Multivariate Data & Tables and Graphs

CS 7450 - Information Visualization
Aug. 30, 2011
John Stasko

Agenda

- Data and its characteristics
- Tables and graphs
- Design principles
Data

- Data is taken from and/or representing some phenomena from the world
- Data models something of interest to us

Data Sets

- Data comes in many different forms
- Typically, not in the way you want them

- What is available to me (in the raw)?
Example

• Cars
  – make
  – model
  – year
  – miles per gallon
  – cost
  – number of cylinders
  – weights
  – ...

Example

• Web pages
Data Models

- Often characterize data through three components
  - Objects
    Items of interest
    (students, courses, terms, ...)
  - Attributes
    Characteristics or properties of data
    (name, age, GPA, number, date, ...)
  - Relations
    How two or more objects relate
    (student takes course, course during term, ...)

Data Tables

- We take raw data and transform it into a model/form that is more workable
- Main idea:
  - Individual items are called cases
  - Cases have variables (attributes)
  - Relational: Relations between cases (not our main focus today)
## Data Table Format

<table>
<thead>
<tr>
<th>Case_1</th>
<th>Case_2</th>
<th>Case_3</th>
<th>...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable_1</td>
<td>Value_{11}</td>
<td>Value_{21}</td>
<td>Value_{31}</td>
</tr>
<tr>
<td>Variable_2</td>
<td>Value_{12}</td>
<td>Value_{22}</td>
<td>Value_{32}</td>
</tr>
<tr>
<td>Variable_3</td>
<td>Value_{13}</td>
<td>Value_{23}</td>
<td>Value_{33}</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

Think of as a function
\[ f(\text{case}_1) = \langle \text{Val}_{11}, \text{Val}_{12}, \ldots \rangle \]

## Example

<table>
<thead>
<tr>
<th>Mary</th>
<th>Jim</th>
<th>Sally</th>
<th>Mitch</th>
<th>...</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSN</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>145</td>
<td>294</td>
<td>563</td>
<td>823</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>17</td>
<td>47</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>Hair</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>brown</td>
<td>black</td>
<td>blonde</td>
<td>red</td>
<td></td>
</tr>
<tr>
<td>GPA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.9</td>
<td>3.7</td>
<td>3.4</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

People in class
### People in class

<table>
<thead>
<tr>
<th>Name</th>
<th>SSN</th>
<th>Age</th>
<th>Hair</th>
<th>GPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mary</td>
<td>145</td>
<td>23</td>
<td>brown</td>
<td>2.9</td>
</tr>
<tr>
<td>Jim</td>
<td>294</td>
<td>17</td>
<td>black</td>
<td>3.7</td>
</tr>
<tr>
<td>Sally</td>
<td>563</td>
<td>47</td>
<td>blonde</td>
<td>3.4</td>
</tr>
<tr>
<td>Mitch</td>
<td>823</td>
<td>29</td>
<td>red</td>
<td>2.1</td>
</tr>
</tbody>
</table>

### Example

**Baseball statistics**

<table>
<thead>
<tr>
<th>Name</th>
<th>Hits</th>
<th>Home Runs</th>
<th>Rbi</th>
<th>Walks</th>
<th>Years In M'Career</th>
<th>At Bats</th>
<th>Career Ht./Gm.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andy Alston</td>
<td>201</td>
<td>1</td>
<td>30</td>
<td>20</td>
<td>1</td>
<td>201</td>
<td>1</td>
</tr>
<tr>
<td>Alex Ashley</td>
<td>315</td>
<td>7</td>
<td>24</td>
<td>30</td>
<td>14</td>
<td>344</td>
<td>1</td>
</tr>
<tr>
<td>Alex Davis</td>
<td>479</td>
<td>136</td>
<td>66</td>
<td>72</td>
<td>16</td>
<td>1624</td>
<td>457</td>
</tr>
<tr>
<td>Andie Dawson</td>
<td>496</td>
<td>141</td>
<td>20</td>
<td>65</td>
<td>33</td>
<td>962</td>
<td>1675</td>
</tr>
<tr>
<td>Andie Galarraga</td>
<td>321</td>
<td>97</td>
<td>10</td>
<td>39</td>
<td>20</td>
<td>205</td>
<td>101</td>
</tr>
<tr>
<td>Alfred Griffin</td>
<td>584</td>
<td>160</td>
<td>4</td>
<td>74</td>
<td>51</td>
<td>4448</td>
<td>1133</td>
</tr>
<tr>
<td>Al Newman</td>
<td>185</td>
<td>37</td>
<td>1</td>
<td>23</td>
<td>6</td>
<td>216</td>
<td>42</td>
</tr>
<tr>
<td>Agnese Galarraga</td>
<td>341</td>
<td>73</td>
<td>0</td>
<td>24</td>
<td>7</td>
<td>389</td>
<td>108</td>
</tr>
<tr>
<td>Andrea Thomas</td>
<td>326</td>
<td>81</td>
<td>6</td>
<td>26</td>
<td>8</td>
<td>234</td>
<td>96</td>
</tr>
<tr>
<td>Andy Thornton</td>
<td>401</td>
<td>92</td>
<td>17</td>
<td>49</td>
<td>65</td>
<td>52</td>
<td>1333</td>
</tr>
<tr>
<td>Alan Trammell</td>
<td>55</td>
<td>159</td>
<td>52</td>
<td>70</td>
<td>10</td>
<td>383</td>
<td>1300</td>
</tr>
<tr>
<td>Alvaro Traverso</td>
<td>183</td>
<td>83</td>
<td>46</td>
<td>51</td>
<td>24</td>
<td>1690</td>
<td>970</td>
</tr>
<tr>
<td>Andy Van Bilk</td>
<td>410</td>
<td>173</td>
<td>73</td>
<td>61</td>
<td>47</td>
<td>412</td>
<td>352</td>
</tr>
<tr>
<td>Alex Wrights</td>
<td>229</td>
<td>42</td>
<td>7</td>
<td>22</td>
<td>13</td>
<td>1941</td>
<td>510</td>
</tr>
<tr>
<td>Bill Alston</td>
<td>196</td>
<td>142</td>
<td>7</td>
<td>32</td>
<td>13</td>
<td>322</td>
<td>826</td>
</tr>
<tr>
<td>Billy Beane</td>
<td>183</td>
<td>39</td>
<td>3</td>
<td>26</td>
<td>3</td>
<td>201</td>
<td>42</td>
</tr>
<tr>
<td>Rudy Bell</td>
<td>568</td>
<td>158</td>
<td>20</td>
<td>69</td>
<td>75</td>
<td>13</td>
<td>1088</td>
</tr>
<tr>
<td>Buddy Bocchi</td>
<td>190</td>
<td>46</td>
<td>5</td>
<td>24</td>
<td>15</td>
<td>279</td>
<td>106</td>
</tr>
<tr>
<td>Bruce Boettie</td>
<td>401</td>
<td>104</td>
<td>6</td>
<td>57</td>
<td>43</td>
<td>623</td>
<td>1478</td>
</tr>
</tbody>
</table>

Ready.
Variable Types

Three main types of variables
- N-Nominal (equal or not equal to other values)
  Example: gender
- O-Ordinal (obeys < relation, ordered set)
  Example: fr, so, jr, sr
- Q-Quantitative (can do math on them)
  Example: age

Alternate Characterization

Two types of data
- Quantitative
  Relationships between values:
    Ranking
    Ratio
    Correlation
- Categorical
  How attributes relate to each other:
    Nominal
    Ordinal
    Interval
    Hierarchical

From S. Few
Metadata

- Descriptive information about the data
  - Might be something as simple as the type of a variable, or could be more complex
  - For times when the table itself just isn’t enough
  - Example: if variable1 is “l”, then variable3 can only be 3, 7 or 16

Data Cleaning

- Data may be missing/corrupted
  - Remove?
  - Modify?
- You may want to adjust values
  - Use inverse
  - Map nominal to ordinal/quantitative
  - Normalize values
    - Scale between 0 and 1
How Many Variables?

- Data sets of dimensions 1, 2, 3 are common
- Number of variables per class
  - 1 - Univariate data
  - 2 - Bivariate data
  - 3 - Trivariate data
  - >3 - Hypervariate data

Representation

- What are two main ways of presenting multivariate data sets?
  - Directly (textually) → Tables
  - Symbolically (pictures) → Graphs

- When use which?
**Strengths?**

- Use tables when
  - The document will be used to look up individual values
  - The document will be used to compare individual values
  - Precise values are required
  - The quantitative info to be communicated involves more than one unit of measure

- Use graphs when
  - The message is contained in the shape of the values
  - The document will be used to reveal relationships among values

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**Effective Table Design**

- See *Show Me the Numbers*
- Proper and effective use of layout, typography, shading, etc. can go a long way
- (Tables may be underused)
Basic Symbolic Displays

- Graphs
- Charts
- Maps
- Diagrams


1. Graph

Showing the relationships between variables’ values in a data table
Properties

- **Graph**
  - Visual display that illustrates one or more relationships among entities
  - Shorthand way to present information
  - Allows a trend, pattern or comparison to be easily comprehended

Issues

- Critical to remain task-centric
  - Why do you need a graph?
  - What questions are being answered?
  - What data is needed to answer those questions?
  - Who is the audience?
Graph Components

- Framework
  - Measurement types, scale
- Content
  - Marks, lines, points
- Labels
  - Title, axes, ticks

Many Examples

www.nationmaster.com
Quick Aside

• Other symbolic displays
  – Chart
  – Map
  – Diagram

2. Chart

• Structure is important, relates entities to each other
• Primarily uses lines, enclosure, position to link entities

Examples: flowchart, family tree, org chart, ...
3. Map

Representation of spatial relations

Locations identified by labels

4. Diagram

- Schematic picture of object or entity
- Parts are symbolic

Examples: figures, steps in a manual, illustrations,...
Some History

- Which is older, map or graph?
- Maps from about 2300 BC
- Graphs from 1600’s
  - Rene Descartes
  - William Playfair, late 1700’s

Details

- What are the constituent pieces of these four symbolic displays?
- What are the building blocks?
Visual Structures

- Composed of
  - Spatial substrate
  - Marks
  - Graphical properties of marks

Space

- Visually dominant
- Often put axes on space to assist
- Use techniques of composition, alignment, folding, recursion, overloading to
  1) increase use of space
  2) do data encodings
Marks

- Things that occur in space
  - Points
  - Lines
  - Areas
  - Volumes

Graphical Properties

- Size, shape, color, orientation...

<table>
<thead>
<tr>
<th>Expressing extent</th>
<th>Spatial properties</th>
<th>Object properties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Position</td>
<td>Grayscale</td>
</tr>
<tr>
<td></td>
<td>Size</td>
<td></td>
</tr>
<tr>
<td>Differentiating marks</td>
<td>Orientation</td>
<td>Color</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shape</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Texture</td>
</tr>
</tbody>
</table>
Back to Data

- What were the different types of data sets?
- Number of variables per class
  - 1 - Univariate data
  - 2 - Bivariate data
  - 3 - Trivariate data
  - >3 - Hypervariate data

Univariate Data

- Representations

Tukey box plot
What Goes Where?

• In univariate representations, we often think of the data case as being shown along one dimension, and the value in another

![Line graph](image1)

Y-axis is quantitative variable

See changes over consecutive values

![Bar graph](image2)

Y-axis is quantitative variable

Compare relative point values

Alternative View

• We may think of graph as representing independent (data case) and dependent (value) variables

• Guideline:
  – Independent vs. dependent variables
    – Put independent on x-axis
    – See resultant dependent variables along y-axis
Bivariate Data

- Representations

Scatter plot is common

price

mileage

Each mark is now a data case

Two variables, want to see relationship

Is there a linear, curved or random pattern?

Trivariate Data

- Representations

3D scatter plot is possible

horsepower

price

mileage

Fall 2011  CS 7450  43
Alternative Representation

Still use 2D but have mark property represent third variable

Alternative Representation

Represent each variable in its own explicit way


**Hypervariate Data**

- Ahhh, the tough one
- Number of well-known visualization techniques exist for data sets of 1-3 dimensions
  - line graphs, bar graphs, scatter plots
  - We see a 3-D world (4-D with time)
- What about data sets with more than 3 variables?
  - Often the interesting, challenging ones

---

**Multiple Views**

Give each variable its own display

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>1</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>3</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>7</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>6</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

---
Scatterplot Matrix

Represent each possible pair of variables in their own 2-D scatterplot

Useful for what?  
Misses what?

More to Come...

• Subsequent day will explore other general techniques for handling hypervariate data
Back to Graphs

• Design guidance
  – Few provides many helpful principles to design effective graphs

Few’s Selection & Design Process

• Determine your message and identify your data
• Determine if a table, or graph, or both is needed to communicate your message
• Determine the best means to encode the values
• Determine where to display each variable
• Determine the best design for the remaining objects
  – Determine the range of the quantitative scale
  – If a legend is required, determine where to place it
  – Determine the best location for the quantitative scale
  – Determine if grid lines are required
  – Determine what descriptive text is needed
• Determine if particular data should be featured and how

S. Few
"Effectively Communicating Numbers"
http://www.perceptuledge.com/articles/Whitepapers/Communicating_Numbers.pdf

Some examples...
**Points, Lines, Bars, Boxes**

- **Points**
  - Useful in scatterplots for 2-values
  - Can replace bars when scale doesn’t start at 0
- **Lines**
  - Connect values in a series
  - Show changes, trends, patterns
  - Not for a set of nominal or ordinal values
- **Bars**
  - Emphasizes individual values
  - Good for comparing individual values
- **Boxes**
  - Shows a distribution of values

**Vertical vs. Horizontal Bars**

- Horizontal can be good if long labels or many items
Multiple Bars

- Can be used to encode another variable

Multiple Graphs

- Can distribute a variable across graphs too

Sometimes called a trellis display
Examples

Before

You want to present quantitative sales performance data for the 4 regions of your company for the four quarters of the year
After?

Before
After?

Before
After?

Before
After?

Book Recommendation

Loaded with examples of how to redesign ineffective tables and graphs
Advice

- Take DB & IR courses
  - Learn about query languages, relational data models, datacubes, data warehouses, ...

Administrativa

- Office hours are posted
HW 1 Discussion

• What findings did you make?
• What was difficult?
• What help did you want?

HW 2

• Table and graph design
• Given two (Excel) data sets, design a table and graph for the data, respectively
• Due next Tuesday
Upcoming

• Visual Perception
  – Reading:
    Stone paper

• Cognitive Issues
  – Reading:
    Norman chapter
    Liu paper

Sources Used

Few book
CMS book
Referenced articles
Marti Hearst SIMS 247 lectures
Kosslyn ‘89 article
A. Marcus, *Graphic Design for Electronic Documents and User Interfaces*
W. Cleveland, *The Elements of Graphing Data*