Principles Of Information Visualization

What is information visualization

Tufte’s guidelines

Visual variables for representing information

The principle of small multiples for displaying information

How metaphors can be used and misused

Direct manipulation and direct engagement

Representations

Good representations
• Captures essential elements of the event/world
• Deliberately leaves out/mutes the irrelevant
• Appropriate for the person and their interpretation
• Appropriate for the task, enhancing judgment ability

How many buffalo?

<table>
<thead>
<tr>
<th># Buffalo</th>
<th># Buffalo</th>
<th># Adults</th>
<th># calves</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>4</td>
</tr>
</tbody>
</table>
**Representation**

A representation is
- A formal system or mapping by which the information can be specified (D. Marr)
- A sign system in that it stands for something other than its self (unknown source)
- A method of encoding information (my description)

For example: the number thirty-four or the buffalo example
- Decimal: 34, (the most familiar number base)
- Binary: 100010, (most closely parallels machine architecture)
- Roman: XXXIV (counting)

**Presentation**

Not the same as representation!

The presentation of information deals with how the representation is placed or organized on the screen

\[5, 5, \text{ IV, } IV\]
This method of representation makes it easier to remember the symbols

Characteristics Of Good Representations

1. The representation makes it easier to find the relevant information.
   - Solving a problem simply means representing it so as to make the solution transparent … (Simon, 1981)

2. (Once the information has been found) good representations makes it easier to make use of the information.
   - Allow people to compute desired conclusions
   - Trying to make use of the information may be a difficult process or “for free” depending on the representation chosen
Representations: The Information Is Present But Hard To Find

Representations: The Information Is Present But Making Sense Of It Requires Much Effort
**Example One: Which Is The Best Flight?**

Length, stop-overs, switches...

<table>
<thead>
<tr>
<th>Flight</th>
<th>Depart</th>
<th>Arrive</th>
<th>Depart Time</th>
<th>Arrive Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC 117</td>
<td>Vancouver - Calgary</td>
<td>7:00</td>
<td>9:00</td>
<td></td>
</tr>
<tr>
<td>Cdn 321</td>
<td>Vancouver - Calgary</td>
<td>9:00</td>
<td>12:00</td>
<td></td>
</tr>
<tr>
<td>Cdn 355</td>
<td>Calgary - Montreal</td>
<td>13:30</td>
<td>19:30</td>
<td></td>
</tr>
<tr>
<td>AC 123</td>
<td>Calgary - Toronto</td>
<td>12:30</td>
<td>16:30</td>
<td></td>
</tr>
<tr>
<td>AC 123</td>
<td>Toronto - Montreal</td>
<td>16:45</td>
<td>17:30</td>
<td></td>
</tr>
</tbody>
</table>

*Time zone: +1 van-cal, +2 cal-tor, mtl

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**Example Two: When Do I Take My Drugs? (From “Things That Make Us Smart” By Don Norman)**

*Note: 10 - 30% error rate in taking pills, same for pillbox organizers*

- Inderal - 1 tablet 3 times a day
- Lanoxin - 1 tablet every a.m.
- Carafate - 1 tablet before meals and at bedtime
- Zantac - 1 tablet every 12 hours (twice a day)
- Quinag - 1 tablet 4 times a day
- Couma - 1 tablet a day

<table>
<thead>
<tr>
<th></th>
<th>Breakfast</th>
<th>Lunch</th>
<th>Dinner</th>
<th>Bedtime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lanoxin</td>
<td>O</td>
<td>O</td>
<td>O</td>
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<tr>
<td>Inderal</td>
<td>O</td>
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<tr>
<td>Quinag</td>
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<td>O</td>
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<td>O</td>
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<td>Zantac</td>
<td>O</td>
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<td></td>
<td></td>
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<tr>
<td>Couma</td>
<td>O</td>
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</table>

*Organized by both time of day and by drug*
Example Three: Napoleon's March To Moscow

by Charles Minard

CARTE FIGURATIVE des pertes successives en hommes de l'Armée Française dans la campagne de Russie 1812-1813.
Gravée par M. Minard, ingénieur Général des Ponts et Chaussées en retirée.
Example Four: Anscombe’s Quartet

Example Five: Do I Deserve A Tax Break
Not All Diagrammatic Representations Are Equally Effective

First representation

A

B

C

D

Second representation

A

B

C

D

From Information Visualization: Perception for Design by Colin Ware.

Tufte's Principles Of Information Visualization

Graphics should reveal the data
• Show the data
• Not get in the way of the message
• Avoid distortion
• Present many numbers in a small space
• Make large data sets coherent
• Encourage comparison between data
• Supply both a broad overview and fine detail
• Serve a clear purpose

1 “Visual Display of Quantitative Information” by E. Tufte
Note: Some of the visual examples on the following slides are taken from Tufte’s books
Show The Data

# Buffalo

# Buffalo

# Adults  # calves

Not Get In The Way Of The Message

Principles of Information Visualization
Chart Junk: A Common Error (The Representation Getting In The Way Of The Message)

Information display is not just pretty graphics

• Graphical re-design by amateurs on computers gives us
  - Overly complicated or even deceptive representations

The Representation Should Not Get In The Way Of The Message

But it’s not just as simple as removing “irrelevant” information.

Extra clutter?

Is the message clearer?

From "Information Visualization: Perception for Design" by Colin Ware
Avoid Distortion: The Representation Alters The Message

Present Many Numbers In A Small Space, Make Large Data Sets Coherent

New York Weather History
• 181 numbers/sq inch
Encourage Comparison Between The Data

1) "Seesoft—A Tool for Visualizing Line Oriented Software Statistics", Eick S.G., Steffen J.L. and Sumner E.E

Broad Overview And Fine Detail
Applying Visual Representations To A Common Task: Browsing A Large Dataset

Example: Browsing for a house

A Model Of Perceptual Processing

• The set of information is large to show all at once.

• Example search results:

• To help assist the person in this type of situation, take advantage of how people process visual information.

1 From "Information Visualization: Perception for Design" by Colin Ware
Stage 1: Parallel Processing To Extract Low Level Properties Of The Visual Scene

Different properties of diagram are processed by the neurons in the retinal.

This processing automatically occurs.

The processing is done in parallel.

A Diagram
Characteristics of visual information that can be automatically processed:
1. Processing cannot be inhibited
2. Information is rapidly processed
3. Information can be processed in parallel
4. Can be understood without training

Communicate information by relying on perceptual powers of the brain without learning.

Examples:
- Color
- Size
- Many more to come...

Stage 1: Parallel Processing To Extract Low Level Properties Of The Visual Scene (3)

Applying Stage 1 Processing To The Problem Of Browsing A Large Dataset

Representing information in a manner that can be automatically processed can help the person browse a large data set.

85689726984689762689764358922659865986554897689269898
85689726984689762689764358922659865986554897689269898
02462996874026557627986789045679232769285460986772098
90834579802790759047982790857908477290875498709856749068975786259845690243790472190790709811450
856897269846897626897644458922659865986554897689269898

Vs.

85689726984689762689764358922659865986554897689269898
85689726984689762689764358922659865986554897689269898
02462996874026557627986789045679232769285460986772098
90834579802790759047982790857908477290875498709856749068975786259845690243790472190790709811450
856897269846897626897644458922659865986554897689269898

James Tam
Stage 2: Sequential Goal-Directed Processing

The focus now shifts from gathering perceptual information about large quantities of information to getting details about a single object.

At this stage information can be represented in a fashion that requires controlled processing (not automatic).

Characteristics of representations that require controlled processing:
1. Requires conscious effort
2. Slow serial processing
3. Hard to learn
4. Easy to forget
5. Formally powerful

Example of a representation that require controlled processing:
• Written language

Automatic Vs. Controlled Processing Of Information

Controlled
For this question you are to write a function that will take as input a string and return an integer value that is the length of the string. The end of the string will always...
Principles of Information Visualization

Visual Variables

- Position
  - Changes in the x, y, z location

- Size
  - Changes in length, area or repetition

- Shape
  - Changes in form

- Value
  - Changes in brightness

- Orientation
  - Changes in alignment

- Colour
  - Changes in hue

Visual Variables (2)

- Texture
  - Variations in pattern

- Motion

www.st-duffer.com
Visual Variables (3)

Characteristics of visual variables

- **Selective**
  Is a change in this variable enough to allow us to select it *from a group*?

- **Associative**
  Is a change in this variable enough to allow us to perceive them *as a group*?

- **Quantitative**
  Is there a numerical reading obtainable from changes in this variable?

- **Order**
  Do changes in the visual variable indicate some sort of ranking?

- **Length\(^1\)**
  Across how many changes in this variable are distinctly perceptible?

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Visual Variable: Position

- **Selective**
  ![Selective Visualization](image1)

- **Associative**
  ![Associative Visualization](image2)

- **Quantitative**
  ![Quantitative Visualization](image3)

- **Order**
  ![Order Visualization](image4)

- **Length\(^1\)**
  ![Length Visualization](image5)

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\(^1\) Think of it as variation
Principles of Information Visualization

Visual Variable: Size

- **Selective**
  - ![Selective](image)

- **Associative**
  - ![Associative](image)

- **Quantitative**
  - $4 \times \square = \square \square$
  - $\sim 2 \times \square = \square$
  - $? \times \square = \square$

- **Order**
  - ![Order](image)

- **Length**
  - Theoretically infinite but practically limited

Visual Variable: Shape

- **Selective**
  - ![Selective](image)

- **Associative**
  - ![Associative](image)

- **Quantitative**
  - ![Quantitative](image)

- **Order**
  - ![Order](image)

- **Length**
  - ![Length](image)
Visual Variable: Value

- **Selective**
- **Associative**
- **Quantitative**
- **Order**
- **Length**
  - Theoretically infinite but practically limited
  - Association ~ < 7 and selection ~ 10
Visual Variable: Color

- **Selective**

- **Associative**

- **Quantitative**

- **Order**

- **Length**
  - Theoretically infinite but practically limited
  - Association ~ < 7 and selection ~ 20

---

Color

- Theoretically infinite but practically limited
- Association ~ < 7 and selection ~ 20
Color Encoding

Common advice says use a rainbow scale

- Marcus, Murch, Healey
- There are problems with rainbows
Additional Issues Associated With Color

Color blindness:
• The majority of people who are color blind are red-green color blind so these colors should be avoided when communicating information.

Field size
• The larger the area to be color coded, the more easily that colors can be distinguished.
• When objects are small and color is used to distinguish the colors use highly saturated colors.
Additional Issues Associated With Color (2)

Field Size (continued)
• When large color coded regions are used (e.g., maps) use colors with low saturation (reduces interference with detailed information e.g., text)

Conventions
• “Commonly accepted” conventions can vary widely by culture and their use should be carefully considered e.g., white is associated with purity in some Western cultures and death with some Eastern cultures.

Visual Variable: Orientation

✔ Selective

✔ Associative

≠ Quantitative

≠ Order

✔ Length

~5 in 2D

? in 3D
Visual Variable: Texture

- **Selective**
- **Associative**
- **Quantitative**
- **Order**

- **Length**
  - Theoretically infinite

Visual Variable: Motion

- **Selective** - motion is one of our most powerful attention grabbers
- **Associative** – objects moving in unison groups them effectively
- **Quantitative** - subjective perception
- **Order**

? Length - distinguishable types of motion?
Motion

Small Multiples: General Principles

Learn once

Invite comparisons
Small Multiples: Showing Time And Change

Small Multiples: Showing Time And Change
Object Display Employing A Single Contoured Object

It’s theorized that mapping many data variables onto a single object will guarantee that these variables are processed together in parallel.¹

¹ From Engineering Psychology and Human Performance (2nd Edition) by Wickens C.D.

Metaphors

Definition of a Metaphor

• One kind of object or idea is used in place of another to suggest a likeness or analogy between them
• Application of name or descriptive term to an object to which it is not literally applicable
**Interface Metaphors**

**Purpose**
- Function as natural models
- Leverages our knowledge of familiar, concrete objects/experiences to understand abstract computer and task concepts

**Problem**
- Metaphor may portray inaccurate or naive conceptual model of the system

A presentation tool is like a slide projector

**Pervade excellent interfaces**

Control Panels with familiar controls

Forms

Hierarchical Folders
A Real Life Metaphor: Life!

The Sims House Party © Maxis

Creating Interface Metaphors

Generating metaphors

• Use metaphors that matches user's conceptual task
  — Desktop metaphor for office workers
  — Paintbrush metaphor for artists...
• Given a choice, choose the metaphor close to the way the system works
• Ensure emotional tone is appropriate to users
  - e.g., file deletion metaphors
    Trashcan
    Black hole
    Paper shredder
    Pit bull terrier
    Nuclear disposal unit...
**Evaluating Metaphors**

**Potential problems:**
- The metaphor has attributes that the system does not have.
- The system has attributes that are not suggested by the metaphor.
- An attribute exists both in the metaphor and in the system but works differently in each.

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**The Metaphor Is More Powerful Than The System**

Will the metaphor make people believe that the system can do more than it currently can?
The System Is More Powerful Than The Metaphor Implies

Will the metaphor restrict how people will try to use the system?
• e.g., file folders

An Attribute Differs Between The Metaphor And The System

e.g., The trash can

Real trashcan  Desk top trashcan
Metaphors Should Not Be Static

Evolve metaphors
- Is metaphor extensible to new features?
- When is the metaphor no longer useful?

Metaphors Should Not Be Static (2)

Evolve metaphors
- Is metaphor extensible to new features?
- When is the metaphor no longer useful?
Misuse Of Metaphors

Caveat
• Metaphors can be overdone!

Common pitfalls
• Overly literal
  - Unnecessary fidelity
  - Excessive interactions
• Overly cute
  - Novelty quickly wears off
• Overly restrictive
  - Capabilities suggested by the metaphor
don’t match the actual capabilities
• Mismatched
  - Does not match user’s task and/or thinking

Milltronics’ Dolphin Plus a configuration package for industrial level and flow sensors
A Example System That Applies A Metaphor: The Data Mountain
Manipulating Real World Objects

Example steering a car:

- Direct mapping between the driver's actions and how the car reacts.
- Objects of interest are visible
  - Steering wheel
  - The world outside of the car

Imagine: Operating A Car In A Indirect Fashion

- Select: steering wheel, rotate left -30d
Direct Manipulation

- An interface that behaves as though the interaction was with a real-world object rather than with an abstract system
- Almost always based on a metaphor
  - Mapped onto some facet of the real world task semantics

Characteristics Of Direct Manipulation

- Objects of interest are visible
- When it is logical: visible objects can be manipulated
- Manipulation occurs by pointing and moving
Indirect Interaction: Traditional Approach To Writing Java GUI’s

Indirect Interaction: Changing The Java Code
Another Example Of Indirect Interaction

Edit bookmarks: delete?

Delete requires a different view

Netscape 7.2

Direct Manipulation

The representation directly affects what can be directly manipulated

Schedule © Microsoft
Is Direct Manipulation The Way To Go?

Some Disadvantages

- Ill-suited for abstract operations or for vision impaired users
  - Spell-checker?
- Tedium
  - Manually search large database vs. query
- Metaphor may be misleading:
  - Overly restrictive may limit usage or overly powerful may imply functions that aren’t available
- Direct manipulation systems require more screen space

Solution

- Most systems combine direct manipulation and abstractions
  - Word processor:
    - WYSIWYG document (direct manipulation)
    - Buttons, menus, dialog boxes (abstractions, but direct manipulation “in the small”)

Conventional Applications: A Mix
Direct Engagement

The feeling of working directly on the task (as opposed to using a particular tool).
To employ it, you need to consider the user of the system and the tasks that he or she engages in.
Often direct manipulation is an important requirement for direct engagement.
  • e.g., A drawing program provides tools that are familiar to artists (brushes, palettes etc.)

Direct Engagement: A Telephone Database

<table>
<thead>
<tr>
<th>Find “Green”</th>
<th>Command system</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;S. Greenberg</td>
<td>no direct manipulation</td>
</tr>
<tr>
<td>&gt;Dept Computer Science</td>
<td></td>
</tr>
<tr>
<td>&gt;University of Calgary</td>
<td></td>
</tr>
</tbody>
</table>

Search for: Green
Result: S. Greenberg
Dept Computer Science
University of Calgary

Form metaphor: syntactic direct manipulation

Rolodex metaphor: full direct manipulation
**Action-Object**

The traditional approach for writing software.

Focus on verbs, actions or functions that the software is capable of.

Often requires learning a complex and arbitrary syntax that varies greatly from system to system and platform to platform:

- e.g., Deleting text: <Ctrl>-<h>, <ctrl-g>, <ctrl-d>, <delete>, <backspace> etc.

**Object-Action**

- Focus on nouns, objects which already have meaning in the task domain of the user.

- Select an object which then has a set of allowable actions.

- Because the user is already familiar with these objects, previous knowledge can help leverage when learning the new systems:
  - e.g., Trash cans for deletion, folders for storing information, inbox for reading new messages, outbox for sending messages

- It requires that the objects of interest have a visual representation (compatible with Direct Manipulation)
Advantages Of The Object-Action Approach

• The syntax is already familiar so the time spent learning the capabilities of the system is reduced.

• The new syntax that the user is required to learn is fairly limited e.g., there are only so many ways that a button can be used.

• Error messages are rarely needed. Actions that are inappropriate, given the current state of system, can be excluded:

What You Now Know

Good Representations
• Captures essential elements of the event / world
• Deliberately leaves out / mutes the irrelevant
• Appropriate for the person, their task, and their interpretation

Information Visualization
• Tufte’s principles
• Exploits our knowledge of visual variables
• Many techniques now available (illustrated with research and commercial systems)
**What You Now Know (2)**

**Metaphors**
- Uses our knowledge of the familiar and concrete to represent abstract concepts
- Need not be literal
- Has limitations that must be understood

**Direct manipulation**
- Visibility of the objects of interest
- Manipulation by pointing and moving

*These four components are the foundation of a true Visual Interface*

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**Interface Design And Usability Engineering**

*This diagram is a variation of the one presented by Saul Greenberg*