Information Visualization

✓ Visualization of abstract information structures
✓ An appropriate visual representation of information needs to be carefully designed
✓ Visual navigation and manipulation tools need to be provided.
✓ Often combined with data exploration/data mining techniques.
Information visualization techniques

1. Data processing techniques: Dimension reduction -- PCA and MDS
2. Tabulation techniques
3. Parallel Coordinates / Radial Coordinates
4. Geometric techniques
5. Pixel Oriented Techniques
6. Dimension Stacking
7. Icon-based techniques
8. Multi-scale/hierarchical techniques
9. Graph / network visualization techniques
10. Text visualization
Data processing techniques: Dimension reduction

n-D data $\rightarrow$ k-D data ($k \ll n$)

- Principal Component Analysis (PCA)
- Multidimensional Scaling
- Nonnegative Matrix Factorization
- Isomap
- Locally-Linear Embedding (LLE)
Principal Component Analysis

- Determine a minimal set of principal components that can express the main variations in the data.

- The new variables/dimensions
  - Are linear combinations of the original ones
  - Are uncorrelated with one another: Orthogonal in original dimension space
  - Capture as much of the original variance in the data as possible
Principal Components

- First principal component is the direction of greatest variability in the data; Second is the next orthogonal (uncorrelated) direction of greatest variability, etc.

- Principle:
  - Linear projection method to reduce the number of parameters
  - Transfer a set of correlated variables into a new set of uncorrelated variables
  - Map the data into a space of lower dimensionality
  - Can be viewed as a rotation of the existing axes to new positions in the space defined by original variables
  - New axes are orthogonal and represent the directions with maximum variability
Computing the Components

- Direction of greatest variability is that in which the average square of the projection is greatest
  - Find \( u \) such that \( E((u.x)^2) \) over all \( x \) is maximized
  - This direction of \( u \) is the direction of the first Principal Component

\[
E((u.x)^2) = E((u^T x) (u^T x)^T) = E(u^T xx^T u)
\]

- The matrix \( C = xx^T \) contains the correlations (similarities) of the original axes based on how the data values project onto them
Computing the Components

✓ Maximise \( u^Txx^Tu \) Such that \( u^Tu = 1 \)

Construct Langrangian \( u^Txx^Tu - \lambda u^Tu \)

Vector of partial derivatives set to zero

\[ xx^Tu - \lambda u = (xx^T - \lambda I) u = 0 \]

✓ It is maximized when \( u \) is the principal eigenvector of the matrix \( C \), in which case

- \( uCu^T = u\lambda u^T = \lambda \) if \( u \) is unit-length, where \( \lambda \) is the principal eigenvalue of the correlation matrix \( C \)
- The eigenvalue denotes the amount of variability captured along that dimension
The first PC retains the greatest amount of variation in the sample.
The \( k \)-th PC retains the \( k \)-th greatest fraction of the variation in the sample.
The \( k \)-th largest eigenvalue of the correlation matrix \( C \) is the variance in the sample along the \( k \)-th PC.
PCA for Facial Images

Each face can be represented as a combination of basic facial components (eigenfaces).
Eigenfaces

90% variations can be captured by top 50 eigenfaces
Sorting based on principle component

<table>
<thead>
<tr>
<th>Countries (110)</th>
<th>Population</th>
<th>Density</th>
<th>Literacy</th>
<th>Babymort</th>
<th>GDP</th>
<th>Birthrate</th>
<th>Deathrate</th>
<th>Lifeexp_F</th>
<th>Lifeexp_M</th>
<th>Lifeexpr</th>
</tr>
</thead>
</table>
Data Space vs. PCA Space
Multi-dimensional Scaling (MDS)

- Based on data similarity
- Focus primarily on maintaining distance between data elements.
MDS

✓ Input: similarity matrix of original data points in $n$ dimensional space
✓ Output: data coordinates in $k$ dimensional space ($k << n$)
✓ Approach: minimize an object function such that the “distances” of data points in the $k$-D space are closest to those in the $n$-D space.
MDS: Object Function

\[ J(Y) = \frac{\sum_{i<j}(d_{i,j} - \delta_{i,j})^2}{\sum_{i<j} \delta_{i,j}^2} \]

- \( \delta_{ij} \): distance of \( i \)th and \( j \)th data points in \( n \)-D space
- \( d_{ij} \): distance of \( i \)th and \( j \)th data points in \( k \)-D space
- \( Y \): set of data coordinates in \( k \)-D space
MDS vs. PCA

- If the distance measure is defined as the Euclidean distance, then MDS = PCA.
- MDS is more flexible, but computationally more expensive.
**Other Data Processing Techniques**

- **Subsetting techniques**: using a subset of the database (sampling, querying).

- **Segmentation/clustering techniques**: group the data items into subsets with common/similar properties and patterns.

- **Aggregation techniques**: Aggregation (sum, min, max, count) of attributes. E.g. histogram, distribution, pie chart, bar chart, etc.
Tabulation

Example Data
- 16 Variables
- 98 Records

| Variable 1 | Variable 2 | Variable 3 | Variable 4 | Variable 5 | Variable 6 | Variable 7 | Variable 8 | Variable 9 | Variable 10 | Variable 11 | Variable 12 | Variable 13 | Variable 14 | Variable 15 | Variable 16 |
|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
|            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |
Detailed Data Table View:
example record
### Coloring individual variables

The table below demonstrates the coloring of individual variables across different vehicles. Each cell represents a value associated with a specific variable on a vehicle. The colors range from low to high, indicating different levels of significance or performance.

<table>
<thead>
<tr>
<th></th>
<th>Variable 1</th>
<th>Variable 2</th>
<th>Variable 3</th>
<th>Variable 4</th>
<th>Variable 5</th>
<th>Variable 6</th>
<th>Variable 7</th>
<th>Variable 8</th>
<th>Variable 9</th>
<th>Variable 10</th>
<th>Variable 11</th>
<th>Variable 12</th>
<th>Variable 13</th>
<th>Variable 14</th>
<th>Variable 15</th>
<th>Variable 16</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
<td>D</td>
<td>F</td>
<td>1.99</td>
<td>20.80</td>
<td>86</td>
<td>B</td>
<td>1.98</td>
<td>1.60</td>
<td>A</td>
<td>0.30</td>
<td>1.53</td>
<td>1.95</td>
<td>0.95</td>
<td>3.33</td>
<td>495</td>
</tr>
<tr>
<td>A</td>
<td>A</td>
<td>B</td>
<td>D</td>
<td>2.21</td>
<td>16.00</td>
<td>96</td>
<td>D</td>
<td>2.65</td>
<td>2.33</td>
<td>A</td>
<td>0.26</td>
<td>1.98</td>
<td>4.70</td>
<td>1.04</td>
<td>3.59</td>
<td>1035</td>
</tr>
<tr>
<td>B</td>
<td>D</td>
<td>F</td>
<td>1.94</td>
<td>19.00</td>
<td>92</td>
<td>B</td>
<td>2.36</td>
<td>2.04</td>
<td>A</td>
<td>0.39</td>
<td>2.08</td>
<td>2.70</td>
<td>0.86</td>
<td>3.02</td>
<td>312</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>2.67</td>
<td>18.60</td>
<td>101</td>
<td>C</td>
<td>2.80</td>
<td>3.24</td>
<td>B</td>
<td>0.30</td>
<td>2.81</td>
<td>5.68</td>
<td>1.03</td>
<td>3.17</td>
<td>1185</td>
</tr>
<tr>
<td>A</td>
<td>A</td>
<td>B</td>
<td>2.70</td>
<td>22.50</td>
<td>101</td>
<td>C</td>
<td>3.00</td>
<td>3.25</td>
<td>A</td>
<td>0.29</td>
<td>2.38</td>
<td>5.70</td>
<td>1.19</td>
<td>2.71</td>
<td>1285</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>D</td>
<td>E</td>
<td>2.42</td>
<td>22.00</td>
<td>86</td>
<td>B</td>
<td>1.45</td>
<td>1.25</td>
<td>A</td>
<td>0.50</td>
<td>1.63</td>
<td>3.60</td>
<td>1.05</td>
<td>2.65</td>
<td>450</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>D</td>
<td>F</td>
<td>2.12</td>
<td>19.00</td>
<td>80</td>
<td>B</td>
<td>1.65</td>
<td>2.03</td>
<td>B</td>
<td>0.37</td>
<td>1.63</td>
<td>3.40</td>
<td>1.00</td>
<td>3.17</td>
<td>510</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>A</td>
<td>B</td>
<td>2.55</td>
<td>18.00</td>
<td>98</td>
<td>C</td>
<td>2.45</td>
<td>2.43</td>
<td>A</td>
<td>0.29</td>
<td>1.44</td>
<td>4.25</td>
<td>1.12</td>
<td>2.51</td>
<td>1105</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>B</td>
<td>C</td>
<td>2.60</td>
<td>17.20</td>
<td>94</td>
<td>C</td>
<td>2.45</td>
<td>2.99</td>
<td>A</td>
<td>0.22</td>
<td>2.29</td>
<td>5.60</td>
<td>1.24</td>
<td>3.37</td>
<td>1265</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>D</td>
<td>F</td>
<td>2.17</td>
<td>21.00</td>
<td>85</td>
<td>B</td>
<td>2.60</td>
<td>2.65</td>
<td>B</td>
<td>0.37</td>
<td>1.35</td>
<td>2.76</td>
<td>0.86</td>
<td>3.28</td>
<td>378</td>
<td></td>
</tr>
</tbody>
</table>

**LOW**  | **MID** | **HIGH**
Transformation to Heatmap

<table>
<thead>
<tr>
<th></th>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| B  | D  | F   |        | B  |       | A    | 1.98  | 1.60  | A    | 0.30  | 1.53  | 1.95  | 0.95  | 3.33  | 495    |
|----|----|-----|--------|----|-------|------|-------|-------|------|-------|-------|-------|-------|-------|--------|-------|
| A  | A  | B   | 2.21  | 16.00| 96    | D    | 2.65  | 2.33  | A    | 0.26  | 1.98  | 4.70  | 1.04  | 3.59  | 1035   |
| B  | D  | F   | 1.94  | 19.00| 92    | B    | 2.36  | 2.04  | A    | 0.39  | 2.08  | 2.70  | 0.86  | 3.02  | 312    |
| A  | A  | A   | 2.67  | 18.60| 101   | C    | 2.80  | 3.24  | B    | 0.30  | 2.81  | 5.68  | 1.03  | 3.17  | 1185   |
| A  | A  | B   | 2.70  | 22.50| 101   | C    | 3.00  | 3.25  | A    | 0.29  | 2.38  | 5.70  | 1.19  | 2.71  | 1285   |
| B  | D  | E   | 2.42  | 22.00| 86    | B    | 1.45  | 1.25  | A    | 0.50  | 1.63  | 3.60  | 1.05  | 2.65  | 450    |
| B  | D  | F   | 2.12  | 19.00| 80    | B    | 1.65  | 2.03  | B    | 0.37  | 1.63  | 3.40  | 1.00  | 3.17  | 510    |
| A  | A  | B   | 2.55  | 18.00| 98    | C    | 2.45  | 2.43  | A    | 0.29  | 1.44  | 4.25  | 1.12  | 2.51  | 1105   |
| A  | B  | C   | 2.60  | 17.20| 94    | C    | 2.45  | 2.99  | A    | 0.22  | 2.29  | 5.60  | 1.24  | 3.37  | 1265   |
| B  | D  | F   | 2.17  | 21.00| 85    | B    | 2.60  | 2.65  | B    | 0.37  | 1.35  | 2.76  | 0.86  | 3.28  | 378    |

LOW [ ] HIGH [ ]
Full Heatmap

Example Record 20

A  A  B  2.70  22.50  101  C  3.00  3.25  A  0.29  2.38  5.70  1.19  2.71  1285
Table Split

- Variable 1
- Variable 2

Split and Sort

Example Record 20

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>A</th>
<th>B</th>
<th>2.70</th>
<th>22.50</th>
<th>101</th>
<th>C</th>
<th>3.00</th>
<th>3.25</th>
<th>A</th>
<th>0.29</th>
<th>2.38</th>
<th>5.70</th>
<th>1.19</th>
<th>2.71</th>
<th>1285</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table Split (2)

- Variable 1
- Variable 2
- Variable 3

Split and Sort

Example Record 20

| A | A | B | 2.70 | 22.50 | 101 | C | 3.00 | 3.25 | A | 0.29 | 2.38 | 5.70 | 1.19 | 2.71 | 1285 |
Table Split – parallel Coordinates

Example Record 20

| A | A | B | 2.70 | 22.50 | 101 | C | 3.00 | 3.25 | A | 0.29 | 2.38 | 5.70 | 1.19 | 2.71 | 1285 |
|---|---|---|------|-------|-----|---|------|------|---|------|------|------|------|------|------|------|
Radial Layout

Transforming a rectangular to a radial layout
Radial coordinates

Example record showing the underlying connections
Radial Visualization

<table>
<thead>
<tr>
<th>A</th>
<th>A</th>
<th>B</th>
<th>2.70</th>
<th>22.50</th>
<th>101</th>
<th>C</th>
<th>3.00</th>
<th>3.26</th>
<th>A</th>
<th>0.29</th>
<th>2.38</th>
<th>5.70</th>
<th>1.19</th>
<th>2.71</th>
<th>1285</th>
</tr>
</thead>
</table>

Example Record 20
Visual Clustering

Three Classes

Example Record 20
Parallel coordinates

- N-axes as vertical bars
- Each data item corresponds to a polyline curve
Points on a line in 10D
✓ Can be messy.
✓ Dimension order dependent
Dimension Correlations

\[ \rho = 1 \]
\[ \rho = 0.8 \]
\[ \rho = 0 \]
\[ \rho = -0.8 \]
\[ \rho = -1 \]
Salary vs. Performance

What baseball teams are spending their money well, and how does it change over the course of the season?
Fortune 500 ranking
In *Advizor* (firewall log data)
In *ProtoVis*
In *D3.js*
Picking
Brushing and Filtering
Axis re-ordering
Combining scatter plot and parallel-coordinates

Scattering Points in Parallel Coordinates

Submitted to IEEE Infovis 2009
Radial Coordinates

- Radial version of parallel coordinates.
- Coordinates axis places on a circle
Radar Chart / Star Plot

- It consists of a sequence of equi-angular spokes, representing different variables.
- Data length on a spoke is proportional to the variable value.
- A line is drawn connecting the data values for each spoke.
Star Plot Examples

Connecticut
New Hampshire
Pennsylvania
Maine
New Jersey
Rhode Island
Massachusetts
New York
Vermont
Table Lens

- For very large scale tables
- Using bar charts to compress rows and columns
- Show details for only some focal areas (focal rows and columns).
<table>
<thead>
<tr>
<th>Player</th>
<th>Avg</th>
<th>Career Avg</th>
<th>Team</th>
<th>Salary 87</th>
</tr>
</thead>
<tbody>
<tr>
<td>Larry Herndon</td>
<td>0.24734983</td>
<td>0.27282076</td>
<td>Det.</td>
<td>225</td>
</tr>
<tr>
<td>Jesse Barfield</td>
<td>0.28862348</td>
<td>0.27288818</td>
<td>Tor.</td>
<td>1237.5</td>
</tr>
<tr>
<td>Jeffrey Leonar</td>
<td>0.27859238</td>
<td>0.27260458</td>
<td>S F</td>
<td>900</td>
</tr>
<tr>
<td>Donnie Hill</td>
<td>0.28318584</td>
<td>0.2725564</td>
<td>Oak</td>
<td>275</td>
</tr>
<tr>
<td>Billy Sample</td>
<td>0.285</td>
<td>0.2718601</td>
<td>Atl.</td>
<td>NA</td>
</tr>
<tr>
<td>Howard Johnson</td>
<td>0.24545455</td>
<td>0.25232068</td>
<td>N Y</td>
<td>2975</td>
</tr>
<tr>
<td>Andru Thomas</td>
<td>0.250774</td>
<td>0.2521994</td>
<td>Atl</td>
<td>75</td>
</tr>
<tr>
<td>Billy Hatcher</td>
<td>0.25775656</td>
<td>0.25211507</td>
<td>Hou.</td>
<td>110</td>
</tr>
<tr>
<td>Omar Moreno</td>
<td>0.2339833</td>
<td>0.2518029</td>
<td>Atl.</td>
<td>NA</td>
</tr>
<tr>
<td>Darnell Coles</td>
<td>0.2725520</td>
<td>0.25153375</td>
<td>Det.</td>
<td>105</td>
</tr>
</tbody>
</table>
Geometric Techniques

✓ Apply geometric transformations, projections, cross-sectioning operations, etc.

✓ Specific techniques
  1. Scatter plot matrix
  2. Landscapes
  3. Slicing
  4. Prosection
Scatter Plot Matrix

- Show 2D projections of $n$-D data.
- Show correlations of pairs of dimensions
- $(n^2/2 - n)$ number of scatter plots.
Scatter Plot Matrix
Automatically look for interesting dimension pairs

Clusters

Correlation

Landscapes

- transform data to a height field
- 3D rendering of height field
Terrain rendering for protein-protein interaction networks

Figure 1. The terrain visualization concepts.
Slicing

2D cross sections of k-D data (the slices are determined interactively)
Prosection

Projection to one or more 2D subspaces
Pixel-Oriented Techniques (pixel map)

- Maximize screen space usage
- Mapping data items to pixels
- The Million Dollar Page
Pixel-Oriented Techniques

- Each attribute value is represented by one colored pixel
- Value ranges of the attributes are mapped to a fixed colormap
- Attribute values for each attribute are presented in separate subwindows

• example:

Visualization of six-dim. data

- attribute values of a data item
Pixel Arrangements

✓ Space-filling curves
✓ Recursive Pattern technique.
✓ Circle Segment technique
✓ Spiral technique
✓ Axes technique
Space Filling Curves

Mapping a 1-D data sequence to a 2-D space: optimizing spatial locality

Peano-Hilbert

Morton (Z-Curve)
a. Peano-Hilbert Technique

b. Morton Technique
Recursive pattern technique

- Let the users to arrange the subwindows according to the data’s inherent structure
Four level structures

<table>
<thead>
<tr>
<th>Row 1</th>
<th>Columns 2 - 6</th>
<th>Row 12</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Diagram" /></td>
<td><img src="image2" alt="Diagram" /></td>
<td><img src="image3" alt="Diagram" /></td>
</tr>
<tr>
<td><img src="image4" alt="Diagram" /></td>
<td><img src="image5" alt="Diagram" /></td>
<td><img src="image6" alt="Diagram" /></td>
</tr>
<tr>
<td><img src="image7" alt="Diagram" /></td>
<td><img src="image8" alt="Diagram" /></td>
<td><img src="image9" alt="Diagram" /></td>
</tr>
<tr>
<td><img src="image10" alt="Diagram" /></td>
<td><img src="image11" alt="Diagram" /></td>
<td><img src="image12" alt="Diagram" /></td>
</tr>
<tr>
<td><img src="image13" alt="Diagram" /></td>
<td><img src="image14" alt="Diagram" /></td>
<td><img src="image15" alt="Diagram" /></td>
</tr>
</tbody>
</table>
Query Dependent Visualization: Spiral Techniques

arrangement in spiral form according to the overall distance
Spiral-Axis Technique

Attribute $j$

pos

neg

pos

neg

Attribute $i$

arrangement in partial spirals in each quadrant

example of the overall distance
Color Icons

✓ An array of color fields representing attribute values.
✓ Arranged (query dependent) in spiral pattern.
Color Icon Example
A Comparison

Spiral Technique

Axes Technique

Color Icon Technique
Similarity-based layout
Circle Segments Technique

- Data is a circle divided into segments
- Each segment represents an attribute
- Attribute values are mapped by a single colored pixel and arrangement starts in the center and proceeds outward
Example: 50 stocks. One circle represents the prices of different stocks at the same time.
Dimension Stacking

- Partition n-D attributes into 2D subspaces which are then stacked into each other.
- Important attributes should be the outer layer.
Oil field visualization: location x-y with grade and depth attributes.
Icon-based techniques

- Data attributes are represented by features of the icons (also called glyphs).
- Example: Stick figures for molecular data.
Stick figures

- Two attributes are mapped to the 2D coordinates, and the rest are mapped to angles and lengths.
- Show texture patterns in the visualization
A census data figure showing age, income, gender, education, etc.

A 5-piece stick figure (1 body, 1 head, 2 arms, and 4 limbs) in different angle/lengths.
Icon-based techniques

✓ 5D data (great lake region): 3 color channels and 2 IR channels
Chernoff Faces

✓ Use face properties (shape, nose, eyes, mouth) to represent multidimensional data
The Face of Crime in the United States

Violent Crime
- Shaper of Face: Robbery
- Height of Face: Murder
- Width of Face: Forcible Rape
- Height of Mouth: Aggravated Assault

Property Crime
- Height of Eyes: Larceny-Theft
- Width of Mouth: Burglary

United States
- Alabama
- Alaska
- Arizona
- Arkansas
- California
- Colorado
- Connecticut
- Delaware
- District of Columbia
- Florida
- Georgia
- Hawaii
- Idaho
- Illinois
- Indiana
- Iowa
- Kansas
- Kentucky
- Louisiana
- Maine
- Maryland
- Massachusetts
- Michigan
- Minnesota
- Mississippi
- Missouri
- Montana
- Nebraska
- Nevada
- New Hampshire
- New Jersey
- New Mexico
- New York
- North Carolina
- North Dakota
- Ohio
- Oklahoma
- Oregon
- Pennsylvania
- Rhode Island
- South Carolina
- South Dakota
- Tennessee
- Texas
- Utah
- Vermont
- Virginia
- Washington
- West Virginia
- Wisconsin
- Wyoming
Small Multiples

“Illustrations of postage-stamp size are indexed by category or a label, sequenced over time, or ordered by a quantitative variable not used in the single image itself.”
2000: State-level support (orange) or opposition (green) on school vouchers, relative to the national average of 45% support

Income under $20,000  $20-40,000  $40-75,000  $75-150,000  Over $150,000

All voters

White Catholics

White evangelicals

White non-evang. Protestants

White other/no religion

Blacks

Hispanics

Other races

Orange and green colors correspond to states where support for vouchers was greater or less than the national average. The seven ethnic/religious categories are mutually exclusive. “Evangelicals” includes Mormons as well as born-again Protestants. Where a category represents less than 1% of the voters of a state, the state is left blank.
<table>
<thead>
<tr>
<th></th>
<th>West</th>
<th>Central</th>
<th>East</th>
<th>South</th>
</tr>
</thead>
<tbody>
<tr>
<td>Columbian</td>
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<tr>
<td>Lemon</td>
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<tr>
<td>Caffe Mocha</td>
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<tr>
<td>Decaf Espresso</td>
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<td>Chamomile</td>
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<td>Darjeeling</td>
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<td>Earl Grey</td>
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<tr>
<td>Decaf Irish Cream</td>
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<tr>
<td>Caffe Latte</td>
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<td>Mint</td>
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<td>Green Tea</td>
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<td>Amaretto</td>
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<tr>
<td>Regular Espresso</td>
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</tbody>
</table>
Dust & Magnet

Dust: data elements; Magnet: Variables
Flexible Linked Axes

Interactively drawing and linking axes (variables). Linked axes are used to show data in scatter plot or parallel coordinates.
FLINAView

Flexible LINked Axes for Multivariate Data visualization

Jarry H.T. Claessen
Jarke J. Van Wijk

IEEE InfoVis 2011