Data Visualization (CSCI 490/680)

Sets

Dr. Maoyuan Sun
(slides prepared by Dr. Koop)
Announcements
Project Design

• Start working on turning your visualization ideas into designs
• Sketch
• Options:
  - Try vastly different options
  - Refine an initial idea
Assignment 4

- Create Choropleth Maps
  - Deal with projections and GeoJSON Data
  - Select appropriate colormaps
- [CS 680 Only] Part 3 is using other libraries, you only need to do one option
- Example image at the right is not a solution to Part 3, needs proper colormapping!
Set and Cluster Visualization

• Set and cluster visualization not covered in depth in the textbook

• Nice summary of set visualization in the following paper:
  - Visualizing Sets and Set-typed Data, B. Alsallakh et al., 2014
  - Also: http://www.setviz.net
Sets

- A set is a collection of **unique** objects
  - Generally **unordered**
  - Example: $S = \{"apple", \"pear\", \"orange\"\}$

- What questions can we ask about sets?
  - Containment: Is some item $x$ in $S$?
  - Intersection: what items are in both $S$ and $T$?
  - Union: what items are in either $S$ or $T$?
  - Difference: what items are in $S$ but not $T$?
  - ...
Set-typed Data - Characteristics

- **Set Algebra**
  - Set operations, Cartesian product, power set, ...

- **Set similarities**
  - Similarity measures (Jaccard, Tversky, etc.)

- **Element degree**
  - Exclusive set membership

- **Dimensionality**
  - $2^n$ possible combinations
  - $2^{(2^n)}$ possible queries

[B. Alsallakh et al., 2014]
Set-typed Data - Representations

**Boolean Attributes**

<table>
<thead>
<tr>
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**Multi-valued Attribute**

- InfoVis; ML; VA; Bio
- InfoVis; VL; Diagrams;
- InfoVis; VA; Time; Sol
- IVA; SciVis; InfoVis; Bio
- InfoVis; VA; PM; Time
- Diagrams; Logic; VL

**Element-Set Tuples**

[B. Alsallakh et al., 2014]
Set-typed Data - Representations

- **Boolean Attributes**
  - Adjacency Matrix

- **Multi-valued Attribute**
  - Adjacency List
  - Element-Set Tuples

[B. Alsallakh et al., 2014]
What are tasks with set data?

[All of the following Slides from B. Alsallakh et al., 2014]
<table>
<thead>
<tr>
<th>Elements</th>
<th>Sets and Set Relations</th>
<th>Element Attributes</th>
</tr>
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<tbody>
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<td><img src="image2" alt="Sets and Set Relations" /></td>
<td><img src="image3" alt="Element Attributes" /></td>
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Elements

- Find elements belonging to a specific set
- Find sets containing a specific element
- Find elements based on their set memberships
- Find elements with a specific set membership degree
- Filter out elements based on their set memberships
- Filter out elements based on their set membership degrees
- Create a new set that contains certain elements
Elements

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Elements

- [Image 1]
- [Image 2]
- [Image 3]
- [Image 4]
- [Image 5]
Elements

Find elements belonging to a specific set
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Find elements belonging to a specific set

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Elements

[Images of various molecular structures]

[Images of people]
Elements

Find sets containing a specific element
Elements

Find sets containing a specific element
Elements

Find sets containing a specific element

affiliations
Elements

Find sets containing a specific element

affiliations

TU WIEN
Ifh/// st. pölten
Elements

Find sets containing a specific element

affiliations

Vienna University
Elements

[Diagram of elements with symbols and images of people]
Elements

Find elements based on their set memberships
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2 affiliations
Find elements with a specific set membership degree

2 affiliations
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2. Find sets containing a specific element
3. Find elements based on their set memberships
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Sets and Set Relations

- Find the number of sets in the set family
- Analyze inclusion relations
- Analyze inclusion hierarchies
- Analyze exclusion relations
- Analyze intersection relations
- Find intersections between $k$ sets
- Find set intersections of a specific set
- Find the set with largest pairwise set intersections
- Analyze set & set intersection cardinalities
- Analyze and compare set similarities
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- Highlight specific sets, subsets, or set relations
- Create a new set using set-theoretical operations
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Sets and Set Relations

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Time-oriented Data Diagrams
Sets and Set Relations

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Diagrams

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- InfoVis
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Analyze set & set intersection cardinalities

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Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams
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Element Attributes

- Find the attribute value of a certain element
- Find the distribution of an attribute in a certain set or subset
- Compare the attribute values of sets or set intersections
- Analyze the set memberships for elements having certain attribute values
- Create a new set out of elements having certain attribute values
<table>
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<tr>
<th>Task</th>
<th>Icon</th>
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<tbody>
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<td>Find the attribute value of a certain element</td>
<td><img src="search_icon.png" alt="Search" /></td>
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<td><img src="graph_icon.png" alt="Graph" /></td>
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<td><img src="creation_icon.png" alt="Creation" /></td>
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InfoVis
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Time-oriented Data (TD)
Diagrams
Analyze the set memberships for elements having certain attribute values.

Set memberships = research areas

Elements = authors

Attribute value = female
Analyze the set memberships for elements having certain attribute values.

Set memberships = research areas
Elements = authors
Attribute value = female

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</tr>
<tr>
<td><img src="image7.png" alt="Element" /></td>
<td><img src="image8.png" alt="Set" /></td>
<td><img src="image9.png" alt="Attribute" /></td>
</tr>
<tr>
<td><img src="image10.png" alt="Element" /></td>
<td><img src="image11.png" alt="Set" /></td>
<td><img src="image12.png" alt="Attribute" /></td>
</tr>
<tr>
<td><img src="image13.png" alt="Element" /></td>
<td><img src="image14.png" alt="Set" /></td>
<td><img src="image15.png" alt="Attribute" /></td>
</tr>
<tr>
<td><img src="image16.png" alt="Element" /></td>
<td><img src="image17.png" alt="Set" /></td>
<td><img src="image18.png" alt="Attribute" /></td>
</tr>
<tr>
<td><img src="image19.png" alt="Element" /></td>
<td><img src="image20.png" alt="Set" /></td>
<td><img src="image21.png" alt="Attribute" /></td>
</tr>
</tbody>
</table>
Techniques
Venn Diagram

Famous Women
- Hillary Clinton
- Mother Teresa

Nicole Kidman
- Jennifer Aniston

James Earl Jones
- Will Smith
- George Clooney

Movie Stars
- Harrison Ford

TV Stars
- Richard Dean Anderson
- Matt Leblanc

[http://askville.amazon.com/idea-Venn-diagram/AnswerViewer.do?requestId=8420613]
Venn Diagram?
Scalability

- How to show the intersection of four sets? 8?
- Euler Diagrams: only show intersections/containments that exist
- Still run into scalability issues
What about cardinality?

Area encoding

Using glyphs

[B. Alsallakh et al., 2014]
Venn Diagram Visualizations

show only required set relations

show unwanted set relations

show set relation cardinalities

[B. Alsallakh et al., 2014]
What if we don't worry so much about nice circles/ellipses?
Compact Euler Diagrams: Use edges
Compact Euler Diagrams: Use nesting

[Image of Euler diagram with names]
Euler Diagram Variants

- Use edges
- Split set into components
- Use a concentric layout

[B. Alsallakh et al., 2014]
Fig. 7: Grouping research articles on a timeline

Fig. 8: Items can be expanded to reveal a larger image or the article's abstract

The boundary moves to accommodate the larger item and other items move along the y-axis to remain visible and selectable.

Sets of hotels, subway entrances, and medical clinics may help them find a hotel that is central to several medical clinics and near a subway entrance.

4.4 Sets over Scatterplots

Scatterplots have clearly defined spatiality due to the numerical positioning of items. We add Bubble Sets to a reimplementation of the well-known GapMinder Trendalyzer. This scatterplot shows fertility rate against life expectancy and is animated over time. Data points represent countries, sized by population. Colour and set membership is defined by the continent. The grouping of the Sub-Saharan Africa countries highlighted in Figure 6 reveals that while most of the countries in this set had high fertility rates and low life expectancies, there were two outliers: Mauritius and Reunion, which are islands in the Indian Ocean. As the data set includes data for many years, and since Bubbles Sets are calculated at interactive rates, the temporal changes can be convincingly shown through animation.

5 Discussion and Future Work

We have presented Bubble Sets, a method for automatically drawing set membership groups over existing visualizations with different degrees of requirements for primary spatial rights. In contrast to other overlaid containment set visualizations, Bubble Sets maximize set membership inclusion and minimize inclusion of non-set members. In fact, Bubble Sets can guarantee that all set members will be within one container, as opposed to the more common multiple disjoint containers. While Bubble Sets cannot guarantee non-set member exclusion, the routing algorithm minimizes these occurrences.

Within our isocontour approach, we have implemented several heuristics to reduce surface calculation and rendering time, such as grouping pixels for potential calculations and restricting the regions in which items influence the potential field. The current implementation works without noticeable lag – items can be dragged and the surface follows for our examples – order of 6–85 nodes, 6–85 sets. For example, it takes on average 65 ms to calculate the virtual edge set, fill the energy field, find the contour, and render the Sub-Saharan Africa set in a window size of 6–85 pixels. That set has 0- items and the entire scatter plot has 6–: points. The majority of this time is spent creating the virtual edge set. An incremental approach, using A* search as in [89] may provide improvements in speed and stability.

As the number of items, the screen resolution, or the number of sets increases, so will the rendering time. Additional techniques, such as grouping close items into larger pseudo-nodes, and caching the energy field values between frames may increase the capacity of the system.

Acknowledgments

Thanks to the following organizations for supporting this research: iCORE, CFI, NSERC, and SMART Technologies.
Bubble Sets & Overlay Techniques

- Given spatial layout is determined by other attributes, want to show set containment without modifying spatial layout
- Idea of "spatial rights"
- Construct regions based on a potential field
- Draw using containment marks
- How do we compute these?
Bubble Sets & Overlay Techniques

- Given spatial layout is determined by other attributes, want to show set containment without modifying spatial layout
- Idea of "spatial rights"
- Construct regions based on a potential field
- Draw using containment marks
- How do we compute these?
  - Marching Squares!
To understand the advantages and drawbacks of our technique, we performed a controlled experiment with 13 participants, comparing KelpFusion to Bubble Sets [7] and LineSets [1]. We discovered that KelpFusion improved on Bubble Sets, outperforming the technique in accuracy and par with LineSets in terms of accuracy but yielded faster completion time. We also found that KelpFusion was on average 20% faster than LineSets and 50% faster than Bubble Sets.

Figure 1. Visualizations using the various methods discussed in this paper. (a) Image generated using the implementation generously provided by the authors of Bubble Sets [7]. (b) Image courtesy of Kasper Dinkla. (c) Image generated using the LineSets implementation [Meulemans et al., 2013]. (d-f) Images generated by our KelpFusion implementation. (a) Bubble Sets (b) Kelp Diagrams (c) LineSets (d) KelpFusion (dense) (e) KelpFusion (medium) (f) KelpFusion (sparse)
Overlays

Region-based [Collins et al., 2009]

Line-based [Dinkla et al., 2012]

Glyph-based [Itoh et al., 2009]

[via B. Alsallakh et al., 2014]
More...

- **Node-Link Visualizations**

- **Matrix-based techniques**

- **Aggregation-based techniques**

[via B. Alsallakh et al., 2014]
More... Parallel Sets

[Diagram showing a parallel sets visualization with categories such as Survived vs. Perished, Sex (Female vs. Male), Age (Child vs. Adult), Class (Second Class vs. First Class vs. Third Class vs. Crew), and an explanation referencing Kosara et al., 2006, Example: J. Davies]
Clusters

• What is a cluster?
  - A **grouping** of objects (sets of objects)
  - Why is this not more precise?

• How do we determine if two items should be in the same cluster?
Clusters

• What is a cluster?
  - A **grouping** of objects (sets of objects)
  - Why is this not more precise?
• How do we determine if two items should be in the same cluster?
  - Distance
  - Relationships: Connectivity and Containment (Hierarchies)
  - Distributions
Clusters

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  - A **grouping** of objects (sets of objects)
  - Why is this not more precise?

• How do we determine if two items should be in the same cluster?
  - Distance
  - Relationships: Connectivity and Containment (Hierarchies)
  - Distributions

• Can an item be in more than one cluster?
  - Hard clustering: no
  - Soft (fuzzy) clustering: yes, for example, with likelihood of being in a cluster
Visualizing Clusters

- If a clustering algorithm assigns each data item to a cluster, we can treat this like set visualization.
- If a spatial distance is used, this often means there is no overlap (e.g. in 2D).
- What visual encodings could work?

[C. Polis, 2014]
Hierarchical Clustering
Hierarchical Clustering

• Each item may belong to multiple groups, but groups are nested
• Data items are organized in a tree
• Creating hierarchical clusters:
  - Agglomerative: start with individuals and group
  - Divisive: start with one group and divide
• Any tree visualization method will work, but…
• …generally containment marks used for clusters
Network Clusters
Network Clusters

• Create groups based on connectivity
• Layout may be important (or could be used to create clusters)
• How to create network clusters:
  - Idea: Low connectivity between groups induces cuts
  - Example: group of friends from home and group of friends at college (and potential intersection)
  - Can also use attribute information
Biclustering

- Bicluster: network concept
- Given two groups, each node in one group is connected to every node in the other group (goes both directions)
Biset edge bundling (and grouping)

(A) presents all edges between related entities. (B) shows that the two entity sets of a bicluster can bundle edges that link pairs of related entities, thus clearing that a bicluster can bundle edges that link pairs of related entities, indicating a coordinated relationship between three people and four locations. It is evident that biclusters can bundle edges that link pairs of related entities, indicating a coordinated relationship.

Fig. 2. An example of a bicluster, indicating a coordinated relationship.
Biset Edge Bundling

There are two ways to perform the four types of exploration: (1) edge-centric exploration, which presents bundles with individual edges. (A) shows all edges between related entities. (B) is the bundle only mode that just displays bundles. The three modes attempt to meet different purposes (e.g., organizing information). BiSet bundles edges based on groups. (2) relationship-centric exploration, which emphasizes bundling based on spatial proximity. BiSet bundles with individual edges. (C) is the edge-centric bundling method. (D) is the relationship-centric bundling method.

In BiSet, entities and bundles are represented respectively. (A) shows all edges between related entities. (B) is the bundle only mode that just displays bundles. The three modes attempt to meet different purposes (e.g., organizing information). BiSet bundles edges based on groups. (2) relationship-centric exploration, which emphasizes bundling based on spatial proximity. BiSet bundles with individual edges. (C) is the edge-centric bundling method. (D) is the relationship-centric bundling method.

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may belong to one bicluster, to more than one bicluster, or to no bicluster at all. The same holds for samples. In general, clustering algorithms can additionally be differentiated by the kind of memberships they produce. In hard clustering, rows and columns are assigned to clusters in a binary way, i.e., they either belong to clusters or not. In soft clustering, the result consists of non-binary membership values that describe to what degree rows and columns belong to the clusters. As the assignment of rows and columns to clusters is fuzzy, this is also known as fuzzy clustering [7,8].

**Bicluster visualization**

Let us consider the visualization of hard clustering results first. In order to understand and interpret hard clustering results, it is necessary to visualize the clusters together with the underlying data. Clustered heatmaps are the standard technique for visualizing both one-way and two-way clustering results. In clustered heatmaps, the rows or columns are reordered, such that clusters can be recognized as contiguous blocks consisting of adjacent cells. Showing clusters as contiguous blocks is highly desired, as it simplifies the detection and interpretation of patterns. However, for biclustering results, where clusters can overlap, rearranging the matrix this way is often impossible. Let us consider the example from Figure 1 that shows a 5x5 matrix with three clusters. In Figure 1(a), the columns are sorted such that the red and yellow clusters are represented as contiguous blocks, as indicated by a thick border. However, this sorting splits the blue cluster into two unconnected blocks. In Figure 1(b), columns B and E are swapped, which makes it possible to show the blue cluster as a contiguous block, but splits the red cluster. Consequently, even in small matrices there is often no optimal order of rows and columns where all clusters form contiguous blocks. The sorting problem can be solved by duplicating rows and/or columns, as demonstrated in Figure 1(c). However, the duplication approach does not scale, as it potentially produces large output matrices for comparably small input matrices.

Interpreting biclustering results is often time-consuming and tedious, as it is usually done statically by visually inspecting many separate plots. Adding fuzzy clustering to this equation makes the situation even more difficult. Fuzzy biclustering is a visualization research problem that cannot be addressed by any of the existing tools. We will first elaborate on how biclustering results can be represented and then introduce the FABIA fuzzy biclustering algorithm [9]. We use FABIA to demonstrate the proposed technique; however, note that any other biclustering algorithm that produces overlapping clusters can be used in the same way. We continue by introducing general requirements for bicluster visualization, which we use to review existing work in this field. We then present Furby, an interactive visualization technique for analyzing fuzzy biclustering results. After a brief description of the implementation, we present how the tool can be used effectively to analyze a real-world dataset. Before concluding the paper, we discuss the scalability of our tool to large datasets.

**Representation of biclustering results**

Biclustering data can generally be represented by three matrices: $X, L$, and $Z$. The $X$ matrix represents the input data to be clustered. The biclustering results are represented by $L$ and $Z$. The $L$ matrix contains the relationship information between rows and biclusters, and the $Z$ matrix contains the same information for columns. While for

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**Bicluster Reordering Problem**

![Bicluster Reordering Problem](image)
Bicluster relationships as a graph

[Streit et al., 2014]