Perception

Sungahn Ko

HAiV

0

Disclaimer

UNIST HAiV

- **The slides cannot be distributed, posted or used outside of this class**
- **Slides in this course courtesy of**
  - Dr. Abish Malik (Purdue)
  - Dr. Yun Jang (Sejong Univ.)
  - Dr. Ross Maciejewski (ASU)
  - Dr. Niklas Elmqvist (UMD)
  - Dr. David Ebert (Purdue)

1

1

Perception

- A key goal of visualization is to produce images of data that support visual analysis[1]
- Human perception plays an important role in visualization
- How we "see" details directly impact the efficiency and effectiveness of an image (Mackinlay's criteria[2])

1 - C. Healey and J. Enns, "Attention and Visual Memory in Visualization and Computer Graphics", IEEE Transaction s on Visualization and Computer Graphics, 2011 (Pre-print)
2 - J. Mackinlay, Automating the Design of Graphical Presentations of Relational Information, ACM Transactions on Graphics, 5(2): 110-141, 1986.
3 - Ware, C. *Information Visualization: Perception for Design.* Morgan Kaufmann Publishers, Inc., San Francisco, Cal ifornia, 2000.

2

2

Perception

- By understanding perception, we can improve the quality and quantity of information being displayed[3]

1 - C. Healey and J. Enns, "Attention and Visual Memory in Visualization and Computer Graphics", IEEE Transaction s on Visualization and Computer Graphics, 2011 (Pre-print)
2 - J. Mackinlay, Automating the Design of Graphical Presentations of Relational Information, ACM Transactions on Graphics, 5(2): 110-141, 1986.
3 - Ware, C. *Information Visualization: Perception for Design.* Morgan Kaufmann Publishers, Inc., San Francisco, Cal ifornia, 2000.

3

3

Psychophysics

- The scientific study of the relation between the stimulus and the sensation[1]
- The analysis of the perceptual processes by studying the effect on a subject's experience or behavior of systematically varying the properties of a stimulus along one or more physical dimensions[2]
- Refers to a general class of methods that can be applied to study a perceptual system

1 – G. Gescheider, *Psychophysics: The Fundamentals*. Lawrence Erlbaum Associates. 1997
2 – V Bruce, PR Green and MA Georgeson. *Visual perception* (3rd ed.). Psychology Press. 1996

4

4

Just Noticeable Difference (JND)

- Smallest detectable difference between a starting and secondary level of a particular sensory stimulus (also referred to as the difference limen)
- For many sensory modalities, the JND is a fixed proportion (in the mid-range of measurements away from the upper and lower bounds)

EH Weber, HE Ross and DJ Murray, *EH Weber on the Tactile Senses*. Psychology Press; 2nd Revised edition editio
n (January 1, 1996)

5

5

Just Noticeable Difference (JND)

- **Proportion of physical measurements $\frac{\Delta I}{I}$=k is what is important (I is the intensity of the stimulation, ΔI is the addition to the stimulation required for the observer to notice)**
- **This is referred to as *Weber's Law* or the *Weber-Fechner Law***

EH Weber, HE Ross and DJ Murray, *EH Weber on the Tactile Senses*. Psychology Press; 2nd Revised edition editio n (January 1, 1996)

6

6

Just Noticeable Difference

- **This is a statistical measurement, not an exact quantity**
- **From trial to trial, the difference one notices will vary**
- **Must conduct many trials in order to determine a threshold**
- **JND is usually reported as the difference at which a person notices 50% of the time**
- **Depends on the situational, motivational and perceptual factors**

7

7

Steven's Power Law

- Proposed relationship between the magnitude of a physical stimulus and its perceived intensity or strength: $S = kI^a$
- Considered to supersede Weber's law on the basis that it descries a wider range of sensations
- S is the subjective magnitude of the stimulation
- k is the proportionality constant that depends on the type of stimulation

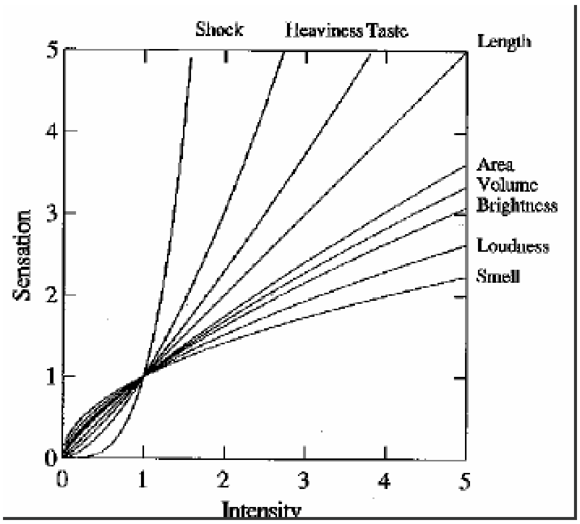
Stevens, S.S. (1957). "On the psychophysical law". *Psychological Review* **64** (3): 153–181

Steven's Power Law

- I is the magnitude of the physical stimulus
- a is the exponent that depends on the type of stimulation

Stevens, S.S. (1957). "On the psychophysical law". *Psychological Review* **64** (3): 153–181

Steven's Power Law



Sensation	Exponent
Loudness	.6
Brightness	.33
Smell	.55 (Coffee) - .6 (Heptane)
Temperature	1.0 (Cold) – 1.6 (Warm)
Heaviness	.1.45
Electric Shock	3.5

Stevens, S.S. (1957). "On the psychophysical law". *Psychological Review* **64** (3): 153–181

Visual Processing

- **Detailed vision is only possible within a small portion of the visible field (approximately an area the size of your thumbnail at an arms length away[1])**
- **To see detailed information from more than one region, the eyes move rapidly between areas**
- **This alternates between a brief stationary period (a fixation) and flicking rapidly to a new location during a brief period of blindness (a saccade – takes at least 200 ms)**

1 - C. Healey and J. Enns, "Attention and Visual Memory in Visualization and Computer Graphics", IEEE Transactions on Visualization and Computer Graphics, 2011 (Pre-print)
2 – A. Yarbus, *Eye Movements and Vision*. New York, New York: Plenum Press, 1967

Visual Processing

- This occurs 3-4 times per second with little awareness on our part[2]

1 - C. Healey and J. Enns, "Attention and Visual Memory in Visualization and Computer Graphics", IEEE Transactions on Visualization and Computer Graphics, 2011 (Pre-print)
2 – A. Yarbus, *Eye Movements and Vision*. New York, New York: Plenum Press, 1967

Visual Attention

- Visual attention is the term used to denote the mechanisms which determine which regions of an image are selected for more focus
- What is attention?
  - Ability to focus on a task
  - Ability to concentrate

1 - C. Healey and J. Enns, "Attention and Visual Memory in Visualization and Computer Graphics", IEEE Transactions on Visualization and Computer Graphics, 2011 (Pre-print)

Visual Attention

- **Aspects of attention**
  - Selective attention
  - Divided attention
  - Automaticity

1 - C. Healey and J. Enns, "Attention and Visual Memory in Visualization and Computer Graphics", IEEE Transactions on Visualization and Computer Graphics, 2011 (Pre-print)

14

14

Selective Visual Attention

- **It is difficult to attend to more than one thing at the same time**
- **When we attend to one task over the other, this is selective attention**
- **Classic Stroop task – Read aloud the color of the word, not the word itself**

Stroop, John Ridley (1935). "Studies of interference in serial verbal reactions". *Journal of Experimental Psychology* **18** (6): 643–66

15

15

Theoretical Interpretations of Selective Attention

- **Bottleneck/filter theories**
  - A bottleneck is a mechanism that limits the amount of info rmation to be attended to
- ***Early selection*[1] - select one message for further proces sing and all others are lost**
- ***Attenuation*[2] – select one message for full processing, others are partially processed**
- ***Late selection*[3] – all messages get through but only one is selected for processing**

1 – D. E. Broadbent, *Perception and Communication*. Oxford, United Kingdom: Oxford University Press, 1958
2 – A. Triesman, “Monitoring and storage of irrelevant messages in selective attention,” *Psychological Review* **87**: 272-300
3 – J. A. Deutsch and D. Deutsch, "Attention: some theoretical considerations,“ *Psychological Review* **70**: 80–90

Pre-attentive Processing

- **Early studies made an important discovery – a limited set of visual features can be detected very rapidly by low-level, fast-acting processes**
- **Human vision rapidly and automatically categorizes visual images into regions and properties based on simple computations**

C. Healey and J. Enns, “Attention and Visual Memory in Visualization and Computer Graphics”, IEEE Transactions on Visualization and Co mputer Graphics, 2011 (Pre-print)

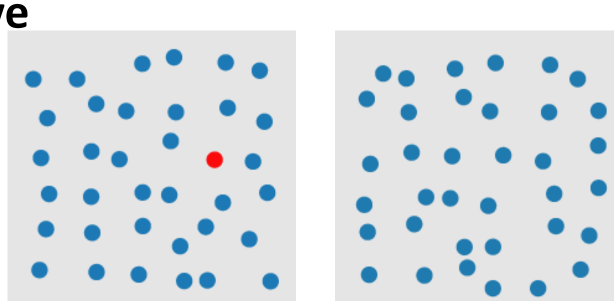
Pre-attentive Processing

- These computations are done in parallel across the image
- These properties are called pre-attentive since their detection seems to precede focused attention

C. Healey and J. Enns, “Attention and Visual Memory in Visualization and Computer Graphics”, IEEE Transactions on Visualization and Computer Graphics, 2011 (Pre-print)

Pre-attentive Processing

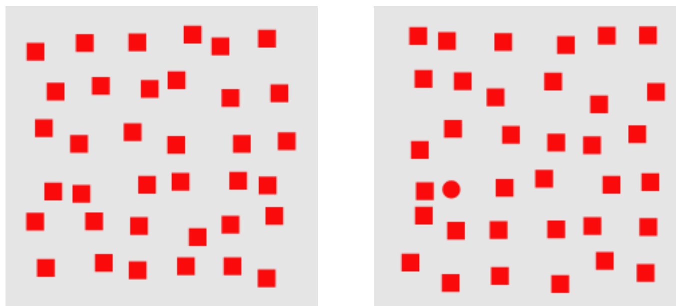
- Tasks that can be performed on large multi-element displays in less than 200-250 ms are considered pre-attentive



An example of searching for a target red circle based on a difference in hue:
(a) target is present in a sea of blue circle distractors; (b) target is absent

C. Healey and J. Enns, “Attention and Visual Memory in Visualization and Computer Graphics”, IEEE Transactions on Visualization and Computer Graphics, 2011 (Pre-print)

Pre-attentive Processing



An example of searching for a target red circle based on a difference in curvature: (a) target is absent in a sea of red square distractors; (b) target is present

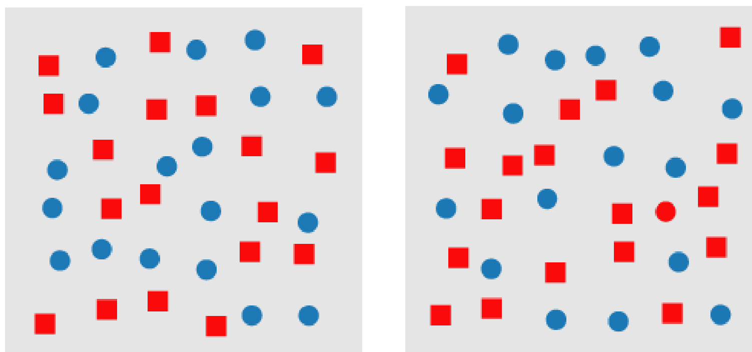
C. Healey and J. Enns, "Attention and Visual Memory in Visualization and Computer Graphics", IEEE Transactions on Visualization and Co mputer Graphics, 2011 (Pre-print)

Pre-attentive Processing

- **In the last two examples, we saw hue and shape as a pre-attentive visual feature**
- **A target identified by a unique visual property allows it to "pop out" of the display**
- **This implies that it is easily detected regardless of the distracters**
- **What happens if we combined two or more visual features?**

C. Healey and J. Enns, "Attention and Visual Memory in Visualization and Computer Graphics", IEEE Transactions on Visualization and Co mputer Graphics, 2011 (Pre-print)

Pre-attentive Processing



An example of a conjunction search for a target red circle: (a) target is absent in a sea of red square and blue circle distractors; (b) target is present

C. Healey and J. Enns, "Attention and Visual Memory in Visualization and Computer Graphics", IEEE Transactions on Visualization and Computer Graphics, 2011 (Pre-print)

22

22

Pre-attentive Features

- **Experiments in psychology have used features to perform the following pre-attentive visual tasks**
- ***Target detection* – users rapidly and accurately detect the presence or absence of a target with a unique visual feature**
- ***Boundary detection* – users rapidly and accurately detect a texture boundary between two groups of elements, where all of the elements in each group have a common visual property**

C. Healey and J. Enns, "Attention and Visual Memory in Visualization and Computer Graphics", IEEE Transactions on Visualization and Computer Graphics, 2011 (Pre-print)

23

23

Pre-attentive Features

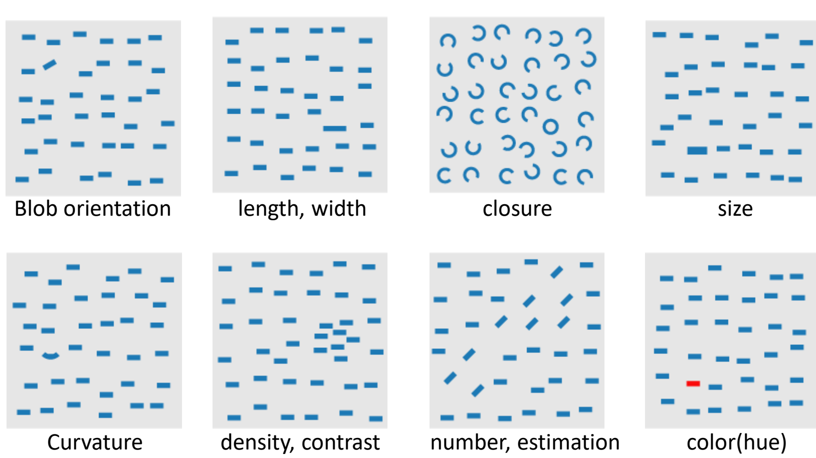
- ***Region tracking*** **– users track one or more elements with a unique visual feature as the move in time and space**
- ***Counting and estimation*** **– users count or estimate the number of elements with a unique visual feature**

C. Healey and J. Enns, "Attention and Visual Memory in Visualization and Computer Graphics", IEEE Transactions on Visualization and Computer Graphics, 2011 (Pre-print)

24

24

Partial List of Pre-Attentive Visual Features

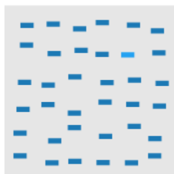


C. Healey and J. Enns, "Attention and Visual Memory in Visualization and Computer Graphics", IEEE Transactions on Visualization and Computer Graphics, 2011 (Pre-print)

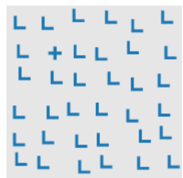
25

25

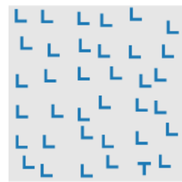
Partial List of Pre-Attentive Visual Features



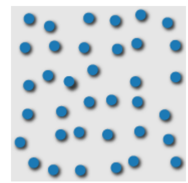
Intensity/luminance



intersection



terminators



3D depth cues

Others include direction of motion, velocity of motion and lighting direction

C. Healey and J. Enns, "Attention and Visual Memory in Visualization and Computer Graphics", IEEE Transactions on Visualization and Co mputer Graphics, 2011 (Pre-print)

Pre-Attentive Visual Features

- These features were measured through a series of experiments using target and boundary detection
- Performance was measured by response time and accuracy
- *Response time* – viewers are asked to complete the task as quickly as possible while maintaining a high level of accuracy

C. Healey and J. Enns, "Attention and Visual Memory in Visualization and Computer Graphics", IEEE Transactions on Visualization and Co mputer Graphics, 2011 (Pre-print)

Pre-Attentive Visual Features

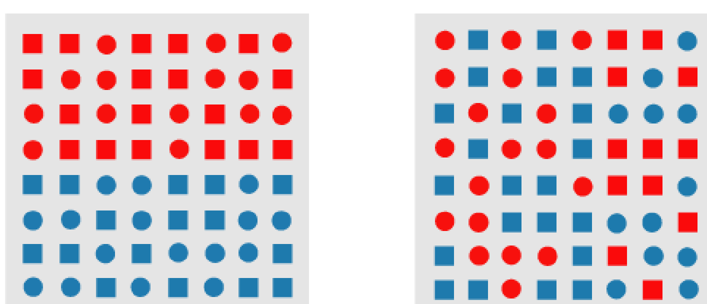
- *Accuracy* – display is shown for a small duration then removed, if the viewer can complete the task accurately regardless of the number of distractors then a feature is assumed to be preattentive

C. Healey and J. Enns, “Attention and Visual Memory in Visualization and Computer Graphics”, IEEE Transactions on Visualization and Co mputer Graphics, 2011 (Pre-print)

28

28

Boundary Detection Experiment



An example of a boundary detection from Treisman's experiments: (a) a boundary defined by a unique feature hue (red circles and red squares on the top, blue circles and blue squares on the bottom) is pre-attentively classified as horizontal; (b) a boundary defined by a conjunction of features (red circles and blue squares on the left, blue circles and red squares on the right) cannot be pre-attentively classified as vertical

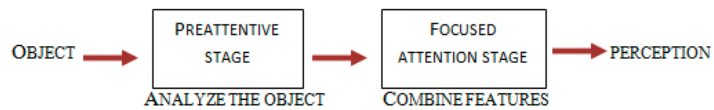
C. Healey and J. Enns, “Attention and Visual Memory in Visualization and Computer Graphics”, IEEE Transactions on Visualization and Co mputer Graphics, 2011 (Pre-print)

29

29

Feature Integration Theory

- **Posited that there are two stages of visual processing, the pre-attentive stage and the focused attention stage**



- **Pre-attentive stage**
  - Primary visual features are processed
  - Objects are analyzed with details (shape, color, etc.)
  - Each aspect is processed in different areas of the brain

1 - Anne Treisman and Garry Gelade (1980). "A feature-integration theory of attention." *Cognitive Psychology*, Vol. 12, No. 1, pp. 97-136
2 - C. Healey and J. Enns, "Attention and Visual Memory in Visualization and Computer Graphics", IEEE Transactions on Visualization and Computer Graphics, 2011 (Pre-print)

30

30

Feature Integration Theory

- **Focused attention stage**
  - Integrate individual features in order to perceive object
  - If object is familiar, associations between object and prior knowledge are made

1 - Anne Treisman and Garry Gelade (1980). "A feature-integration theory of attention." *Cognitive Psychology*, Vol. 12, No. 1, pp. 97-136
2 - C. Healey and J. Enns, "Attention and Visual Memory in Visualization and Computer Graphics", IEEE Transactions on Visualization and Computer Graphics, 2011 (Pre-print)

31

31

Similarity Theory

- **Not all researchers believe in the parallel/serial dichotomy**
- **Similarity theory assumes that search ability varies depending on both the type of task and display conditions**
- **Search time is based on two criteria**
  - *T-N similarity*: amount of similarity between targets and non-targets
  - *N-N similarity*: amount of similarity within the non-targets

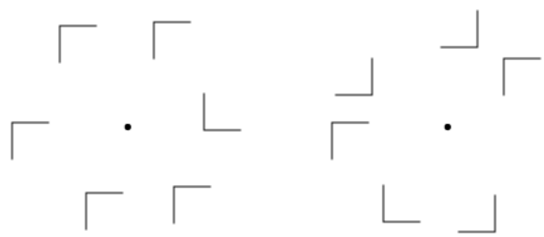
1 - Duncan, J. and Humphreys, G. W. Visual search and stimulus similarity. *Psychological Review 96*, 3 (1989), 433–458.
2 - C. Healey and J. Enns, "Attention and Visual Memory in Visualization and Computer Graphics", IEEE Transactions on Visualization and Computer Graphics, 2011 (Pre-print)

Similarity Theory

- **As T-N similarity increases, search efficiency decreases and search time increases**
- **As N-N similarity decreases, search efficiency decreases and search time increases**

1 - Duncan, J. and Humphreys, G. W. Visual search and stimulus similarity. *Psychological Review 96*, 3 (1989), 433–458.
2 - C. Healey and J. Enns, "Attention and Visual Memory in Visualization and Computer Graphics", IEEE Transactions on Visualization and Computer Graphics, 2011 (Pre-print)

Similarity Theory (Find 'L')



Example of N-N similarity affecting search efficiency for a target shaped like the letter L: (a) high N-N (nontarget-nontarget) similarity allows easy detection of ta rget L; (b) low N-N similarity increases the difficulty of detecting the target L

1 - Duncan, J. and Humphreys, G. W. Visual search and stimulus similarity. *Psychological Review 96*, 3 (1989), 433–458.
2 - C. Healey and J. Enns, "Attention and Visual Memory in Visualization and Computer Graphics", IEEE Transactions on Visualization and Computer Graphics, 2011 (Pre-print)

Guided Search Theory

- **Posits that there are two ways in which pre-attentive processes can be used to direct attention:**
  - *Bottom-up processing* – stimulus driven
  - *Top-down processing* – user driven
- **Information from these two processes create a ranking of items in order of their attentional priority**
- **Follows concepts of the parallel search processing work**

1 - Wolfe, J. M. Guided Search 2.0: A revised model of visual search. *Psychonomic Bulletin & Review 1*, 2 (1994), 202–238.
2 - C. Healey and J. Enns, "Attention and Visual Memory in Visualization and Computer Graphics", IEEE Transactions on Visualization and Computer Graphics, 2011 (Pre-print)

Boolean Map Theory

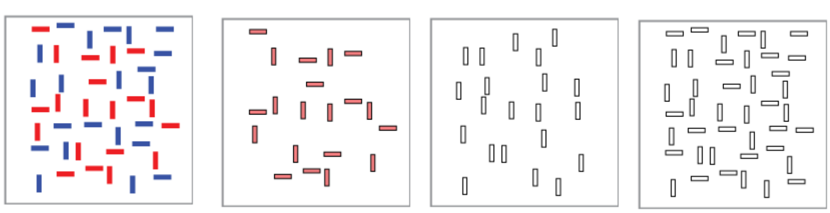
- **Divides visual search task into two parts**
  - *Selection*: involves choosing a set of objects from a scene
  - *Access*: determines what properties of the selected objects a viewer can apprehend
- **Previous work describes these steps as a whole, boolean theory posits them as separate steps**
- **Proposes that visual system is capable of dividing a scene into exactly two parts: selected elements and excluded elements**

1 - Huang, L. and Pashler, H. A boolean map theory of visual attention. *Psychological Review 114*, 3 (2007), 599–631
2 - C. Healey and J. Enns, "Attention and Visual Memory in Visualization and Computer Graphics", IEEE Transactions on Visualization and Computer Graphics, 2011 (Pre-print)

36

36

Boolean Map Theory



An example of creating boolean maps from an image.

1 - Huang, L. and Pashler, H. A boolean map theory of visual attention. *Psychological Review 114*, 3 (2007), 599–631
2 - C. Healey and J. Enns, "Attention and Visual Memory in Visualization and Computer Graphics", IEEE Transactions on Visualization and Computer Graphics, 2011 (Pre-print)

37

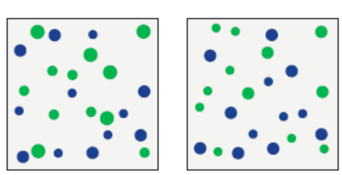
37

Ensemble Encoding

- **Low level visual processes are also able to generate quick summaries of how simple visual features are distributed**

Ensemble Encoding

- **Experiments have shown that observers could:**
  - Extract the average size of a large number of dots[1]
  - Extract the average orientation of a simple edge
  - Extract average color
  - Even extract higher level qualities such as emotions



1 - D. Ariely, "Seeing sets: Representation by statistical properties," *Psychological Science*, vol. 12, no. 2, pp. 157–162, 2001.
2 - C. Healey and J. Enns, "Attention and Visual Memory in Visualization and Computer Graphics", IEEE Transactions on Visualization and Computer Graphics, 2011 (Pre-print)

Feature Hierarchy

- **One of the most important considerations for a visualization designer is**
  - deciding how to present information in a display without producing visual confusion
- **Feature hierarchies suggest the most important data attributes should be displayed with the most salient visual features**

C. Healey and J. Enns, "Attention and Visual Memory in Visualization and Computer Graphics", IEEE Transactions on Visualization and Co mputer Graphics, 2011 (Pre-print)

Cleveland's Heirarchy[1]

- **Cleveland evaluated elements when isolated**
- **Tasks were restricted to magnitude and ratio comparisons**
- **Research indicates this hierarchy may be best in pre-attentive stages or when focusing only on portions of a graphic[2,3,4]**

Best

1 - Position along a common scale

2 – Position along nonaligned scales

3 – Length

4 – Angle/Slope

5 – Area

6 – Volume

7 - Color

Worst

1 – WS Cleveland, *The Elements of Graphing Data*, 1985
2 – Spence, I., and Lewandowsky, S. (1991). Displaying proportions and percentages. *Applied Cognitive Psychology* 5, 61-77
3 – Simkin, D., and Hastie, R. (1987). An information processing analysis of graph perception. *Journal of the American Statistic al Association*, 82, 454-465
4 – Carswell, C. M. (1992). Choosing specifiers: An evaluation of the basic tasks model of graphical perception. *Human Factors* , 4, 535-554

Change Blindness

- Vision is a dynamic process, things being built in our mind are short lived models of the external world
- What a viewer is searching for and what is presented can all have an effect on performance
- An interruption in what is being seen (a blink or blank screen) can render us “blind” to changes that occur in the scene during interruption

1 - R. A. Rensink, J. K. O'Regan, and J. J. Clark, “To see or not to see: The need for attention to perceive changes in scenes,” *Psychological Science*, vol. 8, pp. 368–373, 1997.
2 - C. Healey and J. Enns, “Attention and Visual Memory in Visualization and Computer Graphics”, IEEE Transactions on Visualization and Computer Graphics, 2011 (Pre-print)

42

42

Inattentional Blindness

- Viewers can completely fail to perceive visually salient objects or activities
- http://viscog.beckman.illinois.edu/flashmovie/15.php

1 - H. E. Egeth and S. Yantis, “Visual attention: Control, representation, and time course,” *Annual Review of Psychology*, vol. 48, pp. 269–297, 1997.
2 - C. Healey and J. Enns, “Attention and Visual Memory in Visualization and Computer Graphics”, IEEE Transactions on Visualization and Computer Graphics, 2011 (Pre-print)

43

43

Attentional Blink

- *Attentional blink* – used to study the availability of attention across time
- Findings indicate that when two targets are presented in rapid succession, the second of the two targets cannot be detected or identified when it appears within approximately 100-500 ms following the first target
- If the second target is presented immediately after the first, reports of the second target are quite accurate

1 - D. E. Broadbent and M. H. P. Broadbent, "From detection to identification: Response to multiple targets in rapid serial visual presentation," *Perception and Psychophysics*, vol. 42, no. 4, pp. 105– 113, 1987.
2 - C. Healey and J. Enns, "Attention and Visual Memory in Visualization and Computer Graphics", IEEE Transactions on Visualization and Computer Graphics, 2011 (Pre-print)

Implications of "Blindness" on Visualization

- Significant changes in data may be missed
- Need to ensure that attention is fully deployed on a specific location in a visualization
- Attending to data elements in one frame of an animation may render us temporarily blind to what follows at a location

C. Healey and J. Enns, "Attention and Visual Memory in Visualization and Computer Graphics", IEEE Transactions on Visualization and Co mputer Graphics, 2011 (Pre-print)

Perception in Visualization and Graphics

- **Proper choice of visual features will focus attention to areas in a visualization that contain important data**
- **Properly weighting the perceptual strength of the chosen data representation can help this**
- **Can also track attention to predict where a viewer will look allowing different parts of an image to be managed based on the amount of attention it is expected to receive**

C. Healey and J. Enns, "Attention and Visual Memory in Visualization and Computer Graphics", IEEE Transactions on Visualization and Co mputer Graphics, 2011 (Pre-print)

46

46

Readings

- **Require Readings:**
  - C. Healey and J. Enns, "Attention and Visual Memory in Visualization and Computer Graphics," IEEE Transactions on Visualization and Computer Graphics, 2011
  - C. Ware and W. Knight, "Using Visual Texture for Information Display," ACM Transactions on Graphics 14(1):3-20

47

47

Readings

- **Good References:**
  - Colin Ware:
    - http://www.ccom-jhc.unh.edu/vislab/VisCourse/
  - The Joy of Visual Perception:
    - http://www.yorku.ca/eye
  - Chris Healey
    - http://www.csc.ncsu.edu/faculty/healey/PP/PP.html

48