiple Views

- Juxtapose and Coordinate Multiple Side-by-Side Views
  - Share Encoding: Same/Different
    - Linked Highlighting
  - Share Data: All/Subset/None
  - Share Navigation

<table>
<thead>
<tr>
<th>Encoding</th>
<th>Data</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
<td>All</td>
<td>Redundant</td>
<td>Overview/Detail</td>
</tr>
<tr>
<td></td>
<td>Subset</td>
<td></td>
<td>Small Multiples</td>
</tr>
<tr>
<td>Different</td>
<td></td>
<td>Multiform</td>
<td>Multiform,Overview/Detail</td>
</tr>
<tr>
<td></td>
<td>None</td>
<td></td>
<td>No Linkage</td>
</tr>
</tbody>
</table>

- Partition into Side-by-Side Views

- Superimpose Layers

[Munzner (ill. Maguire), 2014]
Filtering and Aggregation

Reducing Items and Attributes

- **Filter**
  - Items
    - [Diagram]
  - Attributes
    - [Diagram]

- **Aggregate**
  - Items
    - [Diagram]
  - Attributes
    - [Diagram]

Reduce

- **Filter**
  - [Diagram]
- **Aggregate**
  - [Diagram]
- **Embed**
  - [Diagram]

[Munzner (ill. Maguire), 2014]
Focus+Content

- Embed
  - Elide Data
  - Superimpose Layer
  - Distort Geometry

Reduce
- Filter
- Aggregate
- Embed

[Munzner (ill. Maguire), 2014]
Fields in Visualization

Scalar Fields

Vector Fields

Tensor Fields

Each point in space has an associated...
Fields in Visualization

Scalar Fields
(Order-0 Tensor Fields)

Vector Fields
(Order-1 Tensor Fields)

Tensor Fields
(Order-2+)

Each point in space has an associated...

Scalar

\[ s_0 \]

Vector

\[
\begin{bmatrix}
  v_0 \\
  v_1 \\
  v_2
\end{bmatrix}
\]

Tensor

\[
\begin{bmatrix}
  \sigma_{00} & \sigma_{01} & \sigma_{02} \\
  \sigma_{10} & \sigma_{11} & \sigma_{12} \\
  \sigma_{20} & \sigma_{21} & \sigma_{22}
\end{bmatrix}
\]
Isosurfacing

(a) An isosurfaced tooth.

(b) Multiple isosurfaces. [J. Kniss, 2002]
Volume Rendering

[J. Kniss, 2002]
Vector Fields

Streaklines [NASA]

Stream Ribbons [Weiskopf/Machiraju/Möller]

Stream Tubes [Weiskopf/Machiraju/Möller]

Mapping Methods Based on Particle Tracing

- Stream ribbons
  - Trace two close-by particles
  - Keep distance constant

- Stream tubes
  - Specify contour, e.g. triangle or circle, and trace it through the flow

Weiskopf/Machiraju/Möller
The purpose of computing is about insight, not numbers

– R. W. Hamming
The purpose of **visualization** is about insight, not **pictures**

– Card, Mackinlay, Schneiderman
Projects Thursday