# Information Visualization

## **Color & Interaction**

• Slides refer to <u>https://www.cs.ubc.ca/~tmm/</u>



Instrations by Samonn Maguire

#### **Color & Interaction**

- Map Color
- Manipulate: Change, Select, Navigate
- Facet: Juxtapose, Partition, Superimpose



#### Idiom design choices: Encode Encode





mining the state of the second second

### Categorical vs ordered color





Annual sales by state



#### [Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

## Color: Luminance, saturation, hue

- 3 channels Luminance - identity for categorical Saturation • hue - magnitude for ordered Hue • luminance • saturation • RGB: poor for encoding • HSL: better, but beware
  - lightness  $\neq$  luminance



Corners of the RGB
color cube
L from HLS
All the same

Luminance values







#### Spectral sensitivity



Visible Spectrum

## Three-Color Theory

• Human visual system has two types of sensors

- Rods:

- monochromatic, night vision
- Cones
  - Color sensitive
  - Three types of cone
  - Only three values (the tristimulusvalues) are sent to the brain







## Opponent color and color deficiency

- perceptual processing before optic nerve
  - one achromatic luminance channel L
    - edge detection through luminance contrast
  - two chroma channels, R-G and Y-B axis
- "color blind" if one axis has degraded acuity
  - 8% of men are red/green color deficient
  - blue/yellow is rare





[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]







#### Color information



#### CIE L\*A\*B\* color space

• Perception uniform





## Designing for color deficiency: Check with simulator









# Normal vision

#### **Deuteranope Protanope**

#### Tritanope







[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

http://rehue.net

Designing for color deficiency: Avoid encoding by hue alone

- redundantly encode
  - vary luminance
  - change shape







Change the shape

Vary luminance

[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

#### **Deuteranope simulation**

#### Color deficiency: Reduces color to 2 dimensions



[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

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## Designing for color deficiency: Blue-Orange is safe



[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

### Bezold Effect: Outlines matter

• color constancy: simultaneous contrast effect



[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

#### Color/Lightness constancy: Illumination conditions



#### Image courtesy of John McCann

#### Color/Lightness constancy: Illumination conditions



#### Image courtesy of John McCann

## Checker shadow Illusion















→ Categorical

- Ordered
  - Sequential

\* Diverging

#### ➔ Bivariate





Categorical

- Ordered
  - Sequential

\* Diverging

#### → Bivariate

- - color channel interactions
    - size heavily affects salience
      - small regions need high saturation
      - large need low saturation
    - saturation & luminance: 3-4 bins max
      - also not separable from transparency



## Categorical color: Discriminability constraints

• noncontiguous small regions of color: only 6-12 bins



[Cinteny: flexible analysis and visualization of synteny and genome rearrangements in multiple organisms. Sinha and Meller. BMC Bioinformatics, 8:82, <u>2007.]</u>

### ColorBrewer

- <u>http://www.colorbrewer2.org</u>
- saturation and area example: size affects salience!



- problems
  - perceptually unordered
  - perceptually nonlinear
- benefits
  - fine-grained structure visible and nameable



1995.



[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM] [Transfer Functions in Direct Volume Rendering: Design, Interface, Interaction. Kindlmann. SIGGRAPH 2002 Course Notes1

[A Rule-based Tool for Assisting Colormap Selection. Bergman,. Rogowitz, and. Treinish. Proc. IEEE Visualization (Vis), pp. 118 – 125

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- alternatives
  - large-scale structure: fewer hues



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- problems
  - perceptually unordered
  - perceptually nonlinear
- benefits
  - fine-grained structure visible and nameable
- alternatives
  - large-scale structure: fewer hues
  - fine structure: multiple hues with monotonically increasing luminance [eg viridis R/python]



<u> [A Rule-based Tool for Assisting Colormap Selection. Bergman,. Rogowitz, and. Treinish. Proc. IEEE Visualization (Vis), pp. 118 – 125</u> 1995



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  - large-scale structure: fewer hues
  - fine structure: multiple hues with monotonically increasing luminance [eg viridis R/python]
  - segmented rainbows for binned
    - or categorical



<u> [A Rule-based Tool for Assisting Colormap Selection. Bergman,. Rogowitz, and. Treinish. Proc. IEEE Visualization (Vis), pp. 118 – 125</u> 1995



<sup>[</sup>Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. <u>http://www.research.ibm.com/people/I/Iloydt/color/color.HTM]</u> <u>Ittp://www.research.ibm.com/people/I/Iloydt/color/color.HTM]</u> <u>Ittp://www.research.ibm.com/people/I/Iloydt/color/color.HTM]</u> Notes1

### Viridis

• colorful, perceptually uniform, colorblind-safe, monotonically increasing luminance



https://cran.r-project.org/web/packages/viridis/vignettes/intro-toviridis.html



lt	
5	Green-Blind (Deuteranopia)
en-blue	
t	
n-blue	Desaturated

## Map other channels

- SIZE
  - length accurate, 2D area ok, 3D volume poor
- angle
  - nonlinear accuracy
    - horizontal, vertical, exact diagonal
- shape
  - complex combination of lower-level primitives
  - many bins
- motion
  - highly separable against static
    - binary: great for highlighting
  - use with care to avoid irritation

- - → Length
  - → Angle
  - → Area
  - → Curvature
  - → Volume
- Shape

- Motion

# ③ Size, Angle, Curvature, ...







→ Motion Direction, Rate, Frequency, ...









#### Sequential ordered line mark or arrow glyph

Diverging ordered arrow glyph



#### Cyclic ordered arrow glyph

## Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, 2014 - Chap 10: Map Color and Other Channels
- **ColorBrewer**, Brewer.
  - <u>http://www.colorbrewer2.org</u>
- Color In Information Display. Stone. IEEE Vis Course Notes, 2006. - http://www.stonesc.com/Vis06
- A Field Guide to Digital Color. Stone. AK Peters, 2003.
- *Rainbow Color Map (Still) Considered Harmful.* Borland and Taylor. IEEE Computer Graphics and Applications 27:2 (2007), 14 – 17.
- Visual Thinking for Design. Ware. Morgan Kaufmann, 2008.
- Information Visualization: Perception for Design, 3rd edition. Ware. Morgan Kaufmann /Academic Press, 2004.
- https://cran.r-project.org/web/packages/viridis/vignettes/intro-to-viridis.html

Manipulate: Change, Select, Navigate

#### How?



How?

## How to handle complexity: 1 previous strategy + 3 more





### Manipulate



→ Attribute Reduction



Project










### Change over time

- change any of the other choices
  - encoding itself
  - parameters
  - arrange: rearrange, reorder
  - aggregation level, what is filtered...
  - interaction entails change

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### Idiom: Re-encode

### System: Tableau









made using Tableau, <u>http://tableausoftware.com</u>

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### Idiom: Change parameters

### widgets and controls

sliders, buttons, radio buttons, checkboxes, dropdowns/comboboxes

### • pros

clear affordances, self-documenting (with labels)

### cons

uses screen space

design choices

separated vs interleaved controls & canvas



### [Growth of a Nation](http://laurenwood.github.io/)

### Idiom: Reorder

- data: tables with many attributes
- task: compare rankings



[LineUp: Visual Analysis of Multi-Attribute Rankings. Gratzl, Lex, Gehlenborg, Pfister, and Streit. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis 2013) 19:12 (2013), 2277 – 2286.]

### System: LineUp

## Idiom: Realign

- stacked bars
  - easy to compare
    - first segment
    - total bar
- align to different segment

- supports flexible comparison

### System: LineUp





[LineUp: Visual Analysis of Multi-Attribute Rankings.Gratzl, Lex, Gehlenborg, Pfister, and Streit. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis 2013) 19:12 (2013), 2277 – 2286 1

## Shiny example

- APGI genome browser
  - tooling: R/Shiny
  - -interactivity
    - tooltip detail on demand on hover
    - expand/contract chromosomes
    - expand/contract control panes



https://gallery.shinyapps.io/genome\_browser/

### ICGC PANCREATIC CANCER (DUCTAL ADENOCARCINOMA) - GENOME VIEWER

HGNC	Chr	Start	From	То	Consequence	Count
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TP53	17	7578437	G	A	stop_gained	18
KRAS	12	25398284	С	т	missense_variant	12
TP53	17	7578437	G	A	exon_variant	10
SMARCA4	19	11144847	С	т	exon_variant	8
TP53	17	7577121	G	A	downstream_gene_variant	6
TP53	17	7577121	G	A	missense_variant	6
KRAS	12	25398285	С	G	missense_variant	4
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### Idiom: Animated transitions

- smooth transition from one state to another
  - alternative to jump cuts
  - support for item tracking when amount of change is limited
- example: multilevel matrix views
- example: animated transitions in statistical data graphics
  - https://vimeo.com/19278444



### An interactive heatmap visualization

• https://github.com/MaayanLab/clustergrammer



[Using Multilevel Call Matrices in Large Software Projects. van Ham. Proc. IEEE Symp. Information Visualization (InfoVis), pp. 227 - 232, 2003.]

## Select and highlight

- selection: basic operation for most interaction
- design choices
  - how many selection types?
    - click vs hover: heavyweight, lightweight
    - primary vs secondary: semantics (eg source/target)
- highlight: change visual encoding for selection targets
  - color
    - limitation: existing color coding hidden
  - other channels (eg motion)
  - add explicit connection marks between items



### Navigate: Changing item visibility

- change viewpoint
  - changes which items are visible within view
  - camera metaphor
    - zoom
      - geometric zoom: familiar semantics
      - semantic zoom: adapt object representation based on available pixels
        - » dramatic change, or more subtle one
    - pan/translate
    - rotate
      - especially in 3D
  - constrained navigation
    - often with animated transitions
    - often based on selection set

### Navigate

(+)

### ➔ Item Reduction

### Zoom Geometric or Semantic



### ➔ Pan/Translate







### Idiom: Semantic zooming

- visual encoding change
  - colored box
  - sparkline
  - simple line chart
  - full chart: axes and tickmarks



[LiveRAC - Interactive Visual Exploration of System Management Time-Series Data. McLachlan, Munzner, Koutsofios, and North. Proc. ACM Conf. Human Factors in Computing Systems (CHI), pp. 1483 – 1492, 2008.]

### System: LiveRAC

## Navigate: Reducing attributes

- continuation of camera metaphor
  - slice
    - show only items matching specific value for given attribute: slicing plane
    - axis aligned, or arbitrary alignment
  - cut
    - show only items on far slide of plane from camera
  - project
    - change mathematics of image creation
      - orthographic
      - perspective
      - many others: Mercator, cabinet, ...

[Interactive Visualization of Multimodal Volume Data for Neurosurgical Tumor Treatment. Rieder, Ritter, Raspe, and Peitgen. Computer Graphics Forum (Proc. EuroVis 2008) 27:3 (2008), 1055 – 1062.]





### Attribute Reduction

5ñce



Cut



Project



### Navigate: Reducing attributes

- project from 2D sphere surface to 2D plane
  - -can only fully preserve 2 out of 3
    - angles: conformal
    - area: equal area
    - contiguity: no interruptions



https://www.win.tue.nl/~vanwijk/myriahedral/



[Every Map projection]

(https://bl.ocks.org/mbostock/ <u>29cddc0006f8b98eff12e60dd08f59a7)</u>

### **Interaction benefits**

- interaction pros
  - major advantage of computer-based vs paper-based visualization
  - –flexible, powerful, intuitive
    - exploratory data analysis: change as you go during analysis process
    - fluid task switching: different visual encodings support different tasks
  - -animated transitions provide excellent support
    - empirical evidence that animated transitions help people stay oriented

### Interaction limitations

- interaction has a time cost
  - -sometimes minor, sometimes significant
  - -degenerates to human-powered search in worst case
- remembering previous state imposes cognitive load

   rule of thumb: eyes over memory
  - hard to compare visible item to memory of what you saw
  - ex: maintaining context/orientation when navigating
  - ex: tracking complex changes during animation
- controls may take screen real estate

- or invisible functionality may be difficult to discover (lack of affordances)

- users may not interact as planned by designer
  - –NYTimes logs show ~90% don't interact beyond scrollytelling Aisch, 2016

### se ve load

### r (lack of affordances) r ollytelling - Aisch,

### Further reading

• Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, 2014.

- Chap 11: Manipulate View

- Animated Transitions in Statistical Data Graphics. Heer and Robertson. IEEE Trans. on Visualization and Computer Graphics (Proc. InfoVis07) 13:6 (2007), 1240 - 1247.
- Selection: 524,288 Ways to Say "This is Interesting". Wills. Proc. IEEE Symp. Information Visualization (InfoVis), pp. 54 – 61, 1996.
- Smooth and efficient zooming and panning. van Wijk and Nuij. Proc. IEEE Symp. Information Visualization (InfoVis), pp. 15 – 22, 2003.
- Starting Simple adding value to static visualisation through simple interaction. Dix and Ellis. Proc. Advanced Visual Interfaces (AVI), pp. 124 – 134, 1998.

# Facet: Juxtapose, Partition, Superimpose

### Facet

### Juxtapose

 $^{++}$ ۰**\***\*\*  $-2\pi = -\pi_{0}$ 



### Partition









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Juxtapose and coordinate views

- → Share Encoding: Same/Different
  - → Linked Highlighting



→ Share Data: All/Subset/None



Share Navigation



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### Idiom: Linked highlighting

- see how regions contiguous in one view are distributed within another
  - -powerful and pervasive interaction idiom
- encoding: different -*multiform*
- data: all shared



[Visual Exploration of Large Structured Datasets. Wills. Proc. New Techniques and Trends in Statistics (NTTS), pp. 237 – 246. IOS Press, 1995.]

### System: **EDV**

## Idiom: bird's-eye maps

- encoding: same
- data: subset shared
- navigation: shared - bidirectional linking
- differences
  - viewpoint
  - -(size)
- overview-detail



41:1 (2008), 1 - 31.]

### System: Google Maps

# Idiom: Small multiples

- encoding: same
- data: none shared
  - -different attributes for node colors
  - -(same network
     layout)
- navigation:
   shared



[Cerebral: Visualizing Multiple Experimental Conditions on a Graph with Biological Context. Barsky, Munzner, Gardy, and Kincaid. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis 2008) 14:6 (2008), 1253 – 1260.]

### System: Cerebral

### Juxtapose design choices

### • View count

- -few vs many
  - How many is too many? Open research question
- -View visibility
  - Always side by side vs temporary popups
- -View arrangement
  - User managed vs system arranges/aligns

### **Coordinate views: Design choice interaction**



- why juxtapose views?
  - -benefits: eyes vs memory
    - lower cognitive load to move eyes between 2 views than remembering previous state with single changing view
  - -costs: display area, 2 views side by side each have only half the area of one view



### Why not animation?

- disparate frames and regions: comparison difficult
  - -vs contiguous frames
  - -vs small region
  - -vs coherent motion of group
- safe special case

   animated transitions



## System: **Improvise**

- investigate power of multiple views
  - -pushing limits on view count, interaction complexity
  - -how many is ok?
    - open research question
  - -reorderable lists
    - easy lookup
    - useful when linked to other encodings



[Building Highly-Coordinated Visualizations In Improvise. Weaver. Proc. IEEE Symp. Information Visualization (InfoVis), pp. 159 – 166, 2004.]

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### Partition into views

- how to divide data between views 

   Partition into Side-by-Side Views
  - -split into regions by attributes
  - -encodes association between items using spatial proximity
  - -order of splits has major implications for what patterns are visible
- no strict dividing line
  - -view: big/detailed
    - contiguous region in which visually encoded data is shown on the display
  - -glyph: small/iconic
    - object with internal structure that arises from multiple marks







### Partitioning: List alignment

- single bar chart with grouped bars
  - -split by state into regions
    - complex glyph within each region showing all ages
  - -compare: easy within state, hard across ages





### small-multiple bar charts split by age into regions one chart per region compare: easy within age, harder across states



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- split by neighborhood
- then by type
- then time
  - years as rows
  - months as columns
- color by price
- neighborhood patterns
  - where it's expensive
  - where you pay much more for detached type

[Configuring Hierarchical Layouts to Address Research Questions. Slingsby, Dykes, and Wood. IEEE Transactions on Visualization and Computer Graphics (Proc. InfoVis 2009) 15:6 (2009), 977 – 984.]



- switch order of splits - type then neighborhood
- switch color
  - by price variation
- type patterns

- within specific type, which neighborhoods inconsistent



[Configuring Hierarchical Layouts to Address Research Questions. Slingsby, Dykes, and Wood. IEEE Transactions on Visualization and Computer Graphics (Proc. InfoVis 2009) 15:6 (2009), 977 – 984.]

- different encoding for second-level regions
  - choropleth maps



[Configuring Hierarchical Layouts to Address Research Questions. Slingsby, Dykes, and Wood. IEEE Transactions on Visualization and Computer Graphics (Proc. InfoVis 2009) 15:6 (2009), 977 – 984.]

- size regions by sale counts
  - not uniformly
- result: treemap



[Configuring Hierarchical Layouts to Address Research Questions. Slingsby, Dykes, and Wood. IEEE Transactions on Visualization and Computer Graphics (Proc. InfoVis 2009) 15:6 (2009), 977 – 984.]

### Superimpose layers

- *layer*: set of objects spread out over region

   –each set is visually distinguishable group
   –extent: whole view
- design choices
  - -how many layers, how to distinguish?
    - encode with different, nonoverlapping channels
    - two layers achieveable, three with careful design

-small static set, or dynamic from many possible?





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## Static visual layering

- foreground layer: roads
  - -hue, size distinguishing main from minor
  - -high luminance contrast from background
- background layer: regions
  - -desaturated colors for water, parks, land areas
- user can selectively focus attention
- "get it right in black and white" -check luminance contrast with greyscale view

[Get it right in black and white. Stone. 2010. http://www.stonesc.com/wordpress/2010/03/get-it-right-in-black-and-white]







### Superimposing limits

- few layers, but many lines
  - -up to a few dozen
  - -but not hundreds
- superimpose vs juxtapose: empirical study
  - -superimposed for local, multiple for global
  - -tasks
    - local: maximum, global: slope, discrimination
  - same screen space for all multiples vs single superimposed





[Graphical Perception of Multiple Time Series. Javed, McDonnel, and Elmqvist. IEEE Transactions on Visualization and Computer Graphics (Proc. IEEE InfoVis 2010) 16:6 (2010), 927 – 934.]



### CPU utilization over time



### Dynamic visual layering

- interactive, from selection
  - -lightweight: click
  - -very lightweight: hove
- ex: 1-hop neighbors

[Cerebral: a Cytoscape plugin for layout of and interaction with biological networks using subcellular localization annotation. Barsky, Gardy, Hancock, and Munzner. Bioinformatics 23:8 (2007), 1040 – 1042.]



### System: Cerebral
## Further reading

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- Glyph-based Visualization: Foundations, Design Guidelines, Techniques and Applications. Borgo, Kehrer, Chung, Maguire, Laramee, Hauser, Ward, and Chen. In Eurographics State of the Art Reports, pp. 39 – 63, 2013.