Visualization Analysis & Design Full-Day Tutorial

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Why use an external representation?

Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively.

- external representation: replace cognition with perception
- human visual system is high-bandwidth channel to brain
- overview possible due to background processing
- subjective experiences of seeing everything simultaneously
- significant processing occurs in parallel and pre-attentively
- sound lower bandwidth and different semantics
- overview not supported
- subjective experiences of sequential stream
- touch/haptic impoverished record/replay capacity
- only very low-bandwidth communication thus far
- taste, smell, no viable record/replay devices

Why represent all the data?

Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively.

- summaries lose information, details matter
- confirm expected and find unexpected patterns
- assess validity of statistical model
- Annesmo’s Quartet

Why is validation difficult?

Why depend on vision?

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Why focus on tasks and effectiveness?

Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively.

- effectiveness requires match between data/task and representation
- set of representations is huge
- many are ineffective mismatches for specific data/task combo
- faster speed up existing workflows
- how to validate effectiveness:
  - many methods, must pick appropriate one for your context

Why is validation difficult?

- solution: use methods from different fields at each level
- problem-driven work
- anthropological
- design
- computer science
- cognitive psychology
- anthropological

Further reading

- http://www.cs.ubc.ca/~tmm/talks.html#vad17fullday @tamaramunzner

Outline

- Session 1 8:30–10:10am
  - Visualization Analysis Framework
    - Introduction: Definitions
    - Analysis: What, Why, How
    - Marks and Channels
  - Arrage Tables
  - Arrange Spatial Data
  - Arrange Networks and Trees
- Session 2 10:30am–12:10pm
  - Spatial Layout
  - Guidelines & Methods
    - Reduce-Flex Aggregates
    - Rules of Thumb
  - Design Study Methodology
- Session 4 4:15–5:55pm
  - Map Color
  - Context with Guaranteed Visibility
  - Node Link Tree, Design Evolution and Empirical Evaluation.
  - Grosjean, Plaisant, and Bederson.
- http://www.cs.ubc.ca/~tmm/talks.html#vad17fullday @tamaramunzner

Why?

- dataset
- what
- attributes
- dataset types
- data types
- data and dataset types

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Vis designers must take into account three very different kinds of resource limitations:

- computational limits
  - processing time
  - system memory
- human limits
  - human attention and memory
- display limits
  - pixels are precious resource, the most constrained resource
  - information density: ratio of space used to encode info vs unused white space
  - tradeoff between clutter and wasting space, find sweet spot between dense and sparse

Why is validation difficult?

- different ways to get it wrong at each level

Why?

- domain situation
  - you misunderstand their needs
  - you’re showing them the wrong thing
- data/task abstraction
  - algorithm
    - how is it shown?
    - visual encoding idiom how to draw
    - interaction idiom how to manipulate
  - efficient computation

Computational limits: Four levels of visual design

- domain situation
  - who are the target users?
- abstraction
  - translate from specific domain to vocabulary of vis
  - what is shown? data abstraction
  - why is the user looking at it? task abstraction
  - idiom
  - how is it shown?
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Visualization to validate when there is a need to augment human capabilities rather than replace people with computational decision-making methods.

- human in the loop needs the details & no trusted automatic solution exists
- doesn’t know exactly what questions to ask in advance
- exploratory data analysis
- present known results to others
- during algorithm creation to refine, debug, set parameters
- before or during deployment to build trust and monitor

Why is validation difficult?

- solution: use methods from different fields at each level
- problem-driven work
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- design
- computer science
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- anthropological
Three major datatypes

1. Attribute
2. Table
3. Network

Dataset Types

- Tables
- Networks
- Fields
- Attributes
- Links
- Positions
- Grids

Attributes (columns)
- Item(s)
- Fields (continuous)
- Geometric primitives
- Geometry
- Categorical
- Sequential
- Dynamic

Items (nodes)
- Links
- Positions
- Grids

Three major datatypes

1. Attribute
2. Table
3. Network

Dataset Availability

- Static
- Dynamic

Data Types

- Items
- Attributes
- Links
- Positions
- Grids

Dataset and data types

- Attributes
- Values in cell
- Grid of positions
- Network

Why?

- Targets
- Analysis: Analyze
- Analysis: Search, query

Further reading


Visual encoding

- Marks
- Channels

Visual encoding

- Analyze: Analyze
- Analyze: Search, query

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  - Spatial Layout
  - Arranges Tables
  - Arranges Networks and Trees

- Session 3: 2:00-2:45pm
  - Color and Intensity
  - Map Color

- Session 4: 4:15-5:15pm
  - Guidelines & Methods
  - Design Study Methodology

http://www.dcs.gla.ac.uk/~wright/Field/725851
**Channels: Matching Types**

- **Magnitude Channels:** Ordinal Attributes
  - Position on common scale
  - Perceived magnitude
  - Length (1D size)
  - Area (2D position)
  - Depth (3D position)
  - Tilt (angle)
  - Orientation
  - Volume (3D shape)

- **Identity Channels:** Categorical Attributes
  - Color hue
  - Color saturation
  - Motion
  - Shape
  - Angle

**Channels: Expressiveness types and effectiveness rankings**

- **expressiveness principle**
  - match channel and data characteristics
  - encode most important attributes with highest ranked channels

**Accuracy: Fundamental Theory**

- **Stevens' Psychological Power Law**: $E = kI^n$

**Popout**

- find the red dot
  - how long does it take?

- parallel processing on many individual channels
  - speed independent of distractor count
  - speed depends on channel and amount of difference from distractors
  - serial search for (almost all) combinations
  - speed depends on number of distractors

**Relative vs. absolute judgements**

- perceptual system mostly operates with relative judgements, not absolute
  - that's why accuracy increases with common frame/scale and alignment

- Weber's Law: ratio of increment to background is constant
  - filed rectangles differ in length by 1:2, easy judgement

**Further reading**

- **Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, 2014.**
  - Chap. 1: Marks and Overview
  - Visual Thinking for Design. Ware, Morgan Kaufmann, 2008.

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  - Color & Interaction
    - Color
    - Manipulate: Change, Select, Navigate
    - Palettes: Juxtapose, Pattern, Superimpose

- Session 4: 4:15-5:35pm
  - Guidelines & Methods
    - Reduce: Filter, Aggregate
    - Rules of Thumb
    - Design Study Methodology

**Further reading 2014.** Healey. http://www.csc.ncsu.edu/faculty/healey/PP

**Popout**

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**Accuracy: Visual experiments**

- must be sufficient for number of attribute levels to show
  - 2 groups each

**Separability vs. Integrality**

- fully separable
- some interference
- some/much interference
- major interference

- 2 groups each
- 3 groups total: integral area
- 4 groups total: integral area

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Idiom: **scatterplot**
- express values
  - quantitative attributes
  - no keys, only values
- data
  - 2 quant attribs
    - mark points
      - hand or vert position
    - task
      - trend, outliers, distribution, correlation, clusters
- scalability
  - hundreds of items

**LIMITATION:** Hard to make comparisons

[Slide courtesy of Ben Jones]

**Idiom: line chart / dot plot**
- one key, one value
- data
  - 2 quant attribs
    - mark points
      - line connection marks between them
- channel
  - aligned lengths to express quant value
  - separated and ordered by key attrib into horizontal regions
- task
  - Line trend
    - connection marks emphasize ordering of items along key axis by explicitly drawing relationship between one item and the next
- scalability
  - dozens to hundreds of levels for key attrib

**LIMITATION:** Hard to make comparisons

[Slide courtesy of Ben Jones]

**Idiom: stacked bar chart**
- one more key
- data
  - 2 quant attribs
    - mark: vertical stack of line marks
  - channel
    - length and color hue
    - spatial regions: one per giph
    - aligned horizontally, aligned vertically
    - ordered by quant attrib
    - by text (alphabetical) by length attrib (data-driven)
- task
  - compare, lookup values
- scalability
  - dozens to hundreds of levels for key attrib

**LIMITATION:** Hard to make comparisons

[Slide courtesy of Ben Jones]

**Idiom: bar chart**
- one key, one value
- data
  - 1 cat. giph, 1 quant giph
    - mark: bars
- channel
  - length to express quant value
  - spatial regions: one per mark
    - separated and ordered by quant attrib
    - hand or vert position
- task
  - compare, lookup values
- scalability
  - dozens to hundreds of levels for key attrib

**LIMITATION:** Hard to make comparisons

[Slide courtesy of Ben Jones]
**Idioms: Gantt charts**
- one key, two (related) values
  - data
  - 1 csgn str, 2-qant str, 3-mark, line
  - length, duration
  - channels
  - horiz position: start/ends time
  - horiz length: duration
  - task
    - emphasize temporal overlaps, start/ends dependencies between tasks
    - scalability
    - dozens of key levels
    - hundreds of value levels

**Idioms: heatmaps**
- two keys, one value
  - data
  - 2 csgn str, (gene, experimntal condition)
  - 1 qant str, (expression levels)
  - matrix, area
    - zoom-in and out in 3D matrix
      - influenced by 2caretorial attributes
    - channels
      - color by qant str
        - (categorical: hexagonal coloring)
      - find clusters, outliers
      - scalability
    - 19k rows, 100 g key levels, 10 qant str levels

**Idioms: scatterplot matrix, parallel coordinates**
- scatterplot matrix (SPLOM)
  - rectilinear axes, point mark
  - all possible pairs of axes
  - scalability
  - one dozen axes
  - dozens to hundreds of terms
  - parallel coordinates
    - parallel axes, jagged line representing item
    - rectilinear axes, item as point
    - axes ordering is major challenge
    - scalability
    - dozens of axes
    - hundreds of terms

**Task: Correlation**
- scatterplot matrix
  - positive correlation
  - diagonal low-to-high
  - negative correlation
  - diagonal high-to-low
  - uncorrelated
  - parallel coordinates
  - positive correlation
  - parallel line segments
  - negative correlation
  - all segments cross at target point
  - uncorrelated
  - scattered crossings

**Idioms: radial bar chart, star plot**
- radial bar chart
  - red-segments meet at central ring, line mark
  - star plot
    - radial axes, meet at central point, line mark
  - bar chart
    - rectilinear axes, aligned vertically
  - accuracy
    - length unaligned with radial
    - less accuracy than aligned with rectilinear

**Idioms: pie chart, polar area chart**
- pie chart
  - area marks with angle channel
  - accuracy: angle/area less accurate than line length
  - area chart
    - area marks with angle channel
    - more direct analog to bar charts
  - task
    - 1 csgn key str, 1 qant value attr

**Idioms: glyphsmaps**
- rectilinear good for linear vs nonlinear trends
- radial good for cyclic patterns

**Orientation limitations**
- rectilinear: scalability wrt #axes
  - 2 axes best
  - 3: problematic
  - more in afterward
  - 4: impossible
- parallel: unfamiliarity, training time
- radial: perceptual limits
  - angles lower precision than lengths
  - asymmetry between angle and length

- ..can be exploited!
  - (uncovering strengths and weaknesses of radial visualization in empirical settings)
  - (Wegman 1990, 664–675)
  - ..can be exploited!
  - (uncovering strengths and weaknesses of radial visualization in empirical settings)
  - (Shneiderman 2010, 3–28)

**Further reading**

**Idioms: choropleth map**
- use given spatial data
  - when central task is understanding spatial relationships
- data
  - geographic
    - map with 1 qant attribute per region
  - encoding
    - use given geometry for area mark boundaries
    - segmented colordom map (more later)
    - geographic heat map

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  - Spatial Layout
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    - Arrange Spatial Data
    - Arrange Heatmaps and Trees
- Session 3: 2:00–3:45pm
  - Color & Interaction
    - Map Color
    - Manipulation: Change, Select, Navigate
    - Focus/Juxtapose, Portion, Superimpose
- Session 4: 4:15–5:55pm
  - Guidelines & Methods
    - Reduce clutter, Aggregates
    - Focus on Thubur
    - Design Study Methodology

**Arrange spatial data**
- Use Given
  - Geometry
  - Geographic
  - Spatial Fields
    - Scalar fields (one value per cell)
    - Vector fields
      - Direct field rendering
      - Vector and Surface Fields (grey values per cell)
    - Flow (edge-based)
    - Geographic (space seeds)
    - Temporal (change over time)
    - Features (globally derived)
  - Encoding
    - use given geometry for area mark boundaries
    - segmented color dom map (more later)
    - geographic heat map
Idiom: Bayesian surprise maps
- use models of expectations to highlight surprising values
- confounds (population and variance (sparsity)

Idioms: topographic map
- data
  - geographic geometry
  - scalar field
  - 1 attribute per grid cell
- derived data
  - isosurface
  - isosurfaces computed for specific levels of scalar values

Idioms: isosurfaces, direct volume rendering
- data
  - scalar field
  - 1 attribute per grid cell
- tasks
  - shape understanding, spatial relationships
- isosurfaces
  - derived data: isosurfaces computed for specific levels of scalar values
  - direct volume rendering: transfer function maps scalar values to color, opacity

Idiom: node-link best for small networks
- sparse set of seed points
- emphasizes topology, path tracing

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- Session 1 8:30-10:10am
  - Visualization Analysis Framework
    - Introduction: Definitions
    - Analysis: What, Why, How
    - Marks and Channels
  - Spatial Layout
    - Diagrams
    - Arrangement
  - Assign
- Session 2 10:30-12:10pm
  - Guiltredude & Methods
  - Reduce: Filter Aggregates
  - Rules of Thumb
  - Design Study Methodology

Further reading
- A Quick-Start Spatial Data
Further reading

Outline
- Introduction: Definitions
- Session 1: 8:30-10 (keynote)
- Visualization Analysis Framework
  - Analysis: What, Why, How
  - Maps and Channels

- Session 2: 10:00am-12pm
  - Spatial Layout
  - Arranging Tables
  - Arranging Spatial Dots
  - Arranging Networks and Trees
- Session 3: 3:00pm-5:00pm
  - Guidelines and Methods
  - Reducing Time Aggregation
  - Rules of Thumb
  - Design Study Methodology

Spectral sensitivity

Opponent color and color deficiency
- perceptual processing before optic nerve
- one chromatic luminance channel L
- one achromatic luminance channel M
- colorblind if one axis has degraded acuity
- 8% of men are red/green color deficient
- blue/yellow is rare

Designing for color deficiency: Check with simulator
- redundant encode
- vary luminance
- change shape

Designing for color deficiency: Avoid encoding by hue alone
- color constancy: simultaneous contrast effect

Color/Lightness constancy: Illumination conditions
- Reduces color to 2 dimensions
- Luminance values
- Hue

Decomposing color
- first rule of color: do not talk about color!
- color is confusing if treated as monolithic
- decompose into three channels
- ordered can show magnitude
- categorical can show identity
- channels have different properties

Luminance
- need luminance for edge detection
- fine-grained detail only visible through luminance contrast
- legible text requires luminance contrast!
- intrinsic perceptual ordering

Spectral sensitivity
- IRUV
- Visible Spectrum

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Designing for color deficiency: Reduces color to 2 dimensions
- Bezold Effect: Outlines matter
- color constancy: simultaneous contrast effect

Color/Lightness constancy: Illumination conditions
- Image courtesy of John McCain

Idiom design choices: Encode
- Map
- Color
- Motion
- Size, Angle, Curvature, ...
- Hue
- Saturation
- Luminance
- Shape
- Direction, Rate, Frequency, ...
- from categorical and ordered attributes
- Color
- Saturation
- Luminance values
- Hue

Categorical vs ordered color
- Categorical and ordered attributes

Tree drawing idioms comparison
- Idiom design choices: Encode
- Color deficiency:
  - Categorical vs ordered color
  - Color/Lightness constancy: Illumination conditions
  - Bezold Effect: Outlines matter
  - color constancy: simultaneous contrast effect

Further reading
- Color deficiency: Reduces color to 2 dimensions
- Further reading
- Color/Lightness constancy: Illumination conditions
- Image courtesy of John McCain

Opponent color and color deficiency
- perceptual processing before optic nerve
- one chromatic luminance channel L
- one achromatic luminance channel M
- two chroma channels, R - G and Y - B axis
- colorblind if one axis has degraded acuity
- 8% of men are red/green color deficient
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Color/Lightness constancy: Illumination conditions
- Image courtesy of John McCain

Designing for color deficiency: Blue-Orange is safe
- Image courtesy of John McCain

Designing for color deficiency: Check with simulator
- redundant encode
- vary luminance
- change shape

Designing for color deficiency: Avoid encoding by hue alone
- color constancy: simultaneous contrast effect

Color/Lightness constancy: Illumination conditions
- Image courtesy of John McCain
**Binary Diverging Categorical Sequential Categorical**

- Human perception built on relative comparisons
  - Great for color contiguous
  - Surprisingly bad for absolute comparisons
- Noncontiguous small regions of color
  - Fewer bins than you want
  - Rule of thumb: 6-12 bins, excluding background and highlights
  - Alternatives: this afternoon!

**Ordered color: Binary**
- Problems
  - Perceptually unordered
  - Perceptually non-linear
- Benefits
  - Fine-grained structure visible and removable
- Alternatives
  - Large-scale structure fewer hues

**Rainbow Colormaps**
- Problems
  - Perceptually unordered
  - Perceptually non-linear
- Benefits
  - Fine-grained structure visible and removable
- Alternatives
  - Large-scale structure fewer hues

**Clotho and Eris:**
- Human perception built on relative comparisons
  - Great for color contiguous
  - Surprisingly bad for absolute comparisons
- Noncontiguous small regions of color
  - Fewer bins than you want
  - Rule of thumb: 6-12 bins, excluding background and highlights
- Alternatives: this afternoon!

**ColorBrewer**
- [http://www.colorbrewer2.org](http://www.colorbrewer2.org)

**Visualization Analysis Framework**
- Color channel interactions
  - Size heavily affects salience
  - Small regions need high saturation
  - Large need low saturation
  - Intensities & luminance: 3-4 bars max
  - Also not separable from transparency

**Further reading**
- Visualization Analysis and Design, Munzner. AK Peters Visualization Series, CRC Press, 2014
- [Chap 1.8 Map Color and Other Channels](http://www.colorbrewer2.org)
- ColorBrewer: Brewer.
- [http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html](http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html)

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  - Introduction Definitions
  - Analysis: Why, Why Now
    - Marks and Channels
  - Spatial Layout
    - Arrange Table
    - Arrange Spatial Dots
    - Arrange Networks and Trees

- Session 3: 2:00-3:40pm Color & Interaction
  - Map Color
    - Manipulation: Change, Select, Navigate
    - Focus, Juxtapose, Compare, Superimpose
  - Session 4: 4:15-5:15pm Guidelines & Methods
    - Reduce, Filter, Aggregates
    - Rules of Thumb
    - Design Study Methodology

**Map other channels**
- Size, Angle, Curvature, ...
- Length
- Angle
- Nonlinear accuracy
- Horizontal, vertical, exact diagonal
- Shape
  - Complex combination of lower-level primitives
    - Many bars
    - Motion
    - Highly separable against static; binary gray for highlighting
    - Use with care to avoid irritation
Idiom: Animated transitions
- smooth interpolation from one state to another
  - easy to compare
  - best case for animation
  - staging to reduce cognitive load
- example: animated transitions in statistical data graphics

Outline
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  - Session 2 10:20-11:30am
    Visualization Analysis Framework
      - Introduction Definitions
      - Analysis: What, Why, How
      - Marks and Channels
  - Session 3 2:00-3:10pm
    Spatial Properties
      - Arrange Tables
      - Arrange Spatial Data
      - Arrange Networks and Trans

Further Reading
Coordinate views: Design choice interaction

- Why not animation?
  - disparate frames and regions: comparison difficult
  - vs contiguous frames
  - vs coherent motion of group
  - safe special case: unanimated transitions

Partitioning: List alignment
- single bar chart with grouped bars
- split by state into regions
- all-scanned histogram builders update when any ranges change
- encoding different
- data all shared

Partitioning: Recursive subdivision
- split by neighborhood
- then by type
- then time
- years as rows
- months as columns
- color by price
- neighborhood patterns
- where it’s expansive
- where you pay much more for detached type

Superimposing limits
- few layers, but many lines
- up to a few dozen
- but not hundreds
- superimpose vs juxtapose: empirical study
- superimpose for local, multiple for global
- small max, global scope, discrimination
- same space for all multiples vs single superimposed
**No unjustified 3D: Power of the plane**
- High-ranked spatial position channels planar spatial position — not depth!
- We don’t really live in 3D; we see in 2.05D
  - Acquire more info on image plane quickly from eye movements
  - Acquire more info for depth slower, from head/body motion

**Occlusion hides information**
- Occlusion
- Interaction can resolve, but at cost of time and cognitive load

**Perspective distortion loses information**
- Perspective distortion
  - Interferes with all size channel encodings
  - Power of the plane is lost!

**Unjustified 3D all too common, in the news and elsewhere**
- Extruded curves: detailed comparisons impossible
- Perspective distortion dangers
- Occlusion: Hidden information
- Resolution over immersion
- Justified 3D: 3D legitimate for true 3D spatial data
  - Power of the plane
  - Disparity of depth
  - Occlusion hides information
  - Perspective distortion dangers
- Tiled text isn’t legible
  - Spatial layout
  - Text legibility
- For worse when tiled from image plane
- Tilt angle
- Further reading

**Justified 3D: Economic growth curve**
- Constrained navigation stroke through carefully designed viewpoints
- Figure first, form next
- Function first, form next

**3D vs 2D bar charts**
- 3D bars very difficult to justify!
  - Perspective distortion
  - Occlusion
- Faceting into 2D almost always better choice

**Rules of Thumb**
- No unjustified 3D
  - Power of the plane
  - Disparity of depth
  - Occlusion hides information
  - Perspective distortion dangers
- Tiled text isn’t legible
- No unjustified 3D
  - Eye sees beat memory
  - Resolution over immersion
  - Overview first, zoom and filter, details on demand
  - Responsiveness is required
  - Function first, form next

**3D needs very careful justification for abstract data**
- Emphasis in 1990s, but now skepticism
- Be especially careful with 3D for point clouds or networks

**Perspective distortion**
- Derives view from viewpoint
- Acquire more info on image plane quickly from eye movements
- Acquire more info for depth slower, from head/body motion

**Depth vs power of the plane**
- High-ranked spatial position channels: planar spatial position
- Not depth!

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

**Sessions**
- Session 1 8:30-10:10am
- Visualization Analysis Framework
  - Introduction: Definitions
  - Analysis: What, Why, How
  - Marks and Channels
- Session 2 10:30am-12:10pm
- Spatial Layout
  - Arrange Tables
  - Arrange Spatial Data
  - Arrange Networks and Trees
- Session 3 2:00-3:40pm
- Colored and Introspective
  - Map Color
  - Manipulate: Change, Select, Navigate
  - Facet: Juxtapose, Partition, Superimpose
Overview first, zoom and filter, details on demand

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Responsiveness is required

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Why not animation?

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Resolution beats immersion

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Eyes beat memory example: Cerebral

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Design study methodology: definitions

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Design Study Methodology

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Further reading

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Outline

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Methodology for problem-driven work

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Lessons learned from the trenches: 21 between us

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Design study methodology: 32 pitfalls

• and how to avoid them

PF-1: premature design-commitment: jumping forward over stages premature
PF-2: premature commitment: insufficient knowledge of the literature weak
PF-3: premature collaboration: insufficient time before writing weak
PF-4: insufficient time available from potential collaborators weak
PF-5: insufficient time available from potential collaborators weak
PF-6: no need for visualization, problem can be automated weak
PF-7: researcher expertise does not match domain problem weak
PF-8: no need for research engineering vs. research project weak
PF-9: no need for change: existing tools are good enough weak

PF-10: insufficient data collected to write paper weak
PF-11: insufficient data collected to write paper weak
PF-12: insufficient data collected to write paper weak
PF-13: insufficient data collected to write paper weak
PF-14: insufficient data collected to write paper weak
PF-15: insufficient data collected to write paper weak
PF-16: insufficient data collected to write paper weak
PF-17: insufficient data collected to write paper weak
PF-18: insufficient data collected to write paper weak
PF-19: insufficient data collected to write paper weak
PF-20: insufficient data collected to write paper weak

ODC 222

I'm a domain expert! Wanna collaborate?

OFCourse!

Of course they need the cool technique I built last year!
Reflections from the stacks: Wholesale adoption inappropriate

More Information
- Book page (including tutorial lecture slides)
  - http://www.cs.ubc.ca/~tmm/talks.html#vad17fullday
- 20% promo code for book+ebook combo: MVN17
- Illustrations: Eamon Maguire
- Papers, videos, software, talks, courses
  - http://www.cs.ubc.ca/~tmm/papers
  - http://www.cs.ubc.ca/~tmm