**Marks and Channels (Geoms and Aesthetics)**

**Perceptual Principles**

**Visual encoding**
- analyze idiom structure
  - as combination of marks/geoms and channels/aesthetics

**Channels/Aesthetics: Rankings**
- Magnitude Channels: Ordered Attributes
- Identity Channels: Categorical Attributes
- Spatial region
- Color hue
- Size (area)

**Visual encoding**
- analyze idiom structure
  - as combination of marks/geoms and channels/aesthetics

**Channels/Aesthetics: Spatial position**
- Position on common scale
- Position on unaligned scale
- Length (1D size)
- Area (2D size)
- Depth (3D position)
- Tilt/angle
- Area (2D size)
- Volume (3D size)

**Accuracy: Fundamental Theory**
- expressiveness principle
  - match channel/aesthetics & data characteristics

**Accuracy: Vis experiments**
- match channel/aesthetics & data characteristics
- effectiveness principle
  - encode most important attributes with highest ranked channels

**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

**Popout**
- many channels: tilt, shape, proximity, shadow direction, ...
  - but not all! parallel line pairs do not pop out from tilted pairs

**Definitions: Marks and channels**
- marks (geoms)
  - geometric primitives
- channels (aesthetics)
  - control appearance of marks
    - use redundantly code with multiple channels

**Discriminability: How many usable steps?**
- must be sufficient for number of attribute levels to show
  - inewid: few bins but salient
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
• visual systems differ in length by 1/2: fixed difficulty judgments
• white rectangles differ in length by 1:2: easy judgement

Relative luminance judgements
• perception of luminance is contextual based on contrast with surroundings

Relative color judgements
• color constancy across broad range of illumination conditions

Further reading
  – Chapter 5: Hues and Chromes

Designing for color deficiency: Avoid encoding by hue alone
• redundantly encode
  – vary luminance
  – change shape

Designing for color deficiency: Check with simulator

Spectral sensitivity

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

Opponent color and color deficiency
• perceptual processing before optic nerve
  – one achromatic luminance channel (L)
  – edge detection through luminance contrast
  – 2 chroma channels
  – red-green (r) & yellow-blue axis (b)
• "color blind": one axis has degraded acuity
  – 8% of men are redgreen color deficient
  – blue/yellow is rare

Color spaces
• CE "L*ab*" good for computation
  – L* intuitive: perceptually linear luminance
  – "a*b*" axes: perceptually linear hue saturation
• RGB: good for display hardware
• polar for encoding
  – HLS/HSL: somewhat better for encoding
  – saturation channel useful
  – hue only pseudo-perceptual!
• lightness (L) or value (V) = luminance or L*
• Luminance, hue, saturation
  – good for encoding
  – but not standard graphs/tools colorspace

Designing for color deficiency: Blue-Orange is safe

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
  – luminance how bright
  – saturation how colorful
• categorical can show identity
  – hue what color
• channels have different properties
  – what they convey directly to perceptual system
  – how much they can convey: how many discriminable bins can we use?

Idiom design choices: Encode

Categorical vs ordered color

Color Theory
Graphic:  Advanced Color Principles & Practice: Data Tables Customer Conference 2014

Ordered color: Rainbow is poor default
• problems
  – perceptually unordered
  – perceptually nonlinear
• benefits
  – fine-grained structure visible and nameable

ColorBrewer
• http://www.colorbrewer2.org
• saturation and area example: size affects salience!

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

Colormaps
• Categorical
• Ordered
• Sequential
• Diverging

Map other channels
• size
  – length accurate, 2D area ok, 3D volume poor
• angle
  – nonlinear accuracy
• shape
  – complex combination of lower-level primitives
• motion
  – highly separable against static
• binary: great for highlighting
  – use with care to avoid irritation

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Fig. 5. Taxonomy-Based Glyph Design - with a Case Study on Visualization of Biological Experiments. Maguire, Rocca-Serra, Sansone, Davies, and Chen. IEEE Trans. Visualization and Computer Graphics 18:12:2603-2612 (Proc. InfoVis 12.)
Unjustified 3D all too common, in the news and elsewhere

Perspective distortion loses information
- perspective distortion
  - interferes with all size channel encodings
  - power of the plane is lost!

Depth vs power of the plane
- high-ranked spatial position channels planar spatial position
  - not depth!

Occlusion hides information
- occlusion
- interaction can resolve, but at cost of time and cognitive load

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

Perspective distortion dangers
- 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

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Further reading
- "3-D Map and Other Channel"
- ColorBrewer: Brewer.
  - http://www.colorbrewer.org/
- http://www.perceptualEdge.com/View
- http://www.colorbrewer2.org/

Occlusion:
- Points: 1, 2, 3, 4
- Disparity of depth: 1, 2, 3, 4
- Occlusion: 1, 2, 3, 4

No unjustified 3D example: Time-series data
- extruded curves: detailed comparisons impossible

No unjustified 3D example: Transform for new data abstraction
- derived data: cluster hierarchy
- juxtapose multiple views: calendar, superimposed 2D curves

Justified 3D: shape perception
- benefits outweigh costs when task is shape perception for 3D spatial data
- interactive navigation supports synthesis across many viewpoints

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

TowardsAway
Up
Down
Right
Left

Thousands of points up/down and left/right
We can only see the outside shell of the world

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Best practices: Labelling
- make visualizations as self-documenting as possible
  - meaningful & useful title
  - axes and panes/subwindows should have labels
  - make automatic centering

Resolution beats immersion
- does not need sense of presence or stereoscopic 3D
- desktop also better for workflow integration
- consider whether network data requires 2D vs 3D
- visual hierarchy, alignment, flow
- Gestalt principles in action
- density and harder label lookup compared to text
- do not need sense of presence or stereoscopic 3D
- do unify by pushing existing consistencies
- axes and panes/subwindows should have labels
- make automatic centering

Further reading
  - Chap 6: Rules of Thumb
  - Chap 12: We Have Time Requirements
- Usability Testing
- Jakob Nielsen
- Interaction Design: Beyond Human-Computer Interaction
- About Face: The Essentials of Interaction Design
- Task-Centered User Interface Design. Lewis & Rieman, 1994
  - Lewis & Rieman, 1994
- Usability Testing
- Jakob Nielsen