PERCEPTION IN VISUALIZATION

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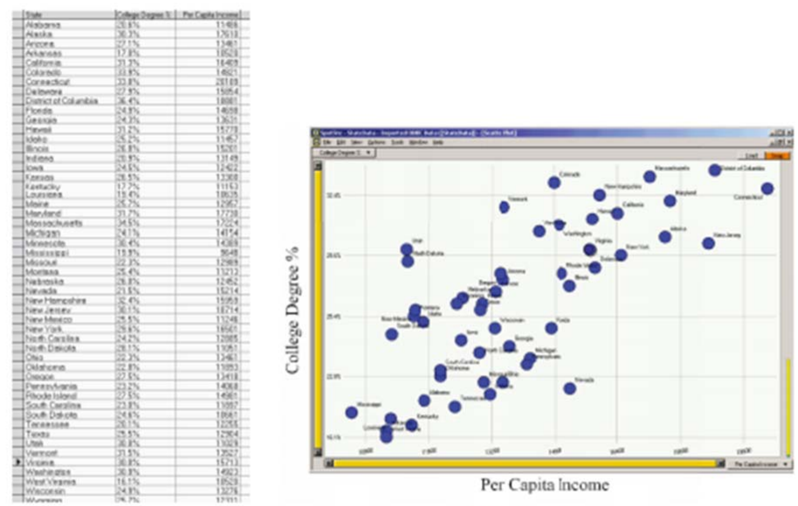
Perception in Visualization

- Scientific Visualization
- Understanding of perception can improve quality and quantity of displayed information
- Visual features assigned to data attributes must
  - Take advantage of the strengths of our visual system
  - Be well-suited to the analysis needs of the viewer
  - Avoid visual interference effects that could mask information



(a) A thousand words (b) A picture

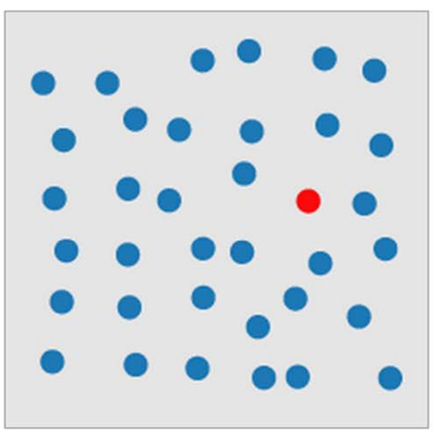
Fig. 1. "A picture is worth a thousand words"

Overview

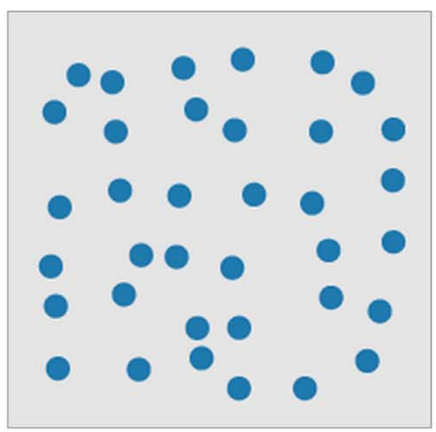
- Preattentive Processing
  - What visual properties attract us, and therefore our focus of attention to a particular object in a scene?
  - Five theories to explain this phenomenon
- Postattentive Vision
  - What happens after we see a scene?
- Change Blindness
  - Effect of blinking on perception of a scene
- Use of Perceptual Properties in Visualization
  - Color
  - Texture
  - …

Preattentive Processing

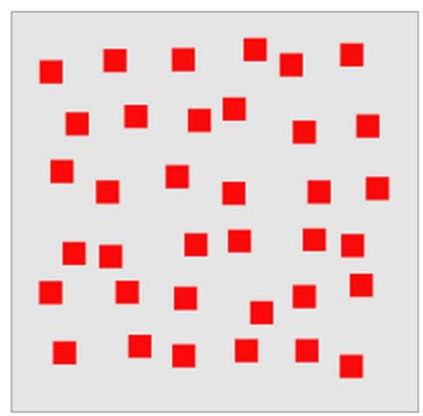
- Set of visual properties that are detected very rapidly and accurately by the low-level visual system
- ***"Preattentive"*** - detection precedes focused attention
- Requires 200 to 250 ms on large multi-element displays
  - Eye movements take at least 200 msec to initiate
- If the low-level visual system can be harnessed during visualization, it can be used to draw attention to areas of potential interest in a display



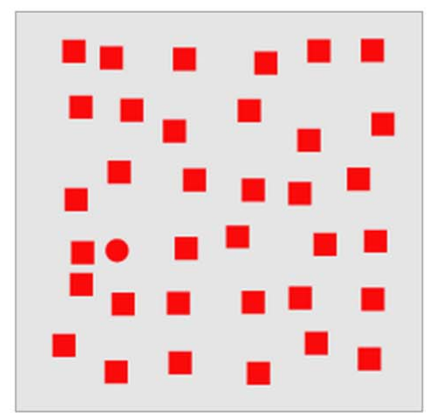
(a)



(b)



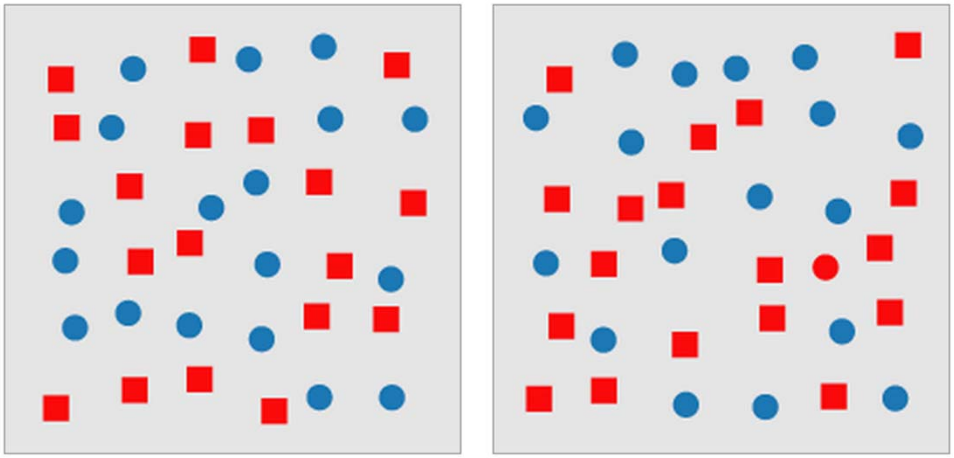
(a)



(b)

Combination of Features

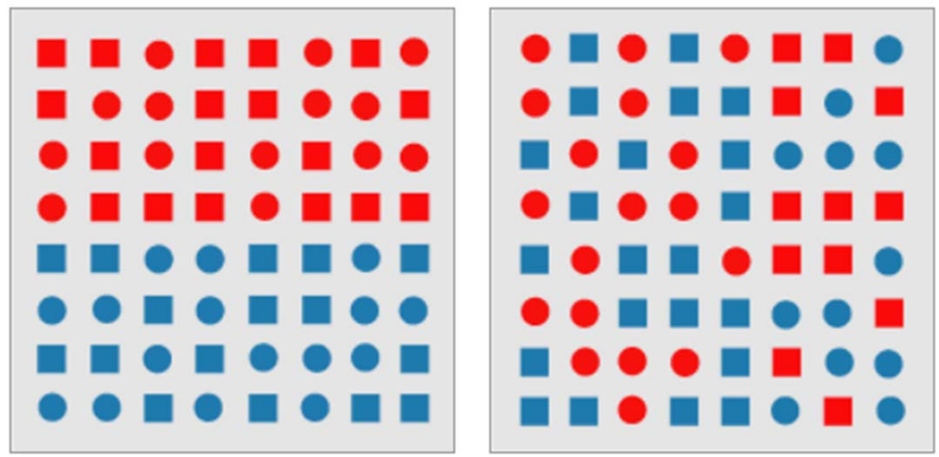
- Target made up of a combination of non-unique features cannot be detected preattentively
- Focused attention or serial search



(a) (b)

Preattentive visual tasks

- *Target Detection*
- *Boundary Detection*
- *Region Tracking*
- *Counting and Estimation*



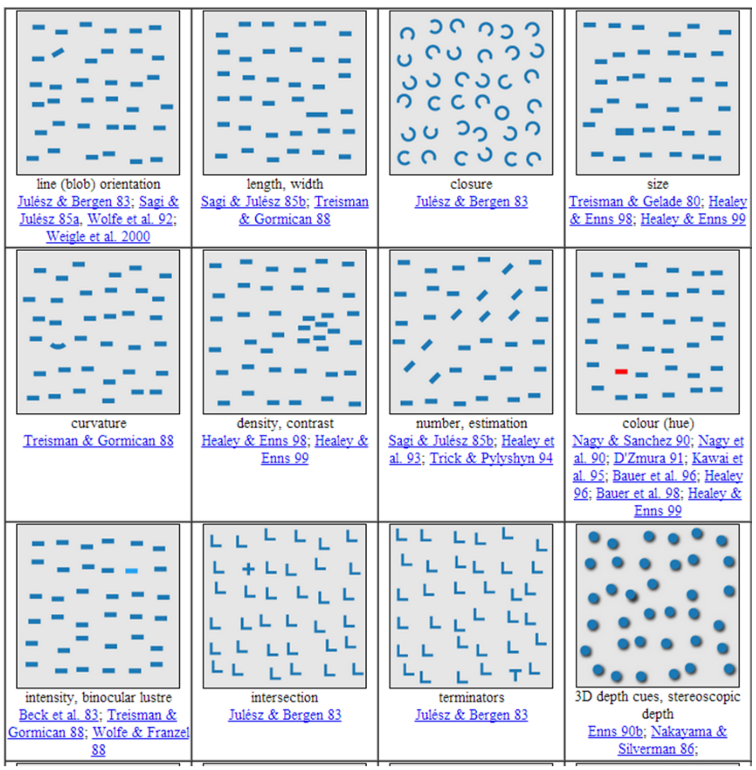
(a) (b)

Five Theories

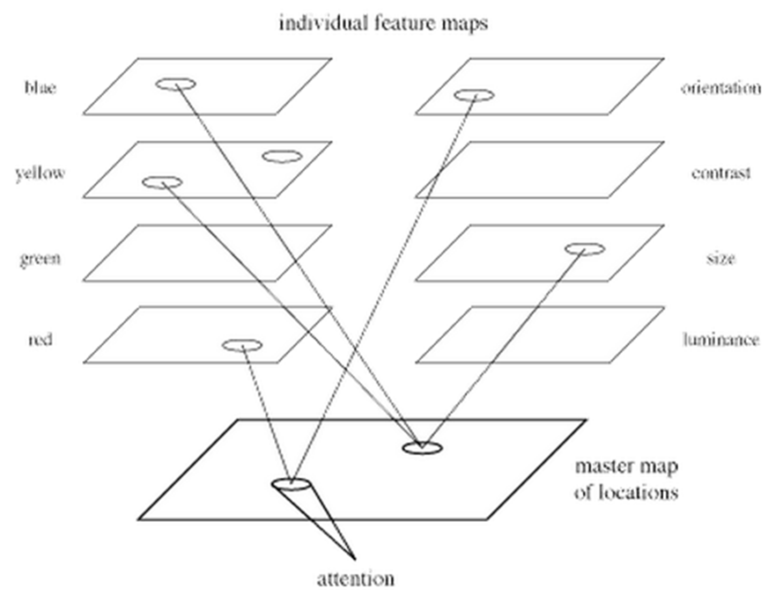
- Feature Integration Theory
- Texton Theory
- Similarity Theory
- Guided Theory
- Boolean Theory

Feature Integration Theory - I

- Anne Treisman – one of the original researchers
  - ***Preattentive features* -** visual properties are detected preattentively
  - *how does human visual system perform* preattentive processing



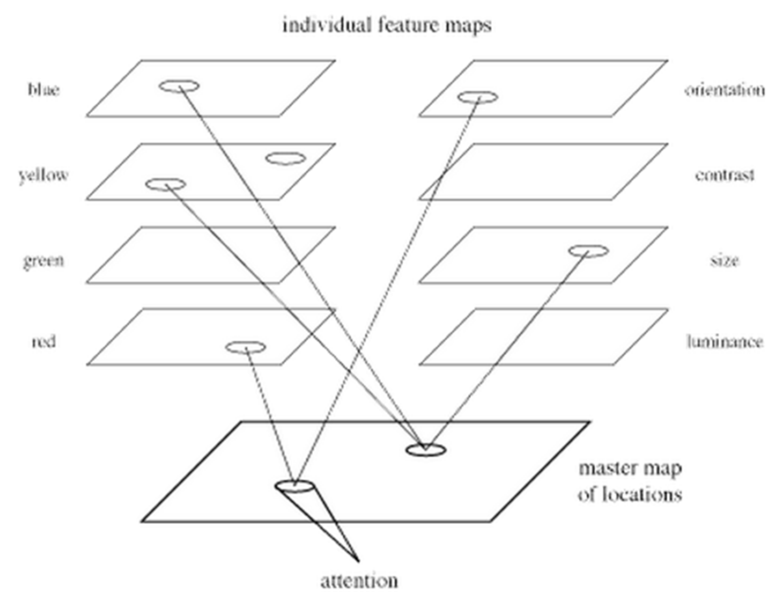
Preattentive Features



Model of the visual system:
set of feature maps + master map

Feature Integration Theory - II

- Model low-level human vision
- When the human visual system sees an image, all features are encoded in parallel into their respective maps
- If the target has a unique feature
  - Access the given feature map to see if any activity is occurring
- Conjunction target:
  - Activity there may be caused by the target, or by distractors



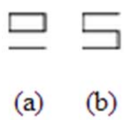
Model low-level human vision: set of feature maps + master map of locations

Feature Integration Theory - Expansion

- The amount of differentiation between the target and the distractors for a given feature will affect search time
- Explain certain cases where conjunction search is preattentive
  - a significant target–nontarget feature difference would allow individual feature maps to ignore nontarget information contained in the master map

Texton Theory

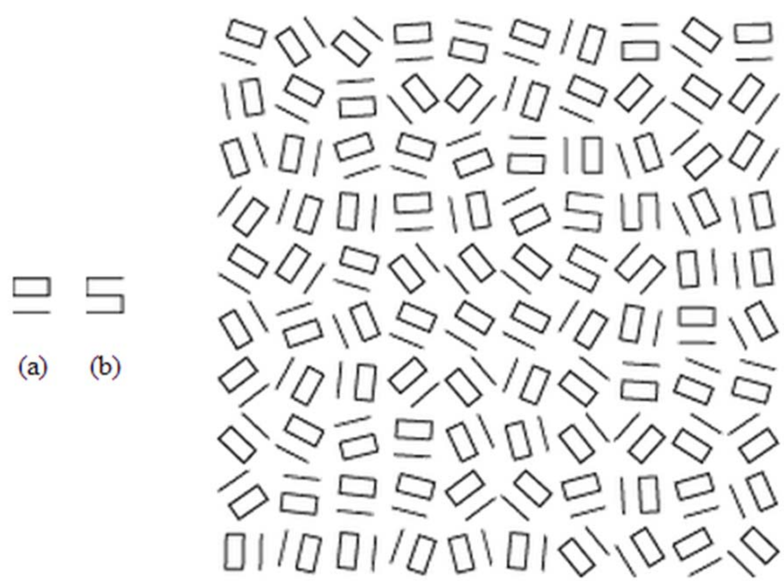
- Bela Julész initial investigations focused on statistical analysis of texture patterns
- Suggested that the early visual system detects a group of features called *textons* - three general categories:
  - Elongated blobs (*e.g.*, line segments, rectangles, ellipses) with specific properties such as hue, orientation, and width
  - Terminators (ends of line segments)
  - Crossings of line segments



- Difference in textons or in their density can be detected preattentively
- Preattentive processing occurs in parallel and focused attention occurs in serial

Texton Theory - II

- Experiment: Texture Segregation
  - Task of locating groups of similar objects and the boundaries that separate them



(a) (b) (c)

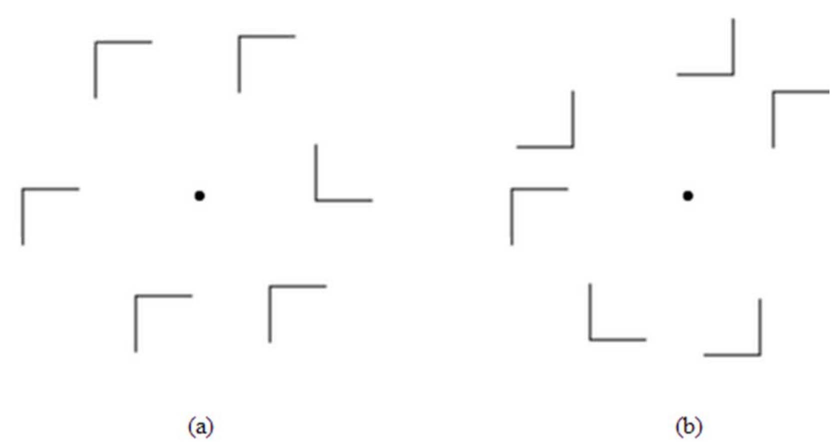
Similarity Theory

Quinlan and Humphreys (1987) did not support the dichotomy of serial and parallel search modes

- Investigated conjunction searches by focusing on two factors
  - # items of information required to identify the target
  - how easily a target can be distinguished from its distractors
- Duncan and Humphreys Model –
  - Depends on the type of task and the display conditions
  - Search time is based on two criteria:
    - T-N similarity and N-N similarity

Similarity Theory - II

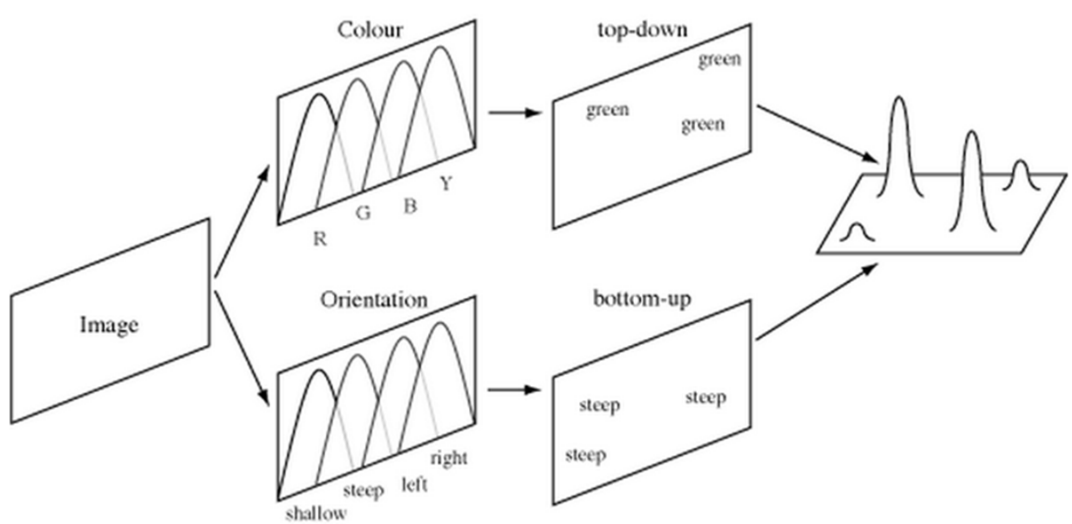
- These two factors affect search time as follows:
  - T-N similarity increases
    - search efficiency decreases, search time increases
  - N-N similarity decreases
    - search efficiency decreases, search time increases
  - T-N similarity and N-N similarity are related
    - decreasing N-N similarity has little effect if T-N similarity is low
    - increasing T-N similarity has little effect if N-N similarity is high



Feature: 'L', (a) High N-N similarity, (b) Low N-N similarity

Guided Theory

- Jeremy Wolfe (1994)
  - Construction of activation map based on bottom-up and top-down information during visual search
  - Attention is drawn to peaks in the activation map
    - Image areas with the largest combination of bottom-up and top-down influence
- Early vision divides an image into individual feature maps



Bottom-up activation measures how different an element is from its neighbors

Top-down activation user-driven attempt to find items with a specific property or set of properties

Boolean Theory

- Huang et al. (2007)
- Visual search divided into two parts:
  - *Selection* - choosing a set of objects from a scene
  - *Access* - determines the properties of the selected objects a viewer can apprehend
- Scene is divided into two parts and later accessed:
  - Selected elements and excluded elements - "boolean map"

(a) (b) (c) (d)

Boolean Map Theory - II

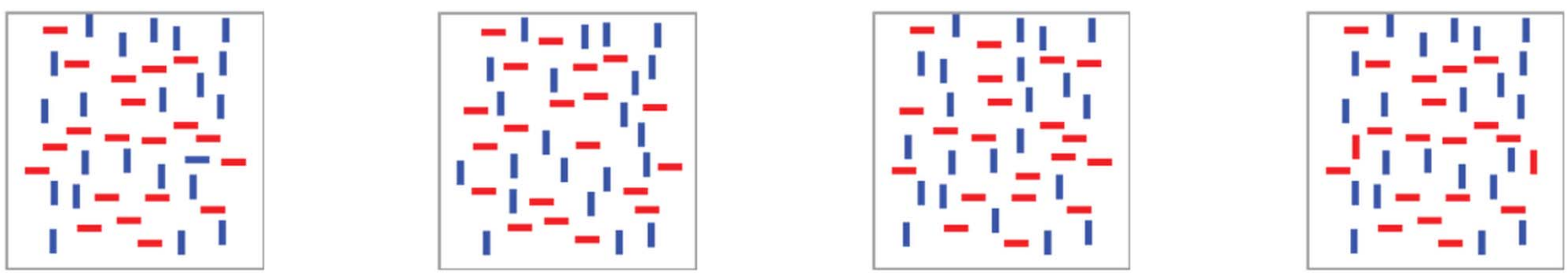
- How is the map created?

1. Viewer specifies single value of a feature
   - All objects containing the feature value are selected, for ex: red objects
   - Map encodes the location of the selected elements, unlike previous theories
2. Applying union and intersection on two existing maps
   - Viewer can only hold and access one boolean map at any given time

(a) (b) (c) (d)

Boolean Theory - III

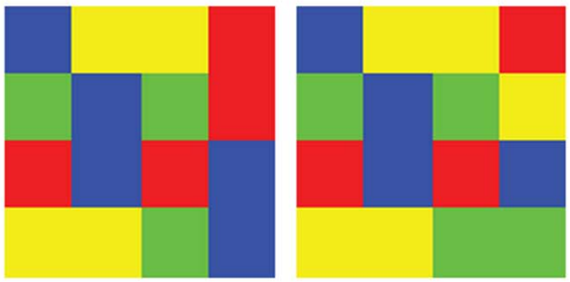
- **Combined feature search** is more difficult because it requires two boolean map operations in series



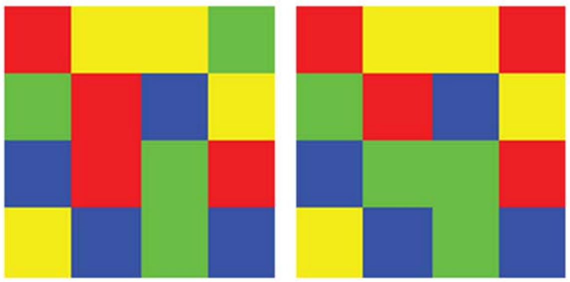
(a) (b) (c) (d)

Search for blue horizontal object

Boolean Theory - Example



(a)



(b)

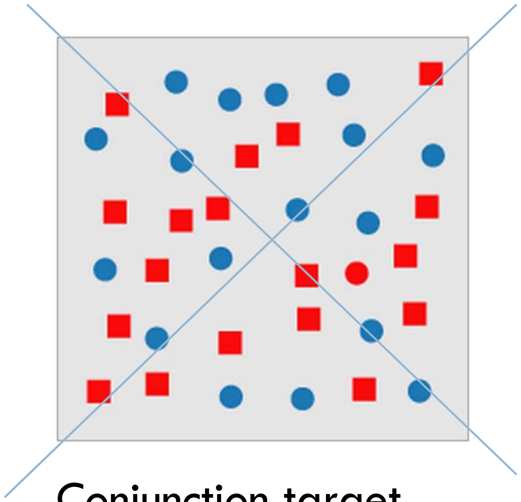
- Identifying differences in color symmetry
- In each figure, there are two mismatched squares between the left and the right block

Summary

- Feature Integration Theory
  - Preattentive Features
  - Feature Maps
- Texton Theory
  - Difference in textons
- Similarity Theory
  - T-N similarity and N-N similarity
- Guided Search Theory
  - Peaks in Activation map = Bottom-up + Top-down
- Boolean Map
  - Selection + Access
  - Boolean maps constructed in mind (set operations applied)

Keypoints

- To use preattentive features in visualization
  - Remember preattentive features are assymetric
    - a sloped line in a sea of vertical lines can be detected preattentively, but the opposite is not true
  - Consider the effect of background distractors with the target feature
  - Avoid use of conjunction targets



Conjunction target

Postattentive Vision

- "What happens to the visual representation of an object when we stop attending to it and look at something else?"
- Jeremy Wolfe (2000)
- Do we develop a rich visual representation as we look at more and more of a scene?
  - No
  - Attention to different objects allows us to learn what is in a scene, but does not "store" the scene

Post-attentive - Experiment

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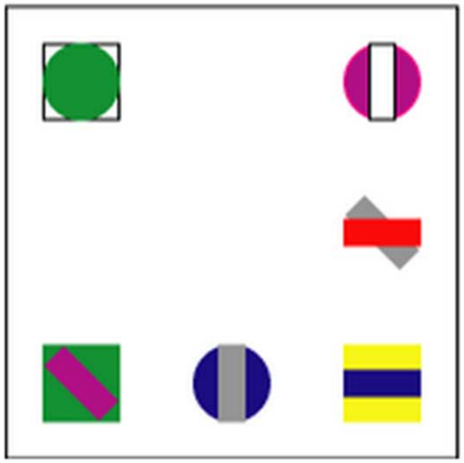


Postattentive Processing

- Significant impact for visualization design
- Generally, visualization displays are novel, and their contents cannot be committed to long-term memory
  - Studying a display may offer no assistance in searching for specific data values
- Hence, preattentive methods would be critical in allowing viewers to rapidly and accurate explore their data

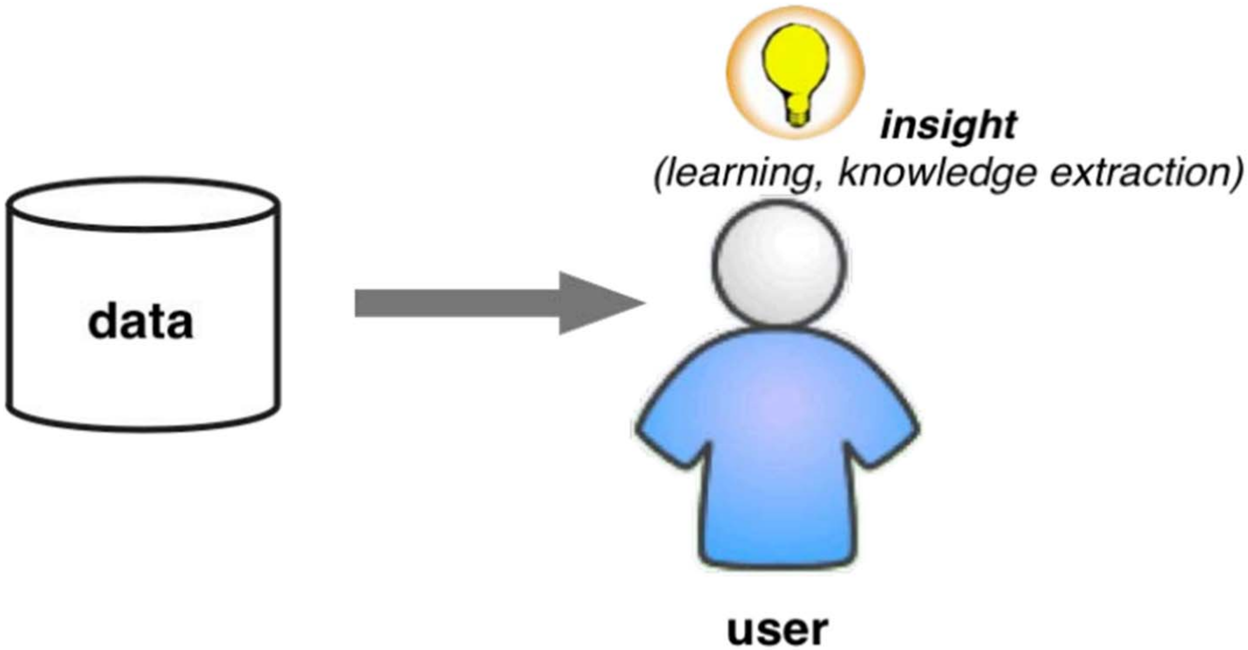
Recent Thoughts

- Ways are explored to apply rules of perception to produce images that are visually salient
- Goal of human vision is **not to create a replica** or image of the seen world in our mind
- No general purpose - What we "see" in a new scene **depends on our goals and expectations**

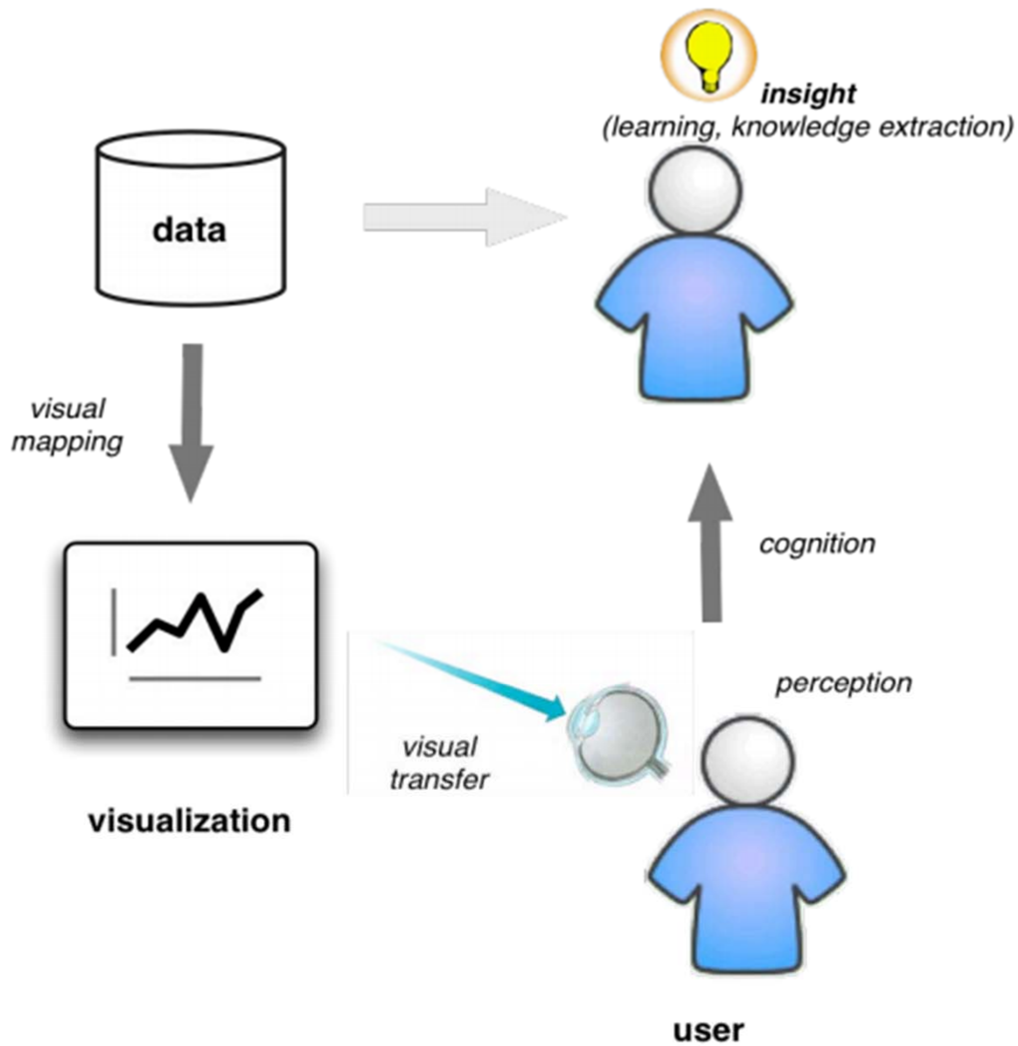
Change Blindness

- An interruption in the view renders us "blind" to significant changes that occur in the scene during the interruption
- Example: http://www.csc.ncsu.edu/faculty/healey/PP/movies/Dinner.gif
- Why does it happen? [Dan Simons]
  - Overwriting, First Impression, Nothing is Stored
- Impact on visualization
  - Attract attention only to the details that are significant in the subsequent images

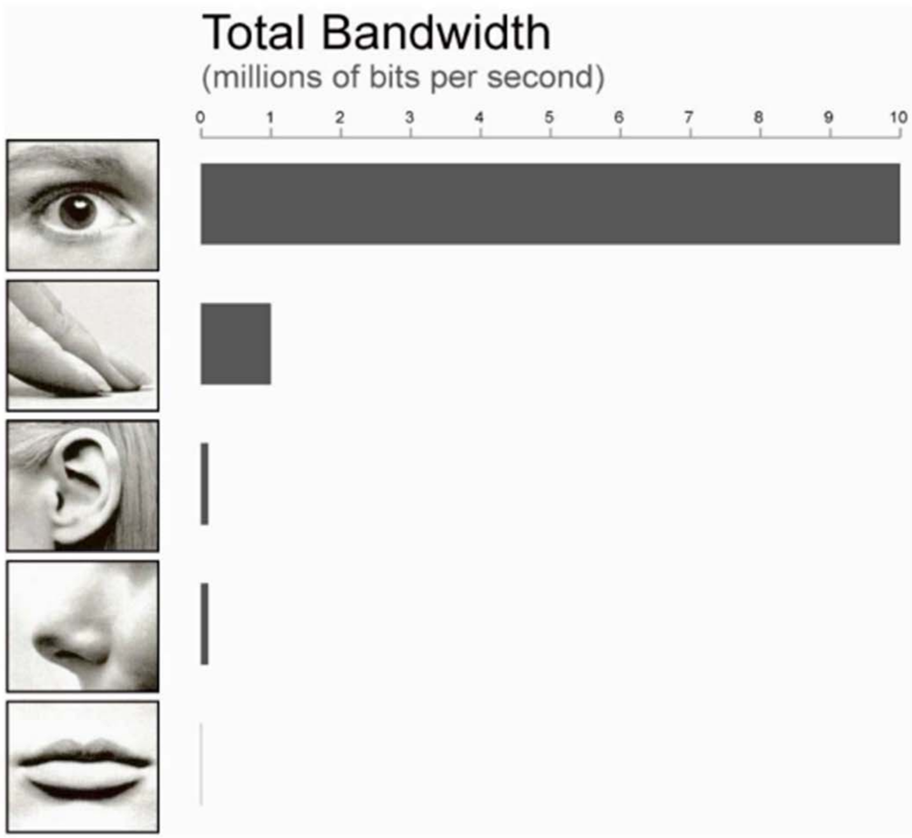
Use of Perceptual Properties in Visualization



Use of Perceptual Properties in Visualization



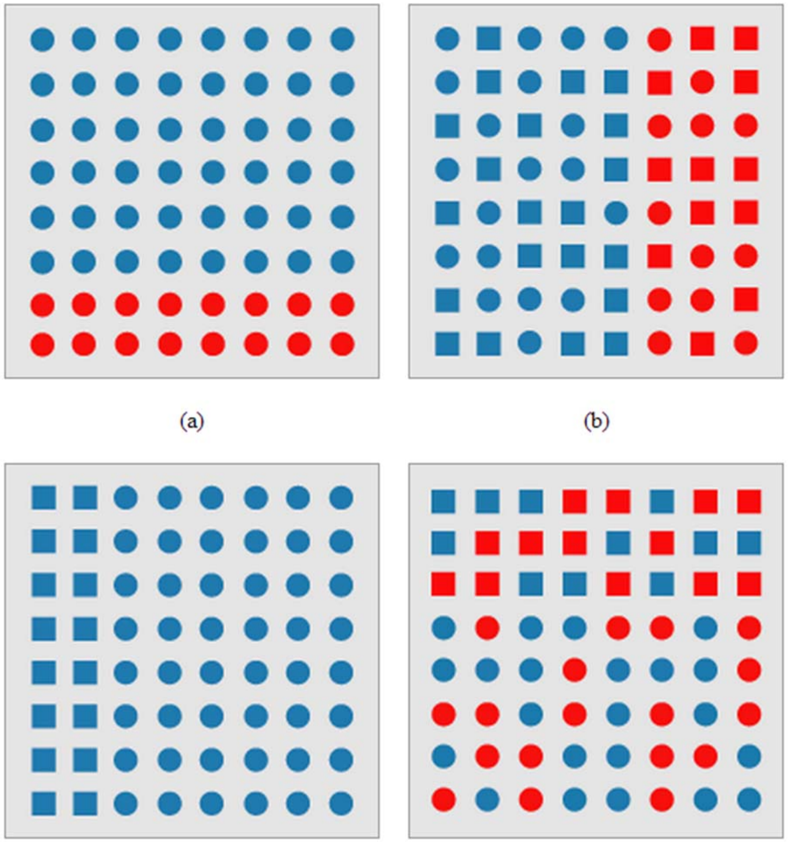
Why do we need visualization?



[Few, 2006]

Feature Hierarchy – for MD data

- Assign different visual features to different data attributes
- For certain tasks, the visual system seems to favor one type of visual feature over another

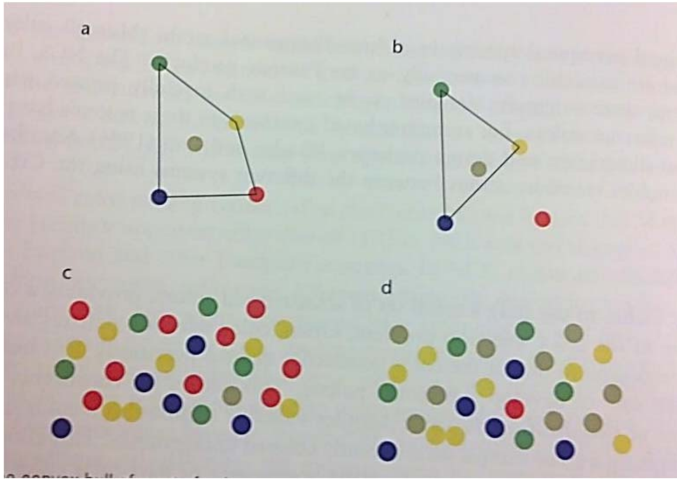


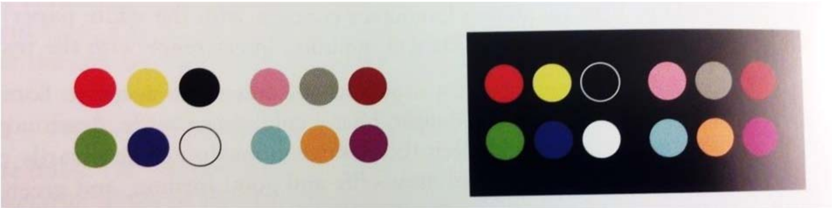
(a) (b) (c) (d)

Hue vs. Shapes

Color – Choice

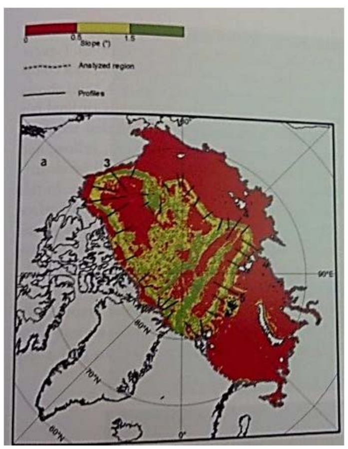
- 7 factors to consider while choosing colors:
  - Distinctness
  - Unique hues
  - Contrast with background
  - Number → Difference
  - Field Size
  - Color blindness, Conventions





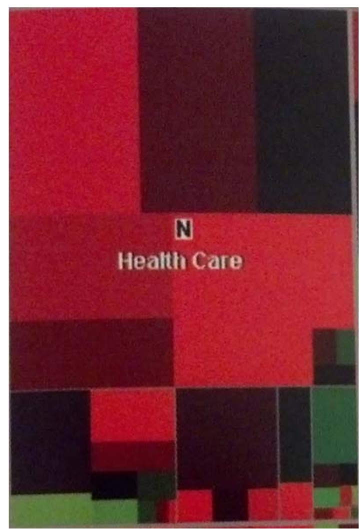
Color – Sequence for Data Maps

- **Pseudocoloring:** Representing continuously varying map values using a sequence of colors
  - Astronomical Radiation charts, medical imaging

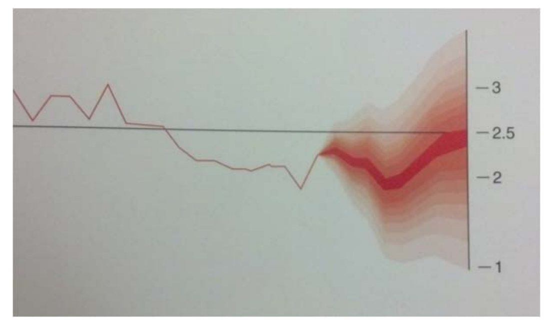


Nominal
Rapid Classification, No order

Ordinal
Monotonic Ordering, Continuous



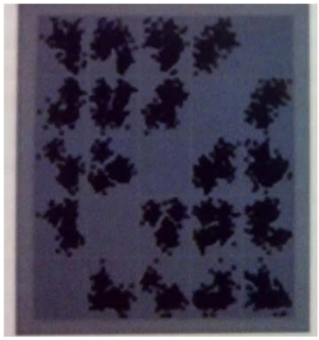
Ratio
Sign of the value, true zero



Interval
each step = equal change in magnitude

Color – Exploration of Data

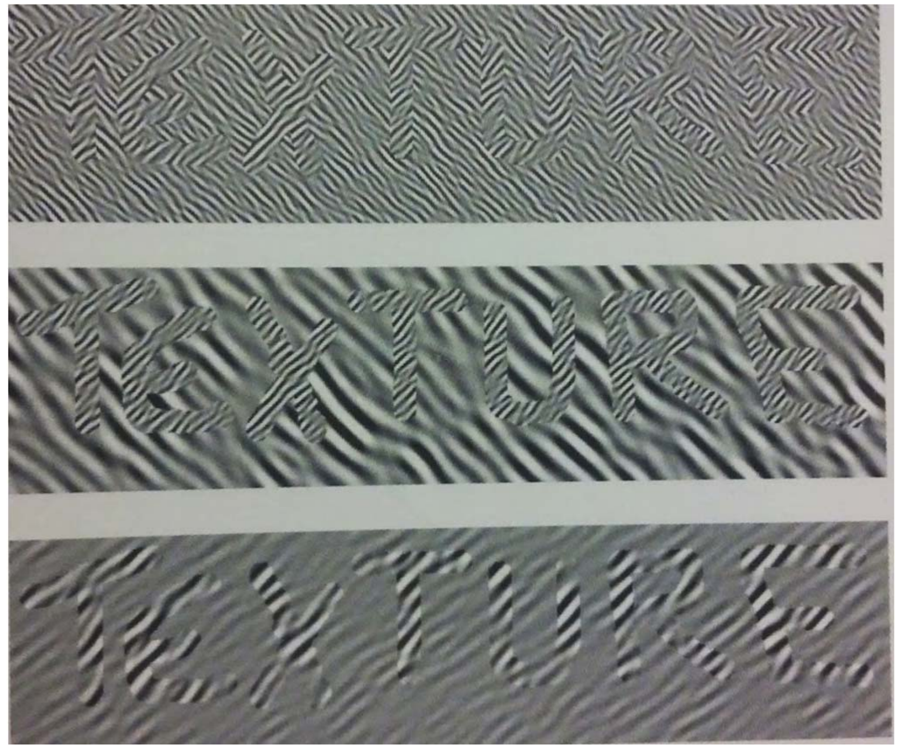
- Exploring **multidimensional** discrete data
- Plot the data, look for pattern and interpret the findings
  - Critical for discovery → act of perception



- Problem with plotting data beyond 3D
- *Solution 1*: **generalized drafter's plot**
  - Display scatter plot pairs of data
  - Disadvantage: difficult to see patterns in >2 dimensions
- *Solution 2*: **color-mapped scatter plot**
  - var1 = x, var2 = y, var3 = amount of red
    var4 = amount of green, var5 = amount of blue

Texture

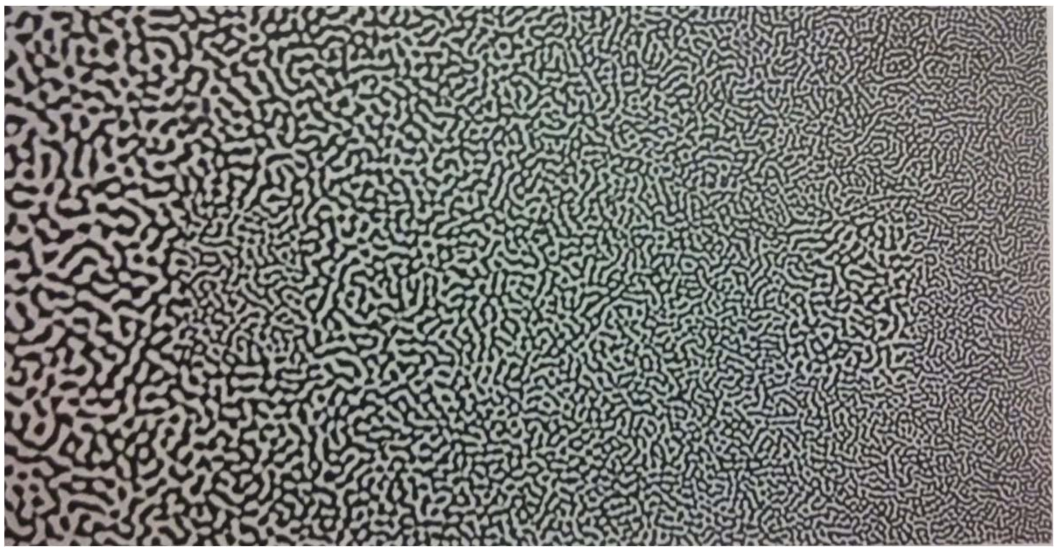
- Dependent on orientation, size and contrast
- For textures to be visually distinct
  - Dominant **spatial features** should differ by at least factor of 3 or 4
  - Dominant **orientations** should differ by more than 30 degrees

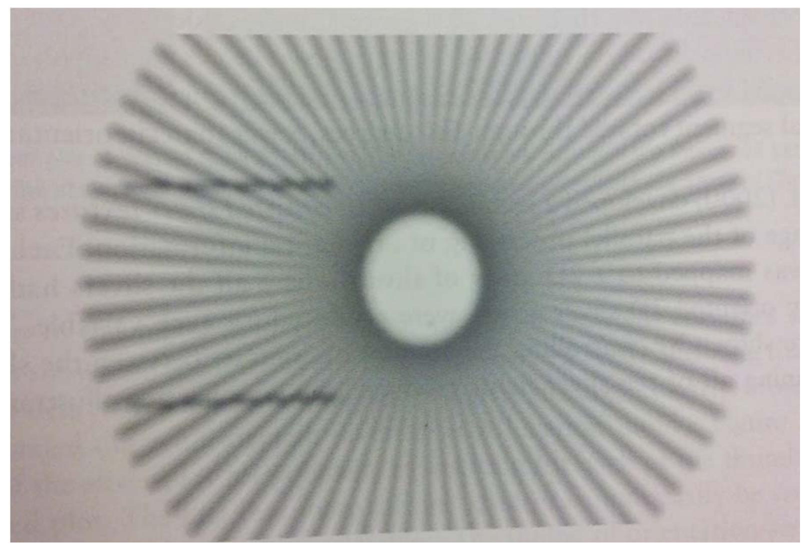


a) Orientation,
b) Orientation + spatial frequency
c) Contrast

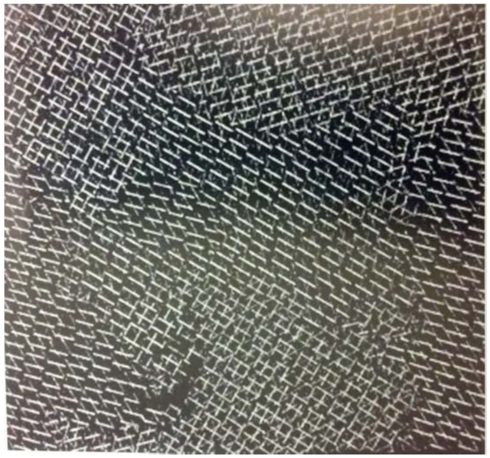
Texture Contrast Effects

- Contrast may affect the appearance of the texture and its meaning



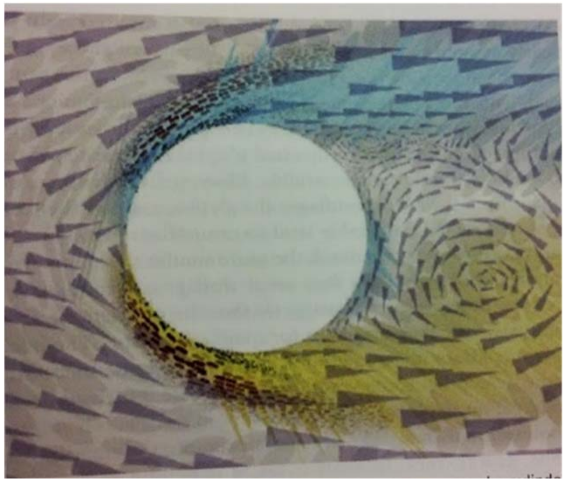


Use of Texture in Displays

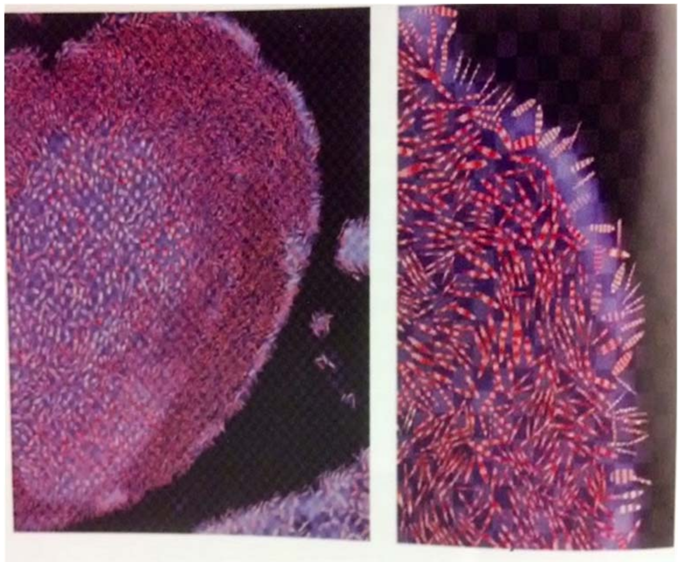


Sliver plot with 8 orientations

sliver plot with 3
orientations, color
for 4th variable



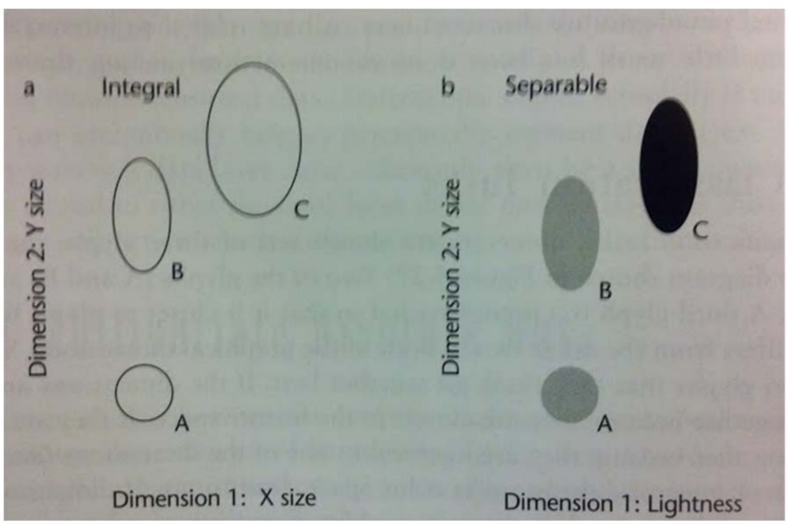
Flow



Combination of properties

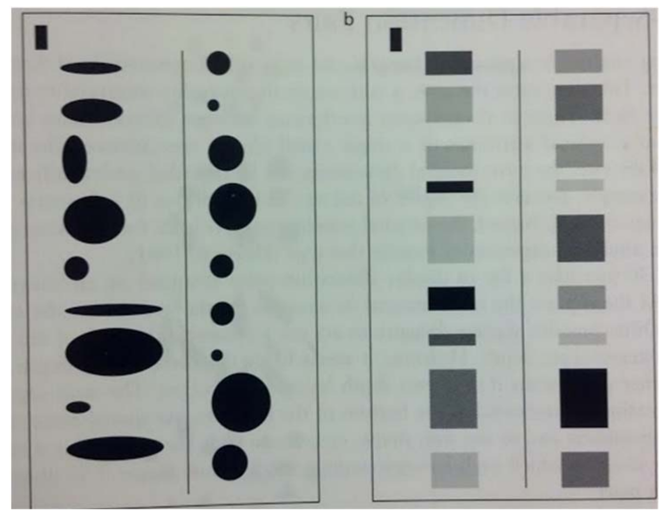
Glyphs and Multivariate Discrete Data

- Use a shape to show multiple attributes
- Perceptual independence of the display dimensions:
  - Integral Dimensions (length and width of rectangle)
  - Separable Dimensions (radius and color of a ball)



Restricted classification

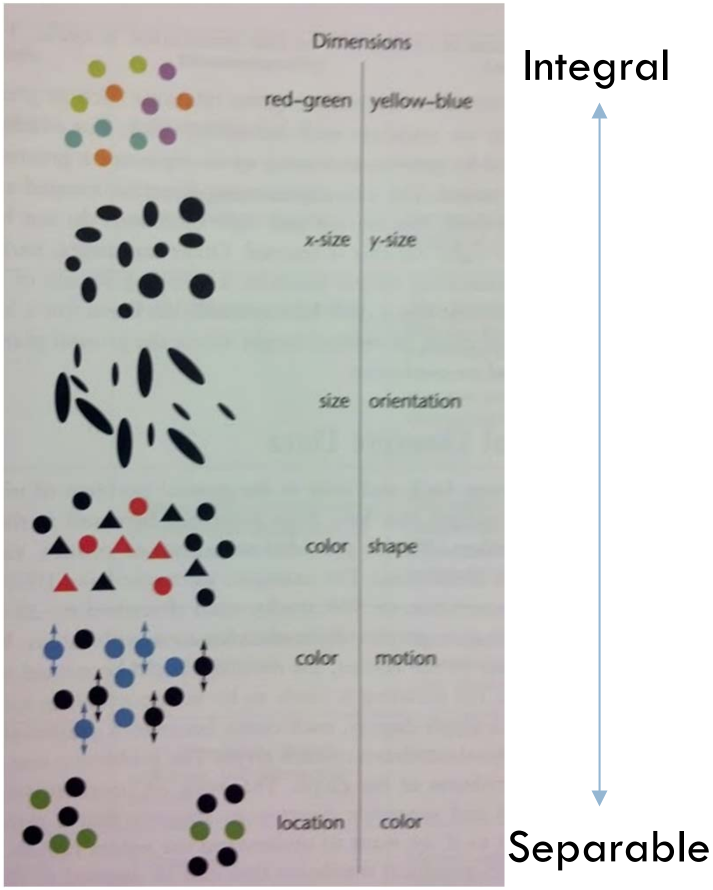
Integral Separable



Speeded classification tasks

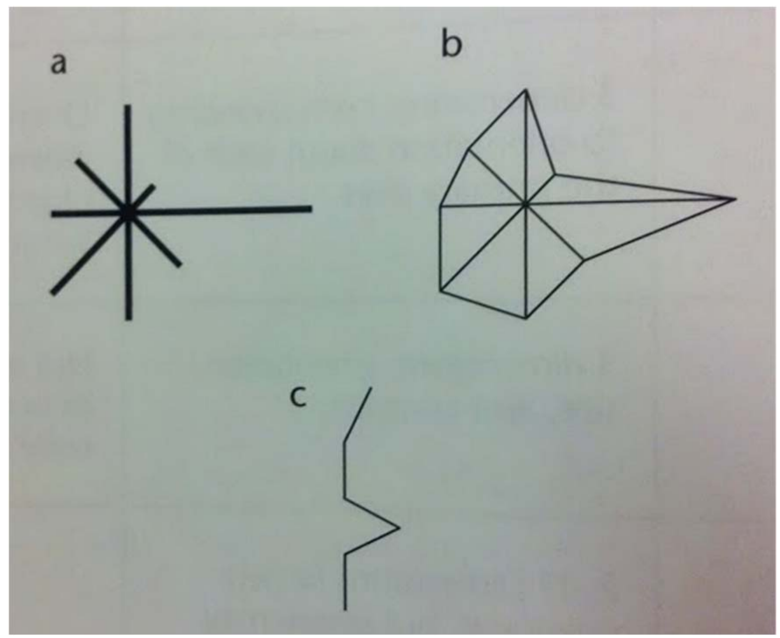
Dimensions- Key points

- If we want users to respond holistically, use **integral** dimensions
- If we want users to respond analytically, understanding one variable at a time, then **separable**
  - Considers color blindness



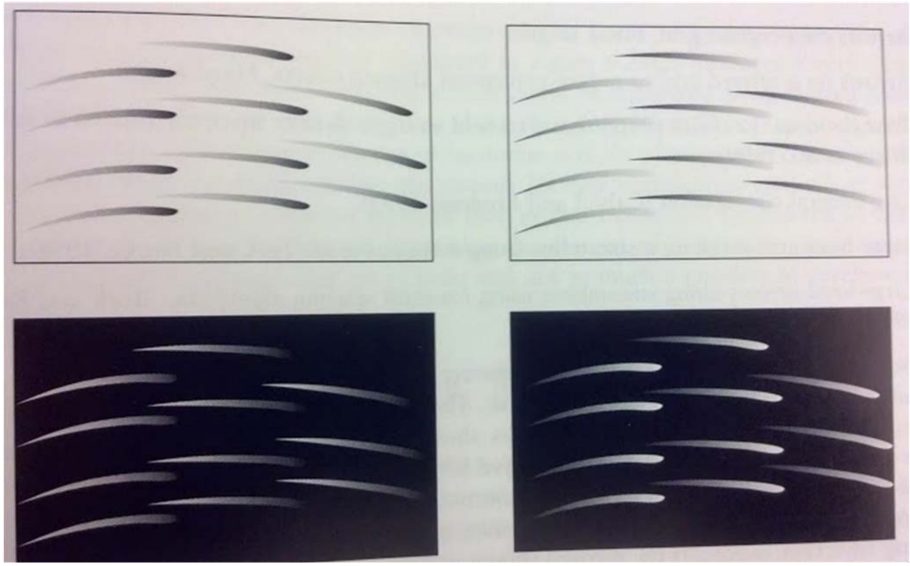
Multidimensional Discrete Data

- Preattentive processing, “early visual processing”, integral & separable dimensions suggest a limited set of visual attributes
- Whiskers, Stars, Excvis
  - Can use colors



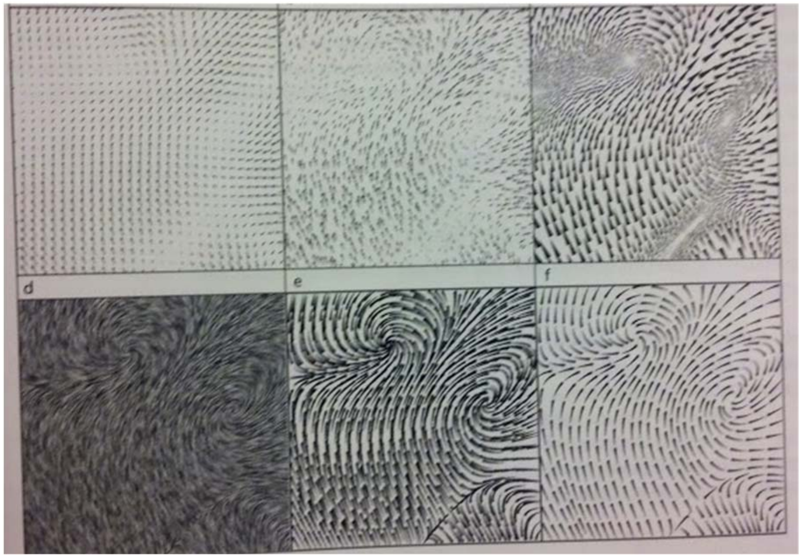
Perceiving Direction

Vector Field Streamlines



Vector direction w.r.t background

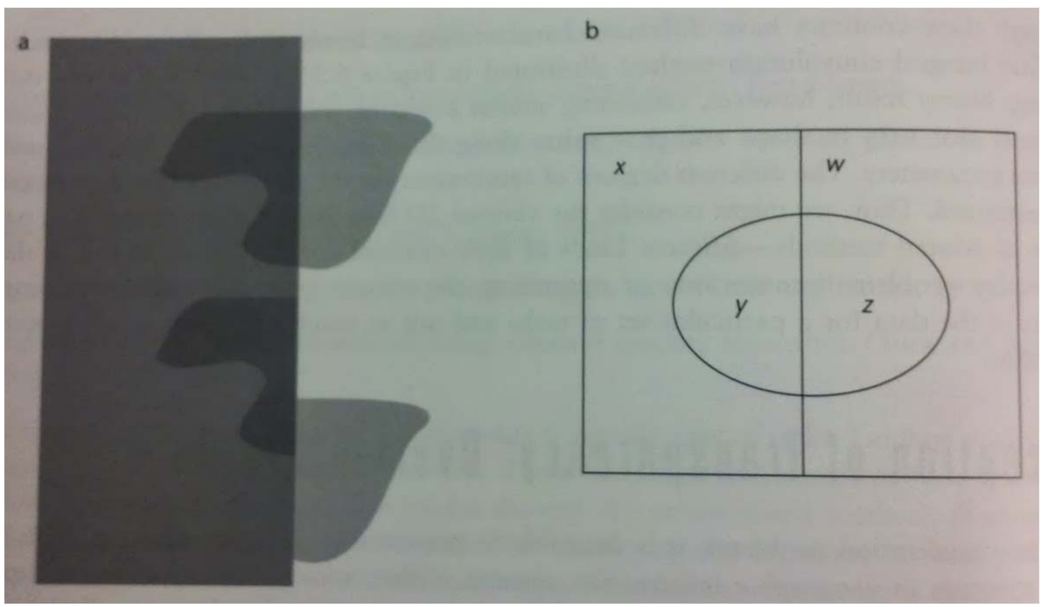
Comparing 2D Flow Viz Techniques



- Factors to consider while making choices:
  - Identification of location and nature of critical points
  - Judging the flow - “advection trajectory”
  - Perceiving patterns of high and low velocity
  - Perceiving patterns of high and low vorticity (curl)
  - Perceiving patters of high and low turbulence

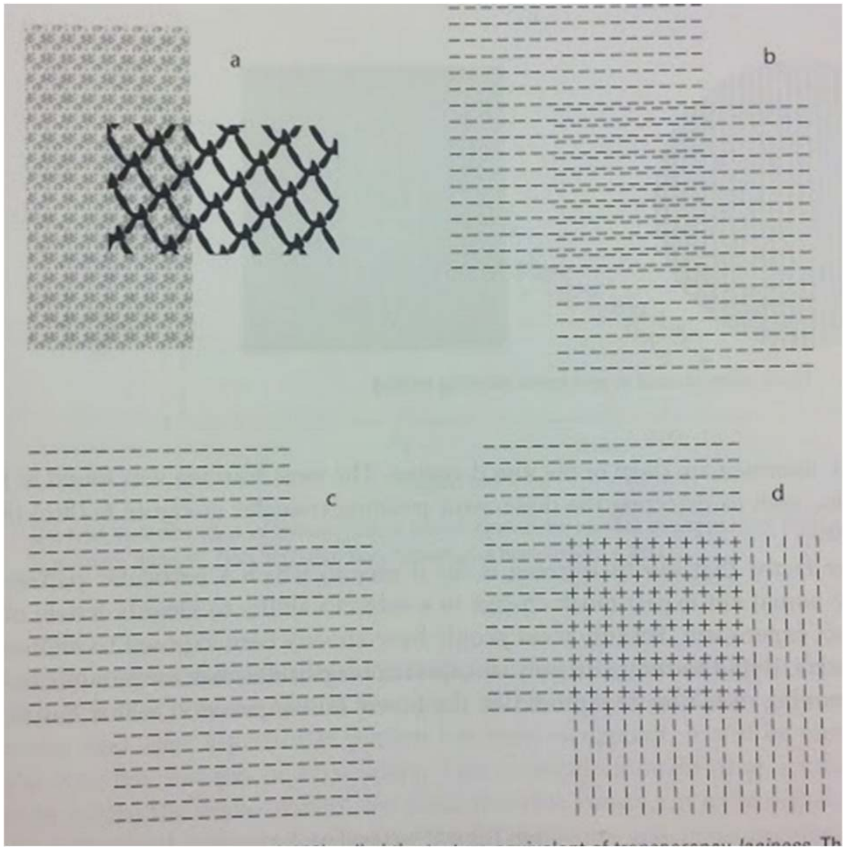
Transparency - I

- Represent data in layered form
  - GIS, Web Interfaces
- Factors to consider: Continuity and ratio of colors



Transparency - II

- **Laciness**: Conditions in which image is perceived as two distinct layers instead of one fused
- General interference rules apply especially in the case of interface designs
  - Play with combinations of colors, texture, motion, etc



Pattern Learning

- Use the fact that people observe patterns in data to present relations
- Some people may take time to "learn" but then it will be easy
- **Familiarity**: Can make use of patterns that are familiar to people (example: lines between points)
  - Use patterns familiar to skills/research
  - Show examples ahead of time for them to notice later

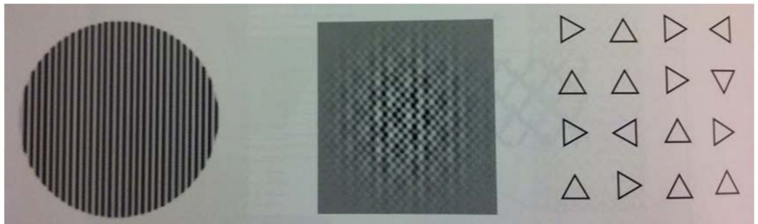
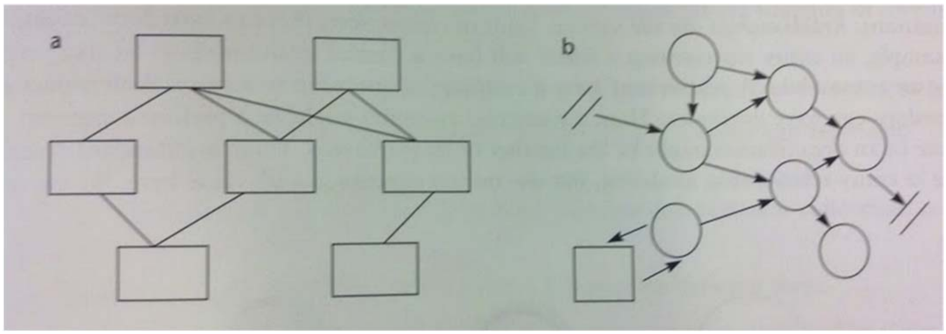
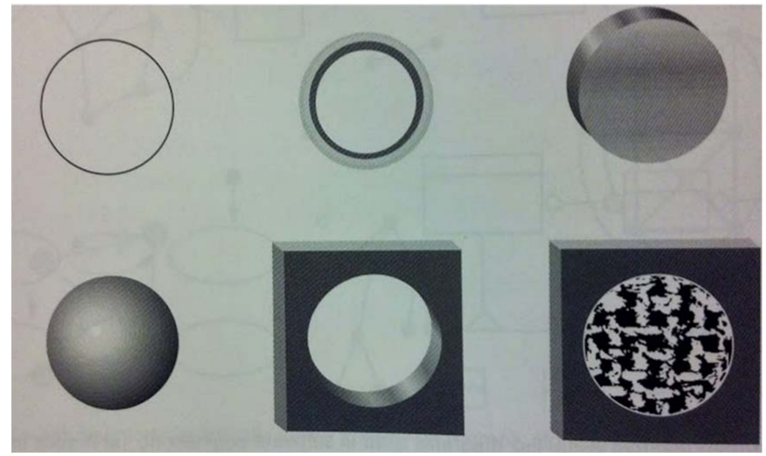


Figure 6.28 Three patterns used in perceptual learning studies.

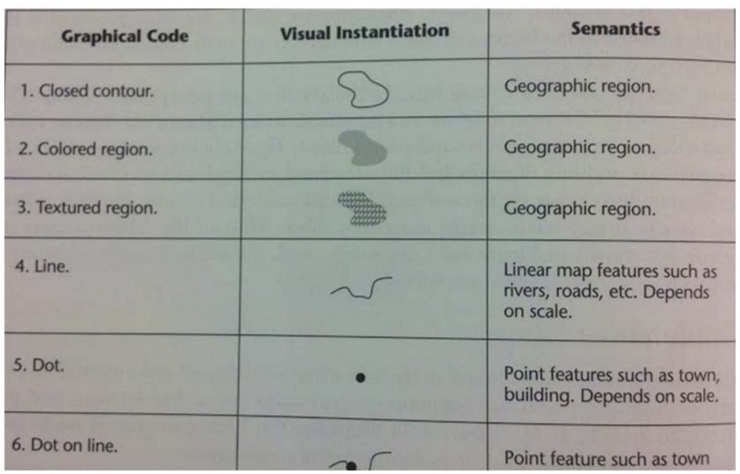
Diagrams (Abstract Representation)



Node Link Diagrams

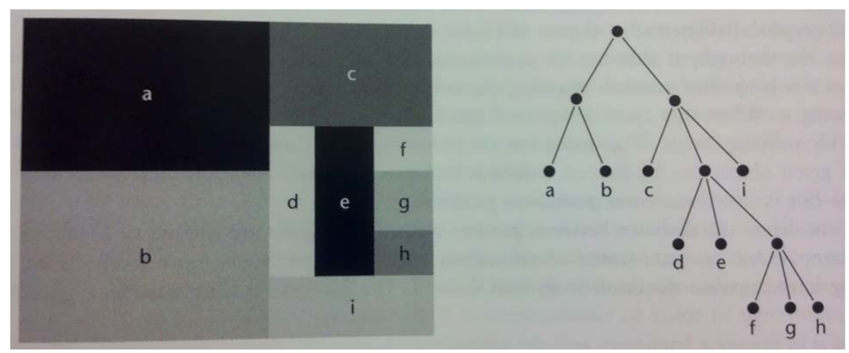


Various representations



Graphical Code	Visual Instantiation	Semantics
1. Closed contour.		Geographic region.
2. Colored region.		Geographic region.
3. Textured region.		Geographic region.
4. Line.		Linear map features such as rivers, roads, etc. Depends on scale.
5. Dot.		Point features such as town, building. Depends on scale.
6. Dot on line.		Point feature such as town

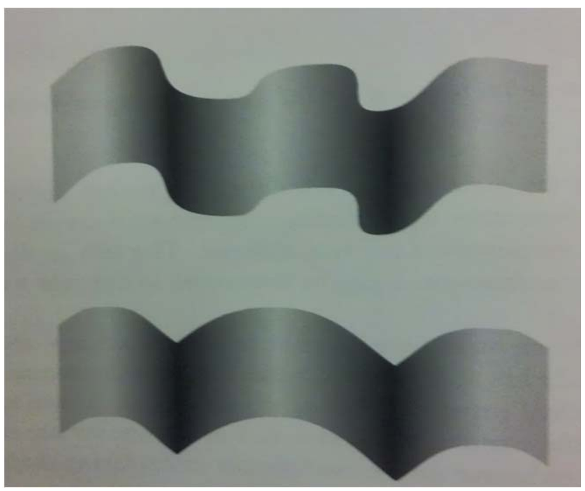
Grammar of Maps



Treemap

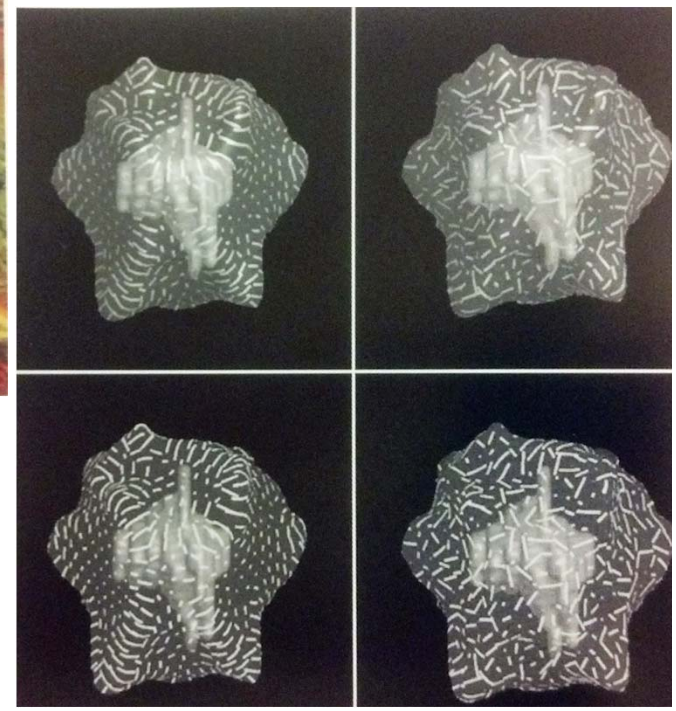
Perceiving the Surface Shapes

- Spatial cues effective for graphics



Shading and Contours

Shading models - Lighting



Surface Texture - Lacing

Perceiving the Surface Shapes

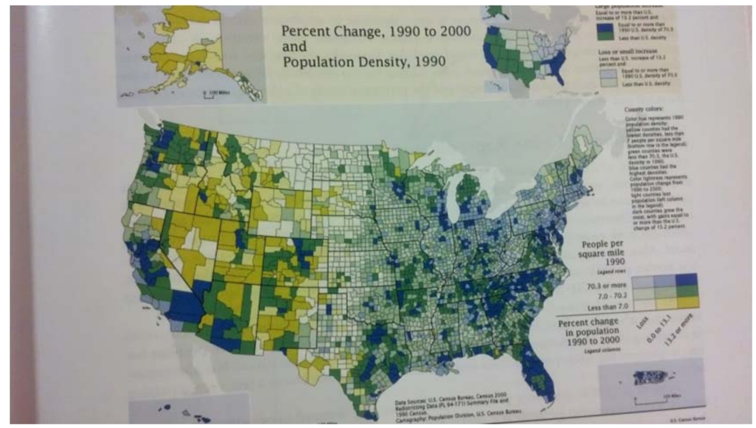
- General guidelines:
  - Simple lighting model should be normally used
  - Inter-reflection must be avoided
  - Specular reflection is useful to reveal fine details
  - Cast shadows can be used ONLY if they don't interfere with other information
  - Surfaces must be textured, but low contrast to avoid interference with shading information

Cushion Maps

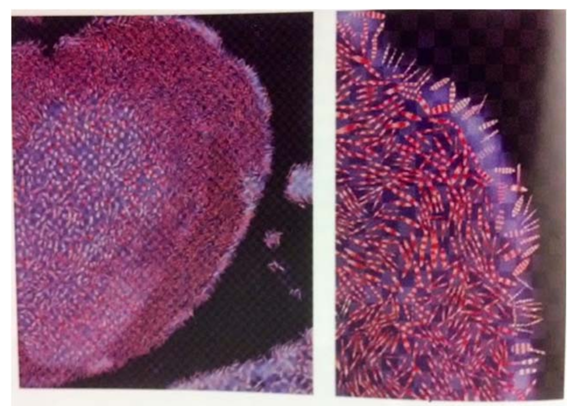
- Use shading to treemaps for better visualization especially of smaller branches

Multidimensional Data Exploration and Visualization - Summary

- Feature Hierarchy
- Color
  - Chrominance and luminance
- Texture
- Glyphs, Stars, Whiskers
  - Integral vs. Separable dimensions
- Surface Shapes
- Combination of all



Chrominance and luminance



Combination of properties

Images vs. Words

- Relationship between visual information and verbal/textual information, for example: labels
- Images:
  - Relationships
  - Better remembered, but not in the case of abstract or new information
  - Details and appearances
- Words/ spoken:
  - Abstract concepts – freedom, etc.
  - Procedural information
  - Program logic
  - Conditions in information

Images, Words, and Gestures

- "Dual coding" is better
  - Active learning in both visual and verbal cognitive subsystems is the most effective
- Diexis
  - Use of gesture to connect spoken words to a visual reference
  - Results in fewer misunderstandings
  - Rules of thumb:
    - If spoken words are to be connected to visualization, then the image must be highlighted just before the speech
    - If written text is to be connected o visualization, links should be made at the end of each relevant sentence of phrase
- Techniques are being applied in the design of programming languages (example: ToonTalk)

Conclusion

- Preattentive Processing
  - What attracts our attention?
- Postattentive Vision
- Change Blindness
- Perceptual properties of
  - Color
  - Texture/Glyphs
  - Motion/2D Flow data
  - Transparency
  - Pattern Learning
  - Diagrams
  - Surface shapes of Objects/Cushion Maps
  - Images, words and gestures
- Different ways of displaying Multivariate Data

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