Perception for visualization: From design to evaluation

Haim Levkowitz
Institute for Visualization and Perception Research (IVPR)
Computer Science Department
University of Massachusetts Lowell, Lowell, MA, USA
haim@cs.uml.edu

http://www.cs.uml.edu/~haim

Maria Cristina Ferreira de Oliveira
ICMC – Instituto de Ciências Matemáticas e de Computação
Universidade de São Paulo, Brazil
cristina@icmc.usp.br

http://www.icmc.usp.br/~cristina

Introduction

- Overview
- Motivation and goals
- Psychophysics
- Outline of tutorial

Overview

- Purpose of collecting information
- Constantly growing ...
- Need to understand how to ...
- Challenges …
- Examples ...

Purpose of collecting information

- Present it to
- Analyze it by
- Human beings
- Constantly growing: amounts & complexity ...

Constantly growing ...

- Amounts collected
- Complexity
  - Information
  - Analysis
- Need to understand how to ...

Need to understand how to ...

- Increase comprehension
- Make analysis easier & efficient

A presentation …

- An experience, not just an image ...
- Aimed at humans
- Has to be designed ...

An experience, not just an image ...

- User-directed, dynamic
- Multidisciplinary …
- Multisensory ...

Multidisciplinary ...

- Graphics
- Imaging
- Psychology
- Man-machine interface
- Databases
- Multimedia

Multisensory ...

- Visual
- Auditory
- Tactile
- More?

Has to be designed ...

- Audience
- Question(s) / tasks ...
- Contents
- Delivery

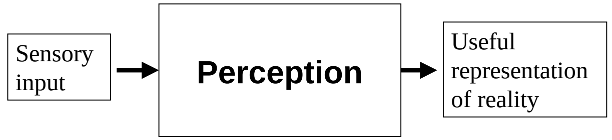
Question(s) / tasks ...

- Explore vs. Confirm
- E.g., detection vs. identification

Perceptually-based presentation …

- Make perceptually effective …
- How? ...
- First: perception …

Perception



Make perceptually effective …

- Understand perceptual processes …
- Harness them ...

Understand perceptual processes ...

- Color
- Size
- Shape
- Texture
- Motion
- Sound

Harness them ...

- Data "Speak" for themselves
- Exploratory vs. confirmatory analyses
- Raise dimensionality
  - MDMV

How? ...

- Substitute pre-conscious for conscious
- Pre-conscious …
- Conscious ...

Pre-conscious ...

- Do not interfere with ability to think
- Parallel
- Hard-wired/entrained
- Fast
- Relentless
- Simultaneously w/conscious analysis

Conscious ...

- Interfere
- Serial
- Ad-hoc
- Slow
- Cause fatigue
- Distract from higher level analysis

Challenges …

- Understand "perception" ...
- Apply perception ...
- Truth and accuracy obligation …
- Effectiveness
- Evaluation and verification ...

Understand "perception" ...

- Lower-level vision (also audition, touch)
- Perception …
- Cognition …
- Aesthetics
- Emotional & cultural

Perception ...

- Color
- Shape
- Size
- Texture
- Motion
- Segmentation

Cognition ...

- Attention (pre-attentive vs. scrutiny; preconscious vs. conscious)
- Memory (iconic, short term, long term)
- Semantics & symbolism

Apply perception ...

- ==> Perceptually-based
  - Representations …
  - Rules & guidelines …
  - Interaction
  - ==> Presentations

Representations ...

- E.g., generalize pixels ⇒ more info
  - Visual
    - Color
    - Geometry …
    - Motion
  - Sound

Geometry ...

- Line orientation
- Area
- Volume
- Curvature
- Texture

Rules & guidelines ...

- Contrast
- Color
- Font
- Size
- Style

Truth and accuracy obligation ...

- Informing vs. entertaining
- Comprehension vs. aesthetics
- Informing ==> as truthful as possible
- Avoid misleading viewers
- E.g., Brooks (Vis '93): background music ...

E.g., Brooks (Vis '93): background music ...

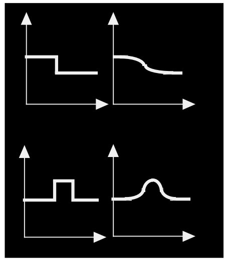
- What message?
- Lower SNR, unless
  - Intentional
  - Accurate
- Show business

Evaluation and verification …

- Tasks …
- Data ...

Tasks ...

- Presence / absence
  - Edge / boundary
  - Target / blob
- Location
- Classification



Data ...

- Real …
- Synthesized ...

Real ...

- "Truth" unknown
- E.g.,
  - Satellite
    - Water vs. land
  - Medical
    - Normal vs. abnormal

Synthesized ...

- "Truth" known
  - Statistics
- Not real

Examples ...

- Medical
- Earth science
- Reconnaissance
- Presentations

Conclusions ...

- What is information presentation
- Perceptually-based information presentation
  - Design
  - Evaluation & verification
- Challenges
- Examples

Moral ...

- Present to inform, not to impress; if you inform, you will impress

after Fred Brooks
Keynote Address
Visualization '93

Emerging discipline

- Eick: "Graphically displaying text"
  - J. Comp. & Graphical Statistics
  - Four progress stages …
- Wong & Bergeron, 1995: "30 years of MDMV Vis"
  - Four stages of MDMV Vis. Development ...

Four progress stages ...

- Skilled artisans: Craft
  - Practical experience guidelines
- Researchers: Scientific principles & theories
- Engineers: Production rules
- Widely available technology

Four stages of MDMV Vis. Development ...

- Pre-1976: The Searching Stage
- 1977-1985: The Awakening Stage
- 1986-1991: The Discovery Stage
- 1992-present: The Elaboration Stage

Topics / schedule

- Introduction (“this”)
- The human visual system (30 min.)
- Human perception (2 hours)
- From theory to implementation (2 hours)
- Evaluation (1 hour)

The human visual system (30 minutes)

- Physical stimulus and perceptual response
- Basic vision: fundamental visual functions

Human perception (2 hours)

- Color vision and perception
  - Color perception and modeling
  - Color deficiencies
- Form and shape perception
- Space and depth perception
- Texture perception
- Motion perception
- Cognitive issues in visual perception
- Auditory perception

From theory to implementation (2 hours)

- From human perception to visualization and image generation
- From human perception to visualization and image understanding
- Multi-view visualization
- Multi-modal visualization and sonification
- Examples and demonstrations

Evaluation and verification (1 hour)

- Is it really necessary?
- Study design
- Study execution
- Analysis and interpretation

Vision and color theory

Topics ...

- Human & Color Vision
- Color vs. Luminance Systems
- Color Deficiencies
- Color Organization Modeling
- Complex Visual Themes
- Device Independent Color Displays

Newton, Opticks 1704, pp. 124-125.

- "the rays, to speak properly, are not coloured. In them there is nothing else than a certain Power and Disposition to stir up a Sensation of this or that Colour."

The human interface

- Visual technologies matched to human visual capabilities
- Print evolved over centuries
- Electronic display revolution-CRT terminals ⇒ virtual reality in 30 years!
- Requirements for image quality …
- Techn. q's rely on visual percep. of human observer ...

Requirements for image quality ...

- Sufficient luminance and contrast
- No flicker
- Effective use of color
- Minimized effects of spatial sampling
- Perceptually lossless image compression
- Convincing impression of depth

Techn. q's rely on visual percep. of human observer ...

- How do humans process luminance, contrast, color, motion?
- How do these mechanisms constrain choice of capture, sample, compress, and display information?

Some definitions

- Physical stimulus …
- Perception …
- Psychophysics …
- Neurophysiology ...

Physical stimulus ...

- Measurable properties of the physical world
  - Luminance
  - Sound pressure
  - Wavelength

Perception ...

- Study sensory phenomena
  - Mediated by higher-level processes
    - Memory
    - Attention
    - Experience

Psychophysics ...

- Study sensations/perceptions physical energies produce
  - Brightness
  - Loudness
  - Color

Neurophysiology ...

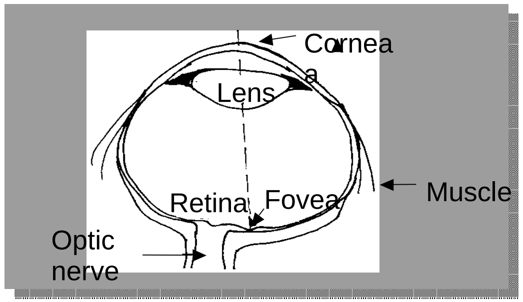
- **Study physiological mechanisms mediating sensory information**
  - **Transduction**
  - **Coding**
  - **Communication**

Color: physics vs. perception

An overview of the human visual system

- **The Eye**
  - **Schematic of the eye ...**
  - **Two lenses-one fixed (cornea); one variable (lens)**
  - **Pupil-operates like camera aperture**
  - **Retina …**

Schematic of the eye ...



Retina ...

- 5 layers of cells at back of eye
  - Photoreceptors-light sensitive cells …
  - 4 other classes of cells …

Photoreceptors-light sensitive cells …

- Rods (~120 million) …
- Cones (~8 million) …
  - No photoreceptors in the optic disk
    - $\Rightarrow$ blind spot

Rods (~120 million) ...

- Achromatic
- Night/low light levels

Cones (~8 million) ...

- Daytime color vision/color coding
- Major concentration in fovea
  - (central one degree of vision)
- 3 wavelength distributions ...

3 wavelength distributions ...

- S: short-violet ("blue")
  - Peak sensitivity 440 nm
- M: medium-yellowish-green ("green")
- 550 nm
- L : long-yellow ("red")
- 570 nm

4 other classes of cells ...

- Image compression
- Lateral inhibition

Eye movements

- Saccades (4/sec.)
  - 6 muscles point eye to areas of interest
  - Clear stable impression of external world
- Minisaccades
  - Keep eye in const. movement
    - Req'd for perception
      - If not, external world fades away

Sensitivity vs. resolution

- 1-1 mapping receptors to ganglion cells
  - $\Rightarrow$ highest spatial resolution (acuity)
  - Fovea
- Many-1 mapping
  - $\Rightarrow$ highest sensitivity
  - Periphery
    - Greater temporal sensitivity

60% of brain receives visual input

- Input to decision making, memory, and concept formation processes
- Looking at a display involves ...
  - More than questions of image quality and detectability
  - How seek out, understand, and use information.

Basic visual mechanisms

- Early Vision: Luminance Perception …
- Contrast and spatial resolution
- Image applications of CSF
- Perceived flicker
- Inexpesive way to reduce perceived flicker ...

Early vision: luminance perception …

- Sensitivity to luminance variations …
- Apparent brightness: not linear function of luminance ...

Sensitivity to luminance variations …

- 14 log-unit range: dim star $\rightarrow$ bright sunlight …
- At any moment, a 2 log-unit range
  - Matched to ambient illumination
- Dynamics of light-and- dark-adaptation

14 log-unit range: dim star → bright sunlight ...

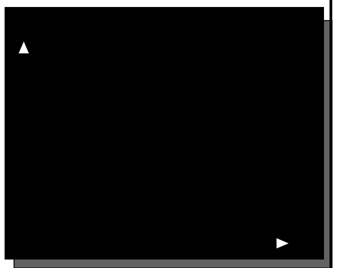
- Sun at noon: 10^8-10^{10} candles/meter2 (Damaging)
- Photopic
  - Filament of 100 watt light bulb: 10^7
  - Comfortable reading: 10
- Mixed (mesopic): 1
- Scotopoic
  - White paper in moonlight: 10^{-2}
  - Weakest visible light: 10^{-6}

Apparent brightness: not linear function of luminance ...

- Non-linear psychophysical relationship ...

Non-linear psychophysical relationship ...

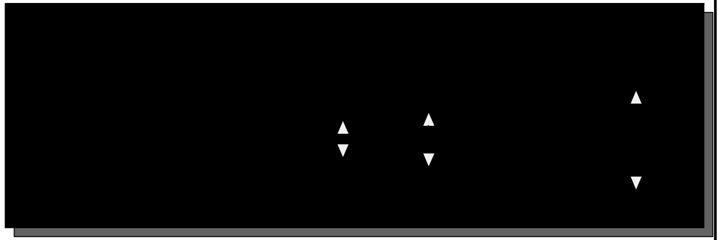
- Reflects visual coding
- Perceptual
- "gamma" function
- "Logarithmic"
- range
- Incorporated
- in many color metrics



Contrast and spatial resolution

- Visual angle …
- Contrast sensitivity …
- Minimum modulation to detect grating patterns ...

Visual angle ...



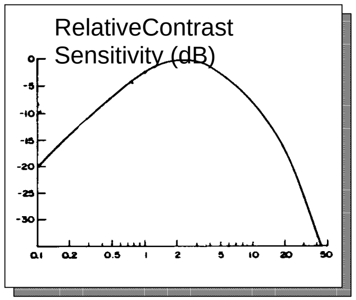
- For some objects ...

For some objects ...

- Character on CRT at 50 cm: 17'
- Diameter of sun, moon: 30'
- Lower case pica-type letter at reading distance 40 cm: 13'
- Quarter at arm's length, 90 yards, 3 miles: 20, 1', 1"
- Diameter of fovea: 10
- Diameter of foveal receptor: 30"
- Position of inner edge of blind spot: 120 from fovea
- Size of blind spot: 7.50 (v), 50 (h)

Contrast sensitivity ...

- Depends on spatial distribution of light and dark



Minimum modulation to detect grating patterns ...

- Tuned function of spatial frequency
- Peak sensitivity at 2-4 cycles/degree
- Decreased sensitivity for
  - Lower (broader)
  - Higher (finer) spatial frequency

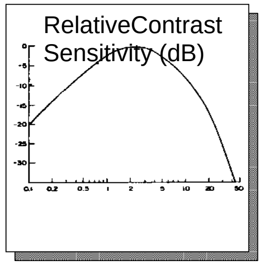


Image applications of CSF

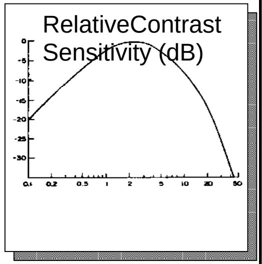
- **Application areas ...**
- **CSF caveats ...**

Application areas ...

- **Image coding …**
- **Digital halftoning …**
- **Display quality ...**

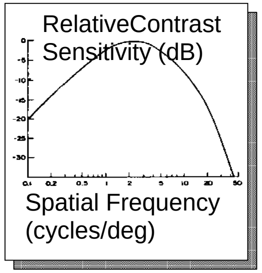
Image coding ...

- **Gain efficiency**
  - **Greatest BW to regions of greatest spatial frequency sensitivity**



Digital halftoning ...

- **Hide sampling noise in regions of lowest contrast sensitivity**



Display quality ...

- Evaluate display modulation transfer function (MTF) with human contrast sensitivity function (CSF)

CSF caveats ...

- Depends on
  - Luminance
  - Color
  - Temporal modulation

Perceived flicker

- Depends on luminance, not color
- Factors affecting flicker ...

Factors affecting flicker …

- Display parameters ...
- Viewing conditions
  - Peripheral vs. foveal gaze
- Observer factors
  - Age, caffeine, depressants

Display parameters ...

- Luminance
- Refresh rate
- Interlaced vs. non-interlaced
- Phosphor persistence
- Display size

Inexpensive way to reduce perceived flicker ...

- Add dark glass, "anti-glare" faceplate
  - Reduce luminance
    - ⇒ Reduce perceived flicker
  - Increase contrast
    - Ambient light attenuated twice
    - Emitted light attenuated once

Introduction to human color vision

- Color vision: Trichromacy …
- Implications of trichromacy
- Second stage: Opponent Processes
- Color deficiencies

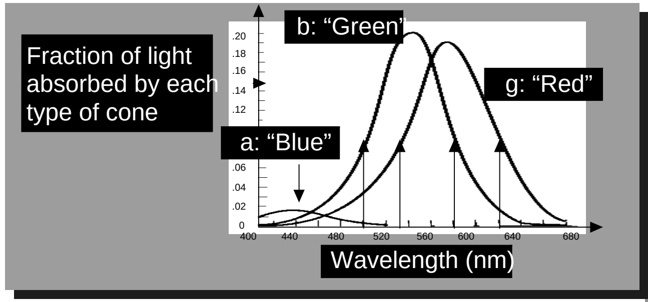
Color vision: Trichromacy ...

- Three broadband filters
  - Tuned to three ranges of wavelength
- "Blue," "green," "red"-misnomers! …
- Perceived hue ...

"Blue," "green," "red"- misnomers! …

- Each one color blind …
- "Blue"
  - Peaks at "blue" wavelength
- "Green" and "red"
  - Largely overlapping
  - Peak at roughly "yellow"

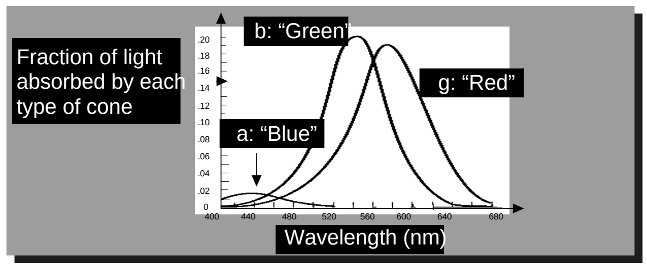
Each one color blind …



Perceived hue …

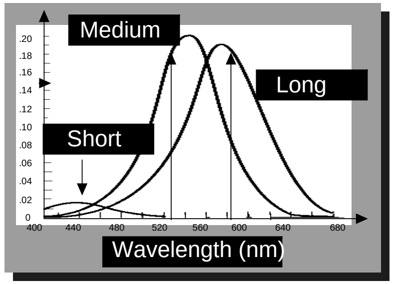
- Combination across three cone mechanisms …
- Example …
- Metamerism ...

Combination across three cone mechanisms ...



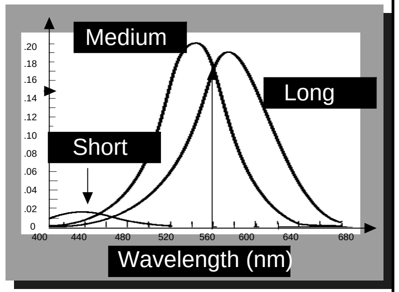
Example ...

- Equal excitation
- to medium
- and long
- ⇒ "yellow"



Metamerism ...

- Solution 1
  - 550 nm monochromatic
- Solution 2
  - 530 nm + 630 nm
- Equivalent sensation



Implications of trichromacy

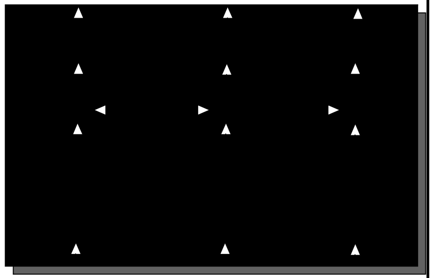
- Any hue
  - Matched by combination of 3 primaries
  - Produced by infinite number of wavelength combinations
- Basis for color TV and VDT technology ...

Basis for color TV and VDT technology ...

- Very efficient-need only 3 primaries to produce millions of colors
  - E.g., does not require "yellow" gun
- Primaries define gamut of colors

Second stage: opponent processes

- Recombine photoreceptor outputs into 3 opponent channels



Color deficiencies

- ~8% males, < 1% females have some genetic color deficiency
- Most common: deuteranomaly …
- Others …
- Color deficiencies and visual displays ...

Most common: deuteranomaly ...

- 5% males, 0.5% females
- Anomalous trichromacy
- Caused by abnormal M-type cone
- $\Rightarrow$ abnormal matches/poor discrimination

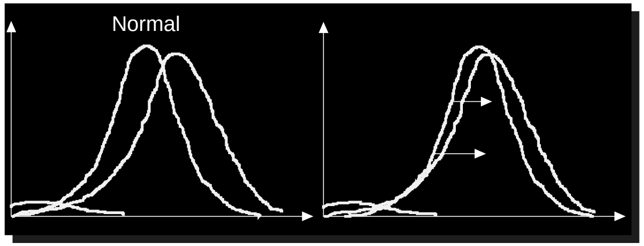
Others …

- Missing/abnormal cone type …
- Much less common

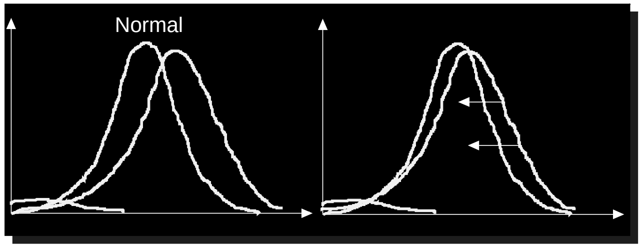
Missing/abnormal cone type ...

- **E.g.,**
  - **Abnormal M-type …**
  - **Abnormal L-type ...**

Abnormal M-type ...



Abnormal L-type ...



Color deficiencies and visual displays ...

- **Color deficient people may not be aware**
- **Simple rule-of-thumb ...**

Simple rule-of-thumb ...

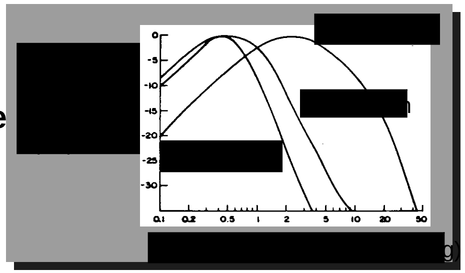
- Code important distinctions with redundancy
  - Luminance
    - E.g., spell-checker highlights misspelled words
      - Red
      - Bright
  - Size

Color-luminance interactions

- Luminance vs. color …
- The Luminance Mechanism …
- The Color System ...

Luminance vs. color ...

- Detect chromatic & achromatic grating patte
- As function
- of spatial frequency



[redacted]

The luminance mechanism …

- Mediates high spatial-frequency tasks …
- Has broader bandwidth ...

Mediates high spatial-frequency tasks ...

- Yellow text on white: hard
  - Little lum. diff. for high spat.-freq. task
  - Luminance system has nothing to work with
- High spatial resolution
  - Depends on luminance
  - Independent of hue

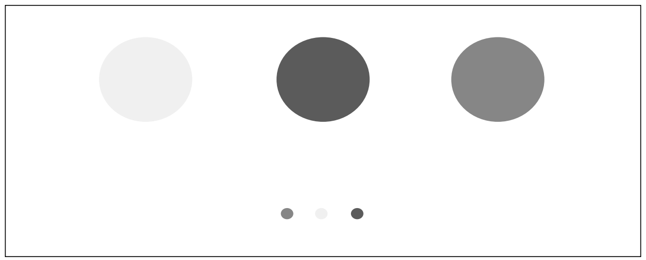
Has broader bandwidth ...

- More BW to encode luminance spatial variations
- Adding color to TV: little add'l BW
  - Color info. in between bands
- Compression schemes
  - Most BW to luminance
  - ⇒ higher image quality w/fewer bits

The color system ...

- More sensitive to low spatial frequencies
- Small color targets achromatic …
- Large color areas more saturated & intense ...

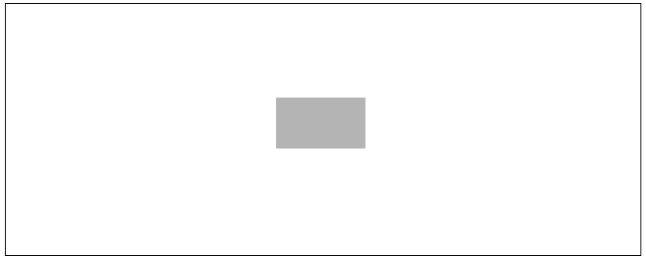
Small color targets achromatic ...



Large color areas more saturated & intense …

- Small "pale salmon" paint chip …
- Looks like "mango frenzy" on a large wall ...

Small "pale salmon" paint chip ...



Looks like "mango frenzy" on a large wall ...

Introduction to color calibration

- Device independent color …
- Selecting the correct color space …
- Cross rendering ...

Device independent color ...

- Definition …
- Steps to device independent color ...

Definition ...

- Color images look comparable
  - On CRT
  - Projected
  - On printer

Steps to device independent color ...

- Calibrate output devices
  - Luminance values?
  - Output device calibration …
- Transform to appropriate color metric
- Choose correct optimization

Output device calibration ...

- D/A values to R, G, B guns?
  - Not good enough!
- Measure luminance response function for each gun
  - Straightforward
- Benefits of calibration …
- Why (uncalibrated) RGB is dangerous ...

Benefits of calibration ...

- Express image chromaticities in standard metric spaces
- Manipulate color in systematic ways

Why (uncalibrated) RGB is dangerous ...

- If R, G, B values are D/A values, not luminance values, transformations from RGB to any metric space will be uninterpretable

Selecting the correct color space …

- Colorimetric approaches …
- Spaces for additive vs. subtractive color devices
- "Uniform Color Spaces" …
- Color naming
- Color constancy

Colorimetric approaches ...

- Based on color matching data
- Commission Internationale De L'Eclairage (CIE)
  - CIE 1931
  - Linear transformations of CIE 1931
  - Taking luminance into account

"Uniform Color Spaces" ...

- Pseudo perceptual
  - Generalized LHS model (Levkowitz)
- Perceptual
  - Incorporating Opponent Process mechanisms
  - Post-receptor processes plus gain control (Guth)

Cross rendering ...

- Color information from one device to another
- Difficult: "gamut mismatch" …
- Solving the gamut mismatch problem …
- Answer from psychophysics

Difficult: "gamut mismatch" ...

- Devices operate at different
  - Luminance levels
  - Range of possible hues depends on luminance
- Pigments/phosphors
  - ⇒ Range (gamut) of colors not fully overlapping

Solving the gamut mismatch problem …

- Pixel-by-pixel chromaticity match …
- Selective color preservation based on image content
- Color name preservation
- Role of color constancy
  - Appearance-preserving uniform transformations?

Pixel-by-pixel chromaticity match ...

- "Best" match? closest in
  - hue, saturation, lightness, some combination?
- In what metric space?
- What combination rule best describes fit?

Color vision for complex visual tasks

- Color and visual search …
- Visual/verbal interactions
- Color contrast and color constancy

Color and visual search …

- Color attracts "pre-attentive" vision …
- Applications …
- Theoretic basis: Treisman 80 …
- Color for feature coding: caveats ...

Color attracts "pre-attentive" vision ...

- Attracts attention
- Facilitates effortless search
- Enables parallel search

Applications ...

- Draw attention to features of interest
- Identify
  - Red car
  - Colorfully-dressed child
  - Scan for multiple instances of feature

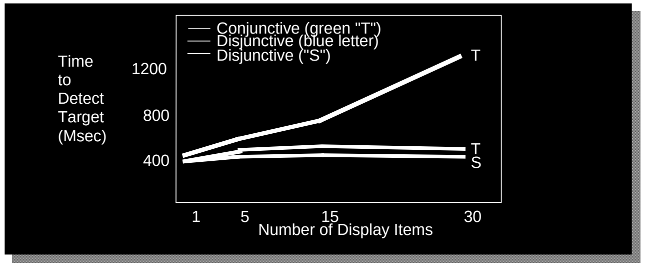
Theoretic basis: Treisman 80 …

- "Popout" effect in visual search …
- Most salient "popout" features ...

"Popout" effect in visual search ...

- Time to detect presence of target
  - Disjunctive target (single feature)
    - Parallel: Ind. of # of items
  - Targets based on conjunction of features
    - Serial: linear w/number of items
  - Treisman and Gelade (1980) ...

Treisman and Gelade (1980) ...



Most salient "popout" features ...

- Color
- Depth
- [Nakayama, 1986]

Color for feature coding: caveats …

- Preattentive features can distract …
- Or attract …
- Engage powerful preattentive aspects for trivial ends
- Role can be overstated
    - Processes requiring attention & analysis also important

Preattentive features can distract ...

HZMANYMX
YTQCOLORS
JMAKEZPG
MWHARDB
IJSEEINGNP

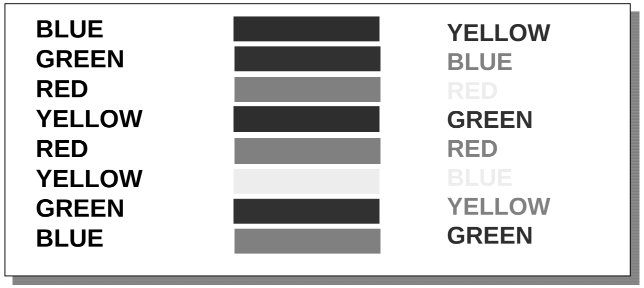
Or attract ...

HZMANYMX
YTQCOLORS
JMAKEZPG
MWEASYBS
IJSEEINGNP

The Stroop Effect (1935) …

- Task: name color of words
  - Nonsense words
    - Color naming very fast
  - Color names
    - Color naming very slow

The Stroop Effect (1935) …



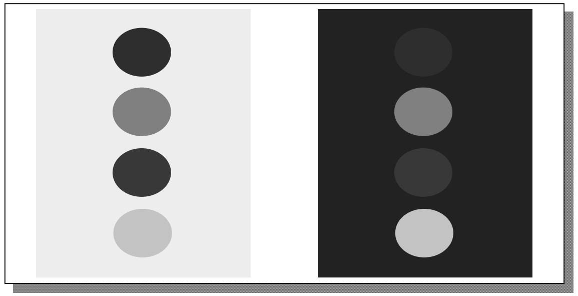
Color contrast and color constancy …

- Color contrast ...

Color contrast …

- Perceived hue depends on surrounding hues …
- Induction of complementary hue …
- Mediated by opponent process mechanisms

Perceived hue depends on surrounding hues ...



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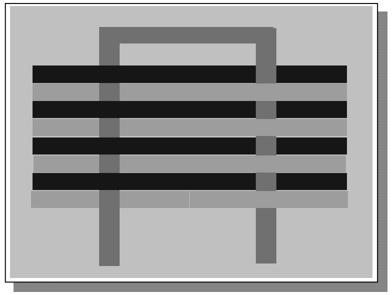
Induction of complementary hue ...



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Perceiving and representing shape & depth

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Objectives

- **Determine how to most effectively represent shape and depth in computer-generated images**
- **Need to understand:**
  - **Potential sources of shape and depth information**
  - **Effectiveness for visual system**

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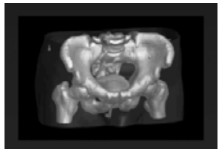
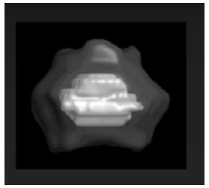
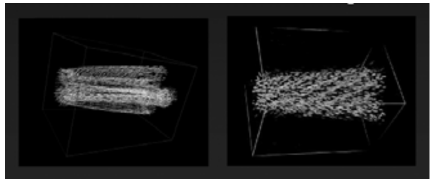
Some driving applications

- **Visualizing 3D shape of layered transparent surface**

Some driving applications

- **Conveying the spatial relationships between discrete elements in 3-space**



Pictorial depth cues:

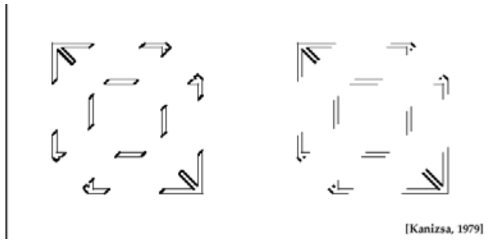
Sources of depth information in static, 2D images

Occlusion: perhaps most important pictorial depth cue

- **Integrated into perception at early stage of visual processing**
- **Occlusion boundaries are key elements in conveying depth order relationships**

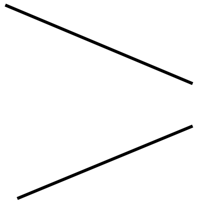
after: K. Nakayama, S. Shimojo and G. H. Silverman. "Stereoscopic Depth: its relation to i mage segmentation grouping, and the recognition of occluded objects", Perception & Psychophysics, 49(3): 230-244, 1991.

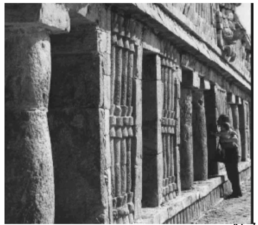
Occlusion and object completion



Pictorial depth cues: linear perspective

- Parallel lines appear to converge as they recede into distance



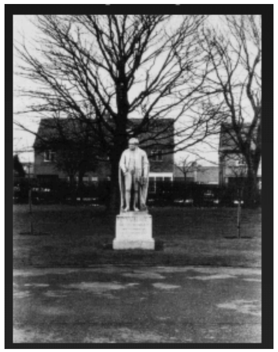


Pictorial depth cues: linear perspective

- Effect most pronounced when lines originate close to viewpoint and extend for considerable distance in depth
- Difficult to appreciate depth from perspective convergence when objects are:
  - Distant from viewpoint
  - Extend only small distance in depth
  - Have smoothly curving, irregular, or unfamiliar shapes

Consequences of perspective

- Zooming in on a picture of a scene is not the same as zooming in on the scene itself



N. Wade. Visual Allusions, Lawrence Erlbaum Associates, 1990. original image

Zooming: picture vs. scene

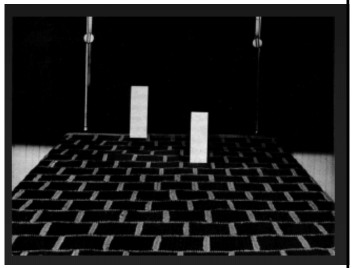
picture | actual scene

After zooming in on

N. Wade, Visual Allusions, Lawrence Erlbaum Associates, 1990

Pictorial depth cues: relative height

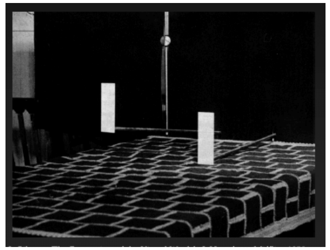
- Relative height of base of object in image plane is
  - Cue to relative depths of objects resting on common horizontal groundplane & viewed from above
  - *Not* reliable indicator of relative depth under other circumstances



J. J. Gibson. The Perception of the Visual World, © Houghton Mifflin, 1950.

Pictorial depth cues: relative height

- In absence of indications to contrary, observers tend to perceive objects as resting on the groundplane in front of which they appear



James J. Gibson. The Perception of the Visual World, © Houghton Mifflin, 1950.

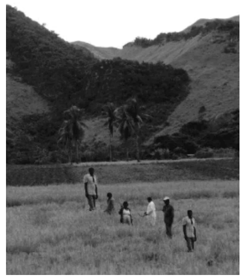
Pictorial depth cues: relative size

- Relative familiar size
  - Object subtends smaller visual angle on retina as its distance from viewpoint increases
  - We have learned to interpret info about relative dist of familiar or self-similar objects from diff's in their relative apparent sizes

Pictorial depth cues: relative size

- Relative size subordinate to other depth cues
- Apparent size influenced by perceived distance, as in “moon illusion” (sky seems farther away at horizon)

Man on left:
giant in distance, or standing on hill in foreground?
How much larger than man on right?



after Wolfgang Metzger. Gesetze des Sehens, W. Kramer & Co., 1975

Pictorial depth cues: atmospheric attenuation

Pictorial depth cues: atmospheric attenuation

- **Aerial perspective: visibility of distant objects compromised by pollutants / moisture in air**
  - **With increasing depth, objects lose contrast**
    - **Internally & wrt background**
  - **Stimuli that have lower luminance contrast w/ background perceived to be more distant**

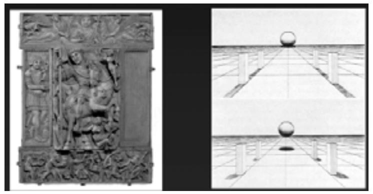
Pictorial depth cues: depth of field

- **Real life: rarely conscious of things "out-of-focus"**
- **Photos: not uncommon; blur increases with distance in depth from focal point of lens**
- **Depth-of-field effects: may indicate separation in depth, but convey no information about sign / magnitude of depth distance**

Pictorial Depth Cues: cast shadows

- **Cast shadows can affect perception of depth in image and height over groundplane**

Louvre: guide to the collections →



Yonas, Goldsmith and Hallstrom. "Development of Sensitivity to Information Provided by Cast Shadows in Pictures," *Perception*, 7(3): 333-341, 1978.

Perception of shadows
(luminance attenuation due to light source occlusion)

- Shadow perception completely dependent upon luminance information
- Image subregions defined by other means not interpreted in same way

Pictorial depth cues

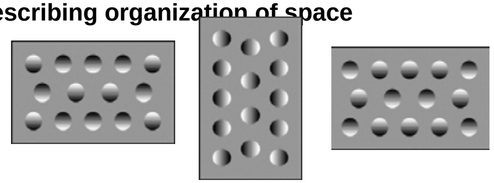
- Effects of equiluminance on perceived depth
  - Livingstone and Hubel [1987]:
    - More difficult to perceive when objects defined by equiluminant color differences than by luminance differences in an image:
  - Depth from stereo
  - Shape from shading
  - Shape from texture
  - Depth from motion
  - Depth from occlusion
  - Depth from linear perspective

Shape from shading

- Computational “shape-from-shading” methods
  - Solve for direction of surface normal at given point on object by
  - Inverting illumination equation, subject to simplifying assumptions
- Human visual system
  - Does not appear to do this same way
  - Does resolve ambiguities in consistent manner
  - May employ implicit assumptions to do so

Shape from shading

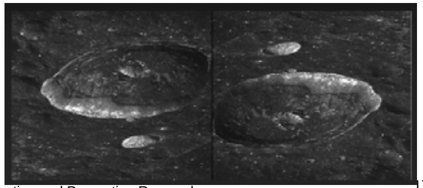
- *Global* (not local) understanding of shape from shading
- Describing organization of space



- after V. S. Ramachandran, “Perceiving Shape from Shading,” *Scientific American*, 259(2): 76-83, 1988.

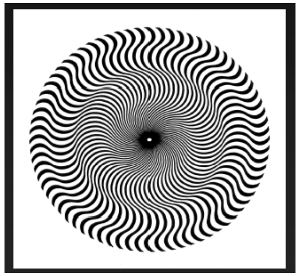
Depth inversion: possible explanations

- Light “from above”
- Preference for
  - “Ground” vs. “ceiling” surfaces
  - Convex vs. concave forms (mask illusion)



More on depth inversion

- Depth inversion also occur when shape is defined by texture
- [N. Wade, VIsual Allusions]



Shape as organization of space

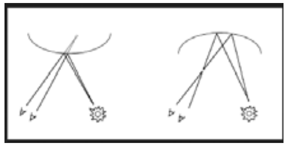
- Observers cannot reliably
  - Estimate only on basis of shading information
    - Local surface shape
    - Absolute surface curvature
  - Determine depth order of points in disparate parts of image
- Observers can judge
  - Relative slants & curvatures of adjacent surface patches
  - Depth order of points in neighboring regions

Conveying shape with shading

- Artists have stressed importance of lighting
- Veridical shape perception easier in some light fields than in others
  - Faces
    - Easier to recognize when lit from above
    - Look eerie when lit from below
  - Objects appear flattest when light field is isotropic
    - (Parallel light rays emanating from viewpoint)

Shape from specular highlights

- Viewed in stereo, specular highlight appears to float
  - In front of convex surface
  - Behind concave one
- Observers use information to disambiguate convex from concave surfaces



after: A. Blake and H. Bulthoff, "Shape from Specularities: computation and psychophysics" *Philosophical Transactions of the Royal Society of London*, B, 331: 237-252, 1991.

Shape from specular highlights

- Apparent location is viewpoint dependent
  - tend to cling to highly curved areas
  - direction of highlight motion can be used to disambiguate surface curvature:
    - on convex surfaces, specular highlights move in direction of observer's motion
    - on concave surfaces, they move in opposing direction
- Shape perception is facilitated by specular highlights [Todd and Mingolla 1983]

Oculomotor cues to depth

- Visual system able to get direct information about absolute distances of objects from physical sensations associated with muscles of eyes
- Accommodation
  - Tightening of ciliary muscle to change curvature of lens of eye to bring objects nearer than about 10 feet into focus
  - Observers get reliable estimates of absolute depth from accommodation cues only for objects closer than about 50cm
  - Differences in accommodation indicate differences in depth for objects farther than 50cm, but
  - Relationship between accommodative response and perceived distance is no longer linear

Oculomotor cues to depth

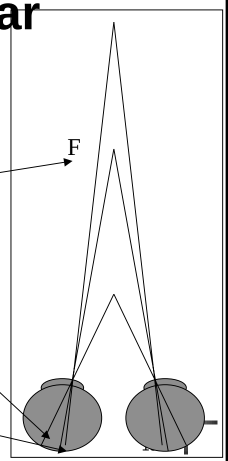
- Vergence
  - When looking at nearby object with both eyes, they turn in slightly; lines of sight converge at point on surface
  - Experimental evidence indicates that observers can infer distance of object on basis of vergence cues within depth range of up to 6m
  - Vergence responses evoked from perspective images viewed monocularly
  - Perceive more depth in perspective image if look at it with only one eye

Oculomotor cues to depth

- **Accommodation and vergence responses are strongly linked**
  - **Under typical viewing conditions, stimulus to one evokes coordinated response by both**
  - **When accommodation and vergence stimulated in opposite directions, perceived depth tends toward average of stimulated depths**
  - **Perceived depth of stereo images displayed on computer monitor affected by accommodative cues to depth of display**

Depth from binocular disparity

- **Each eye sees slightly different view of world**
- **(F)ocal point falls on corresponding locations in retinal images of each eye, but**
- **Objects closer than F seen in *crossed disparity***
- **Objects farther than F seen in *uncrossed disparity***



Depth from binocular disparity

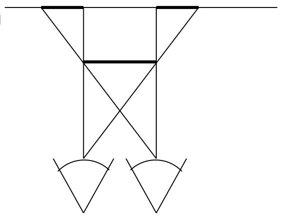
- **~95% of population perceive depth from binocular disparity [Coutant and Westheimer 1993]**
- **Can distinguish stereo depth differences < width of single photoreceptor [Sekuler and Blake 1994]**
- **Depth information from binocular disparity is relative, not absolute**
  - **Distances > 1m underestimated**
  - **Distances < 1m overestimated [Johnston 1991]**

Depth from binocular disparity

- **Integrated perception of 3D from stereo pair**
  - **Individual images contain no immediately accessible feature info [Julesz 1964]**
- **Perception of depth in random dot stereograms facilitated when monocularly conspicuous features added [Saye and Frisby 1975]**

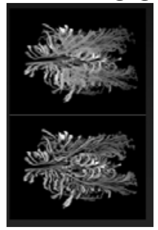
Inter-ocularly unpaired regions

- When can't integrate input from two eyes, visual system alternates between perception of one and other, or input from one eye dominates
- Existence of inter-ocularly unpaired regions in image gives rise to perception of depth discontinuity [Nakayama and Shimojo 1990]



Inter-ocularly unpaired regions

- Artists exploit this when they indicate depth discontinuities with subtle flanking gaps



Depth from motion

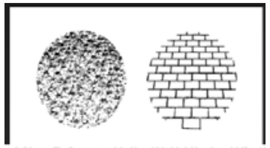
- Motion Parallax
  - Depth from changing viewpoint
- Kinetic Depth Effect
  - Depth from object rotation
- Active motion vs. Passive motion
- Head motion vs. Object motion
- *Depth from motion is understood best when motion is under control of the observer*

Motion parallax vs. stereo

- Perception of depth from motion parallax similar to perception of depth from binocular disparity
  - Geometrically comparable
  - Similar spatial frequency sensitivity
- Some significant differences
  - People who cannot perceive stereoscopic depth can perceive depth from motion parallax
  - Inaccuracies occur under different stimulus conditions
- Not redundant; more depth perceived in displays containing both stereo and motion than either alone

Shape and depth from texture

- Texture gradients powerful cue to shape and depth.
- But
  - How perceive shape and depth from texture?
  - What kinds of textures show this info best?

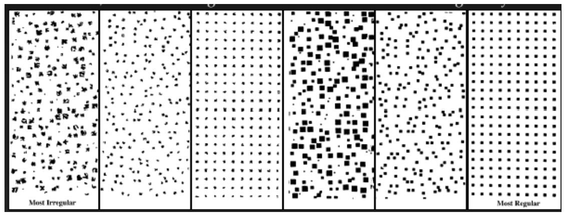


J. J. Gibson. The Perception of the Visual World, © Houghton-Mifflin, 1950.

Defining texture regularity

- Observers' judgments of surface slant more accurate when stimuli depict "regular" vs. "irregular" texture
  - But, what are significant characteristics of texture regularity?
  - Cont. ...

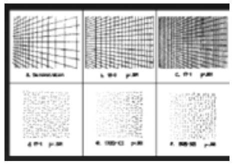
Defining Texture Regularity



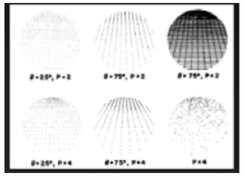
© H. R. Flock and Anthony Moscatelli. "Variables of Surface Texture and Accuracy of Space Perceptions," *Perceptual and Motor Skills*, 19:327-334, 1964.

Slant from patterns of texture

- Linear convergence cues dominate in indicating surface slant;
- Dot density alone not effective



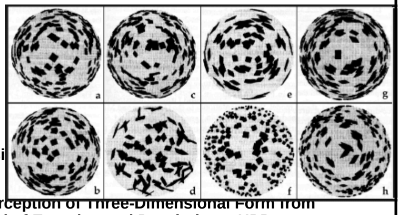
F. Attneave and R. K. Olsen. "Inferences About Visual Mechanisms from Monocular Depth Effects," *Psychonomic Science*, 4: 133-134, 1966.



M. L. Braunstein and John W. Payne. "Perspective and Form Ratio as Determinants of Relative Slant Judgments," *Journal of Experimental Psychology*, 81(3): 584-590, 1969.

Curvature from patterns of texture

- Different texture characteristics important for perception of surface curvature than for perception of surface slant
  - a) perspective projection
  - b) parallel projection
  - c) irregular shapes
  - d) random orientations
  - e) constant area
  - f) no compression
  - g) elongated
  - h) elongation without compressi



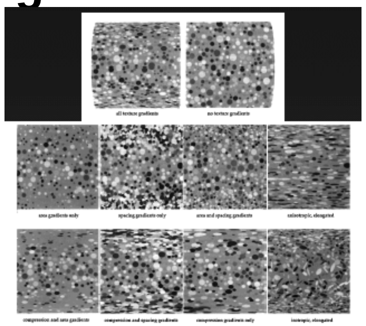
- J. T. Todd and R. A. Akerstrom. “Perception of Three-Dimensional Form from Patterns of Optical Texture,” *Journal of Experimental Psychology: HPP,* 13(2):242-255, 1987.

Shape from texture under stereo viewing

- Perceived curvature, under stereo viewing, is *least* when *texture element compression is constant* in the projected image
- Presence or absence of gradients of element size and/or element spacing has little effect on perceived curvature under stereo-viewing
- Even when surfaces are displayed in stereo, veridical texture enhances depth perception

Shape from texture under stereo viewing

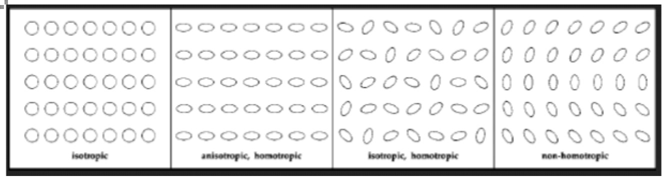
- Cumming, Johnston and Parker. “Effects of Different Texture Cues on Curved Surfaces Viewed Stereoscopically,” *Vision Research*, 33(5/6): 827-838, 1993.



Shape from texture: homotropy assumption?

- Most computational models for shape-from-texture assume either isotropy or homogeneity of texture element orientation or distribution
- Human observers may presume homotropy [Stone 1993] *(that the orientations of the texture elements are invariant with respect to position)*

Shape from texture: homotropy assumption?

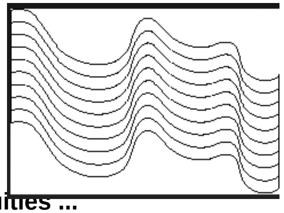


isotropic	anisotropic, homotropic	Isotropic, homotropic	non-homotropic

- after J. V. Stone. “Shape from Local and Global Analysis of Texture,” ***Philosophical Transactions of the Royal Society of London, B,*** **339:53-65, 1993.**

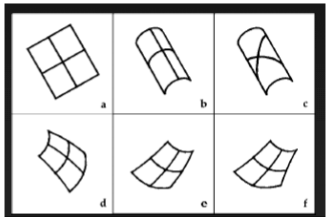
Shape from line direction

- **Stevens [1981] describes the shape description potential of lines oriented in the principal directions**



- **But, ambiguities ...**

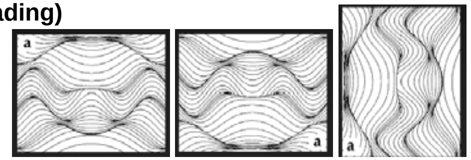
Ambiguities



- **a) k1 = k2 =0 (planar)**
- **b) k1 > 0; k2 = 0 (cylindrical)**
- **c) but if lines are not principal directions...**
- **d) k1 > 0, k2 > 0 (“elliptical”)**
- **e) convex or concave?**
- **f) SIGN(k1) <> SIGN(k2) (“hyperbolic”)**

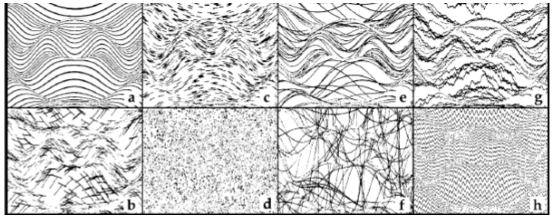
Sensitivity to orientation?

- **Less depth when figures rotated no longer depict height functions on receding planes [Todd and Reichel 1990]**
- **(same loss of depth if surface shape shown by shading)**



© J. T. Todd and F. D. Reichel. “Visual Perception of Smoothly Curved Surfaces from Double-Projected Contour Patterns,” Journal of Experimental Psychology: HPP, 16(3):665-674, 1990.

Shape from oriented lines



© J. T. Todd and F. D. Reichel. "Visual Perception of Smoothly Curved Surfaces from Double-Projected Contour Patterns," *Journal of Experimental Psychology: Human Perception and Performance*, 16(3):665-674, 1990.

Shape from oriented lines

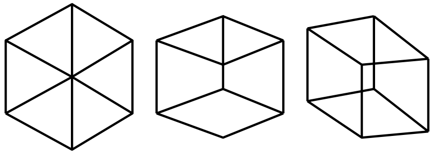
- Impression of 3D shape can be achieved when
  - + Discontinuous short segments (c) or "T"s (b) used
  - + Lines vary up to 45º in orientation (e)
  - + Random noise added to direction of line (g)
- But 3D shape hard to see when:
  - - Segments too short to convey direction (d)
  - - Orientation of lines varies up to 360º (f)
  - - Lines replaced by high frequency

Viewpoint and shape/depth perception

- Observers have preferred views for remembering sizes/shapes of objects
- Considerable inter-observer agreement preferred [Perrett and Harries 1988]
- Visual system presumes "generic" viewpoint
- Favors interpretations of form stable under slight shifts of orientation [Nakayama and Shimojo 1992]
- Biased toward perceiving objects as being more closely aligned to frontoparallel plane [Mingolla and Todd 1986 (and others)]

Viewpoint and shape/depth perception

- From least to most likely to be perceived as 3D object:



Estimating the relative importance of the different depth cues

- Cue-conflict paradigms
  - Present stimuli with contradictory indications of depth given by different cues
    - Determine which dominate
  - Problems: cue conflict stimuli "unecological"-- I.e., unrepresentative of behavior under ordinary circumstances
- Cue combination strategies
  - Determine how much more depth perceived as display supplemented with complementary sources of depth information

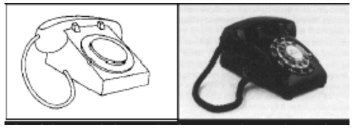
Integration of depth cues

- "Redundant" cues combine to convey more depth [Bruno and Cutting 1988, others]
  - Four cues: relative familiar size, height in image plane, occlusion, and motion parallax
    - Either indicated or unspecified
  - Subjects consistently perceived more depth when more cues present
  - Multiple, corroborating indications of depth appeared to have reinforcing effect, strengthening overall depth impression

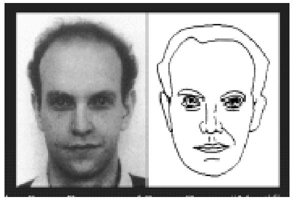
Representing form with line

- Goal: simple representation that captures essence of form
- Many objects easily recognized from line drawings [Biederman and Ju 1998]
- Line drawings provide valuable cues to 3D shape [Christou, Koenderink and van Doorn 1996]
- But facial recognition from line drawings generally poor [Davies *et al.* 1978];
  - Shading crucial [Bruce *et al.* 1992]

Representing form with line



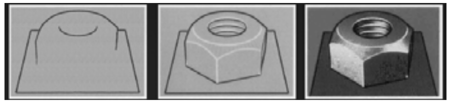
I. Biederman, G. Ju. "Surface versus Edge-Based Determinants of Visual Recognition," *Cognitive Psychology*, 20: 38-64, 1988.



G. Rhodes, S. Brennan, S. Carey. "Identification and Ratings of Caricatures: implications for mental representations of aces," *Cognitive Psychology*, 19: 473-497, 1987

Fundamental elements of line drawing: silhouette and contour curves

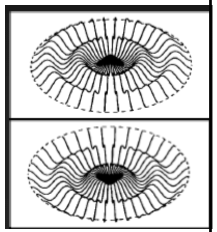
- **Silhouette curves define figure / ground separation**
- **Contour curves delineate depth discont's in image**
- **Emphasizing these lines can add clarity to an image [Saito and Takahashi]**



T. Saito and T. Takahashi. "Comprehensible Rendering of 3-D Shapes," *Computer Graphics* 24(4): 197-206 *(proc. SIGGRAPH '90).*

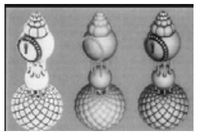
More fundamental elements of line drawing: ridge and valley lines

- **Definition: "locus of points where principal curvature assumes extreme value along line of curvature"**
- **Ridge and valley lines mark curvature discont's in 3D (and illumination discont's in 2D)**
- **Ridges and valleys are viewpoint independent features**
- **Objects perceived to divide into parts along valley lines [Hoffman and Richards 1984]**



Emphasizing 3D shape with lines

- **Accessibility Shading [Miller 1994]**



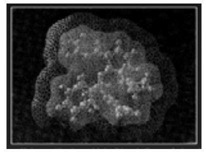
G. Miller. "Efficient Algorithms for Local and Global Accessibility Shading," *Computer Graphics Proceedings, Annual Conference Series*, pp. 319-326, 1994.

- **Valley Lines on Transparent Surfaces [Interrante *et al.* 1995]**

V. Interrante, H. Fuchs and S. Pizer. "Enhancing Transparent Skin Surfaces with Ridge and Valley Lines," *proc. Visualization '95*, pp. 52-59.

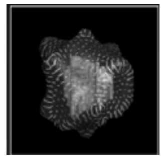
Conveying the 3D shape of transparent surfaces with distributed texture

- **procedurally-defined surface texture [Rheingans 1996]**



P. Rheingans. "Opacity-modulating Triangular Textures for Irregular Surfaces," proceedings of Visualization '96, pp. 219-225, 1996.

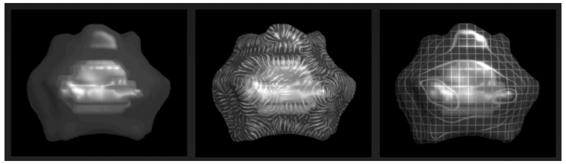
- **principal direction stroke texture [Interrante *et al.* 1996]**



V. Interrante, H. Fuchs and S. Pizer. "Conveying the 3D Shape of Smoothly Curving Transparent Surfaces via Texture," IEEE Transactions on Visualization and Computer Graphics, 3(2):98-117, April/June 1997.

Conveying shape with texture

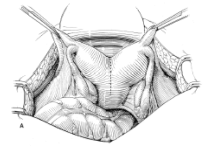
- **What kind of texture shows shape best?**
- **What if want to represent *multiple* layered surfaces?**



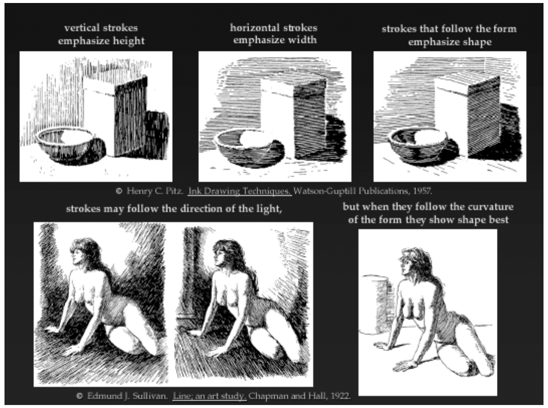
V. Interrante. “Illustrating Surface Shape in Volume Data via Principal Direction-Driven 3D Line Integral Convolution,” proc. SIGGRAPH 97, pp. 109-116.

Conveying shape with line: artistic inspiration

- ***Surgical Repair of the Septate Uterus, figure A* John V. Hagen. © Mayo Foundation, 1990.**



- ***Lumbosacral and Sacroiliac fusion* © Russell Drake, medical illustrator, Mayo Foundation, 1932.**



Conclusions

- **Understanding how we *perceive* shape and depth, ==> clues to how can better *represent* shape and depth in computer-generated images**
- **Depth cues involve modeling**
  - **Straight lines emphasize perspective convergence**
  - **Overhead, oblique illumination better convey shape from shading**
  - **Depth cueing make object fade into background with distance**
  - **Surface texture, more...**

Conclusions (cont.)

- Some depth cues direct consequence of geometry of scene
- Other depend on display technology:
  - Head-tracking, stereo, special devices for more direct object manipulation
- More depth cues helps;
  - Representing shape and depth in many "redundant" ways

Cognitive issues in visual perception

Our perception of a visual stimulus depends

- Not only on what we see
- But also on how we interpret it

From seeing to perceiving

- Perception, interpretation, and comprehension of visual input influenced by:
  - Context and organization
  - Attentional focus
  - Expectations
  - Prior knowledge
  - Past experiences
  - Subjective biases

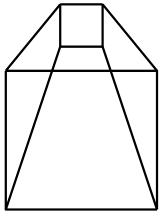
Perception: deriving integrated understanding from disparate features

- Visual perception can be affected by verbal priming
- Once achieved, the preferred organization is "irresistible and irreversible"

R. F. Street. *A Gestalt Completion Test*, Teachers College, Columbia University, 1931

Bi-stable figures

- Unchanging visual stimulus perceived in different ways at different times
- Dual interpretations, once achieved, can be alternated at will



Ambiguous images

- **1st interpretation of this ambiguous figure can be influenced by visual (but not verbal) priming [Leeper 1935, Sekuler and Blake 1994]**
- **"Wife or mother-in-law?" [Hill 1915]**

Favors "old woman" interpret.

Favors "young woman" interpret.

Influence of context and organization

- **When prematurely impose organization on ambiguous image, it becomes more difficult to subsequently reinterpret [Bruner and Potter 1964]** [Bruner and Potter 1964]

Mary Cassatt [1845-1926]

Influence of context and organization

- **Object identification is poorer in altered contexts**

Scrambled and unscrambles objects

[Biederman et. al 1973, from Sekuler & Blake 1990]

Cognitive influences include

- **Tend to see what have seen before**
  - **"Hollow mask" illusion (preference for familiar shape) [Gregory]**
- **Tend to see what "want to see"**
  - **School children asked to identify ambiguous pictures give more food-related responses before mealtime than after [Sanford 1936]**
- **Tend to see what "think should be there"**
  - **Radiologists' reporting amputated limbs as "normal" [Gale 1993]**

More cognitive influences

- "Need" influences perception
  - Children draw coins (in plain view) larger than real size
  - More pronounced for poorer children
    - [Bruner and Goodman 1947]
- Biases influence perception
  - People recall orientations of continents more axially-aligned than they really are
    - [Tversky 1991]

Gestalt principles of organization

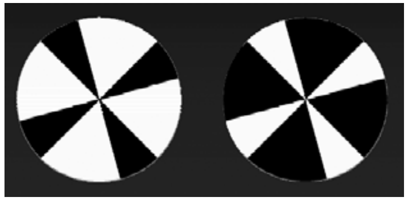
- "The whole is different than the sum of the parts"
- Primacy of figure/ground organization in visual perception [Rubin 1915]
- Perceptual grouping [Wertheimer 1912]
- Prägnanz
  - Tendency in perception towards simplicity, symmetry, regularity, wholeness;
  - Mirrored in the world of physics
- Perceptual constancy:
  - Indication of primacy of relationships

Figure / ground segregation

- Distinguishing objects from space between them
  - Contour belongs to figure
  - Figure appears to be in front of ground
  - Ground perceived to extend behind figure

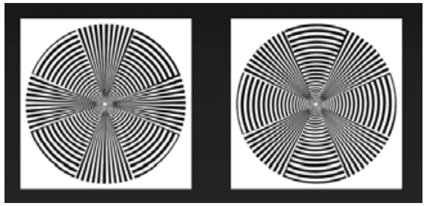
Influences on figure/ground perception

- Size: smaller area ==> perceived as figure



Influences on figure/ground perception

- Orientation: horizontal / vertical ==> perceived as figure



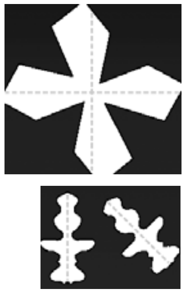
Influences on figure/ground perception

- Symmetry ==> figure

- Convexity ==> figure

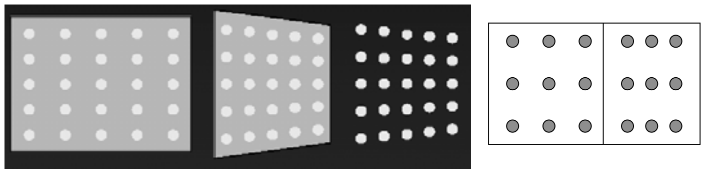
Symmetry and orientation

- Symmetry perception is sensitive to our default frame of reference [Rock 1973]
- Symmetry is most easily recognized when it occurs about vertical axis (of object)



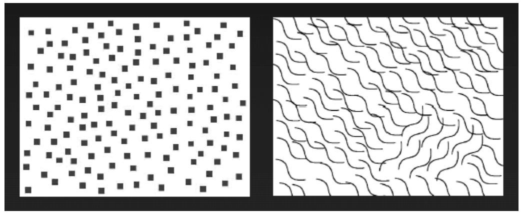
Perceptual grouping

- Proximity (phenomenal, not retinal)



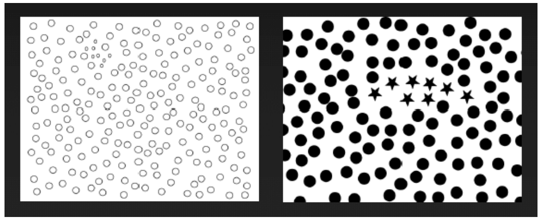
Perceptual grouping: similarity

- **Color** **orientation**



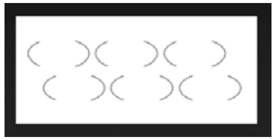
Perceptual grouping: similarity

- **Size** **form**



Perceptual grouping

- **Closure**



- **Good continuity**

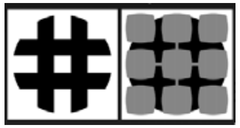
- **Common fate**

Prägnanz: tendency toward simplicity

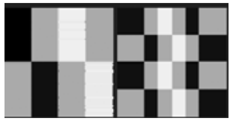
- **Object boundaries seem perceptually completed along curves of minimum energy**
- **Thinner objects appear to pass behind thicker ones**

Prägnanz: tendency toward simplicity

- Perceptual completion of occluded figures



- Transparency perception



Visual attention (space-based models)

- Spotlight metaphor
  - Can direct our attention to specific area of image;
  - All stimuli grouped in this area attended to
  - Evidence of our ability to simultaneously attend to disparate locations in visual field inconclusive

Visual attention (space-based models)

- Zoom lens metaphor
  - Can narrow / widen diam. of area attended to
  - When attention is spread over larger area, it operates at lower resolution; narrowing focus allows attention to finer detail

---

- Evidence that attention can modulate levels of activity of cells in visual cortex [cited in Sekuler and Blake 1994]
- Inhibitory effect on unattended stimuli

Allocation of visual attention

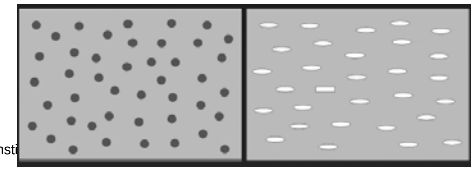
- Two mechanisms for attention distribution:
  - Goal-directed (“guided”, “top-down”)
  - Stimulus-driven (“captured”, “bottom-up”)
- What kinds of features/events can capture attention?
- Under what circumstances?
  - How efficiently can we direct attention to a non-spatial feature, such as color or shape?

Types of attention capture [Yantis]

- Strongly involuntary
  - In rare cases, event draw attention even when observer actively trying to ignore it
- Weakly involuntary
  - Abrupt visual onset that coincides with creation of new visual object draw attention, if observer is not actively trying to ignore it
- Non-obligatory
  - Irrelevant feature or event may interfere with visual search when observer actively searching for feature "singleton"

Feature detection: "pop-out" phenomenon

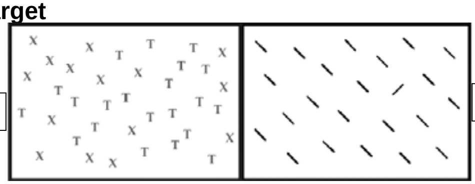
- Target element
  - Characterized by separable, basic feature
- "Pop out"
  - From field of homogeneous distractors
    - Do not share that feature



Factors influencing search efficiency

- "Pop-out" occurs when
  - Target has feature not possessed by any distractor, and,
  - Distractors have no features in common with target

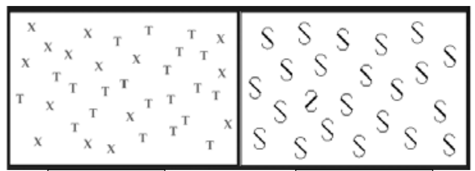
Blue "T"



/ among \

Factors influencing search efficiency

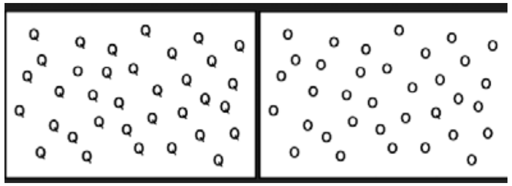
- Serial search is required when element of target appears among distractors



Green "T" Inverted "S"

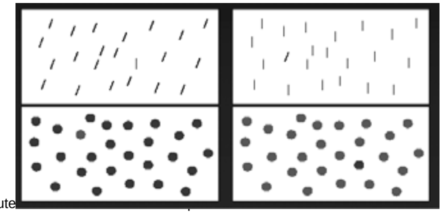
Factors influencing search efficiency

- **Target distinguished by lack of relevant feature requires serial search**



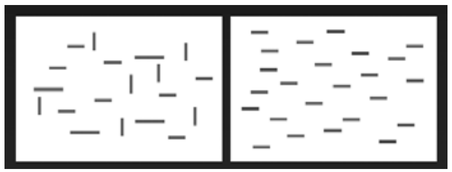
Search asymmetries

- **Search is faster when target (rather than distractors) characterized by “prototypical” feature**



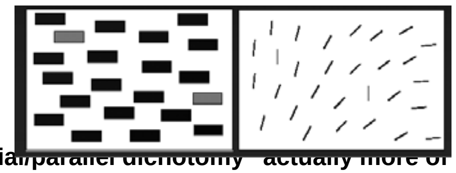
Factors influencing search efficiency

- **Search slower when distractors vary in characteristic that distinguishes target, when identity of target is unknown**



Factors influencing search efficiency

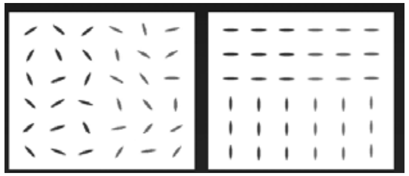
- **Search efficiency ultimately depends on saliency of (local) differences between target and distractors [Duncan and Humphreys 1989]**



- **“Serial/parallel dichotomy” actually more of continuum...**

Texture segregation

- *Regions* of textured image may be preattentively segregated, based on perceptual grouping of element properties or features

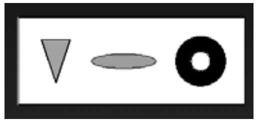


Triesman's *Feature Integration Theory* of object perception

- The theory:
  - Basic features detected preattentively (independently and in parallel)
  - Focused attention required to combine features
- The implications:
  - Errors of integration occur when attentional allocation insufficient
  - Serial search required to detect target that is defined by conjunction of features

Triesman's *Feature Integration Theory* of object perception

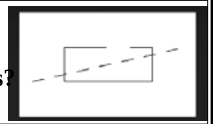
- However....
  - Integration errors suppressed when stimuli have semantic meaning
  - Targets defined by across-feature conjunctions may be detected "in parallel" when items can be perceptually grouped by one of features



Visual Attention: object-based models

- Observers can more accurately report on multiple features in image of overlapping objects when features belong to same object [Duncan 84]

-- Line dotted or dashed?
-- Gap on box to left or right of center?
-- Line tilted upwards to the right or downwards?
-- Box long or short?

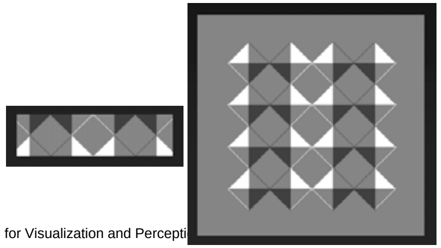


Visual Attention: object-based models

- Strong evidence for preattentive object representation: [Wolfe 96]
  - Targets defined by within-feature conjunctions (e.g., color) may be preattentively" detected when features are hierarchically structured

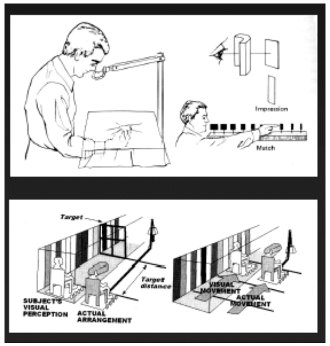
Global influences on local perception

- Perceived lightness depends on global interpretation, in 2D and 3D [Adelson 1993]



Visual perception in context

- Visual input dominates haptic input for form perception [Rock 1975]
- Vestibular cues dominate weak visual cues to the extent of passive motion [Harris et. al 1997]

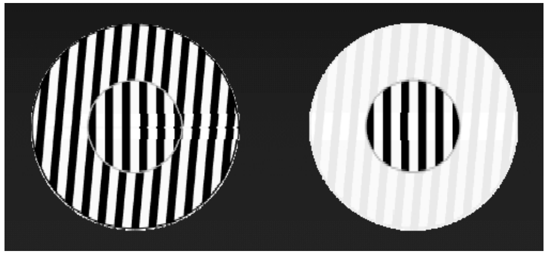


Geometrical illusions: Introduction

- Geometrical illusions not conceptual
  - Knowing that two lines are parallel or same length doesn't immediately void illusion
- However, many illusions
  - Decrease in strength with repeated exposure
  - Remain weakened for extended time
- Do not originate in retina
- Persist when stimulus divided into
  - Test
  - Inducing component
    - Presented separately to each eye

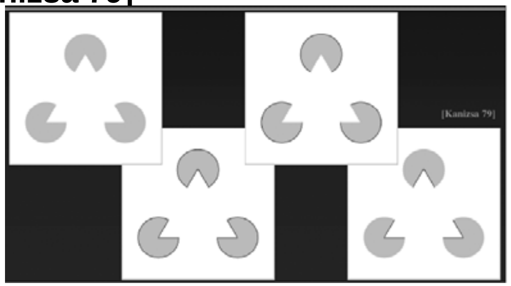
Geometrical illusions

- **Tilt illusion**



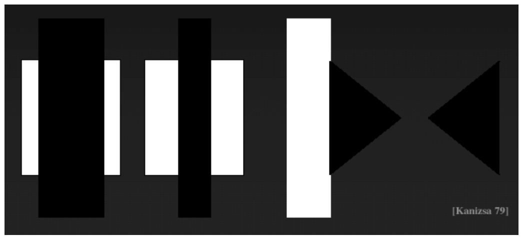
Amodal completion: percept not concept

- **[Kanizsa 79]**

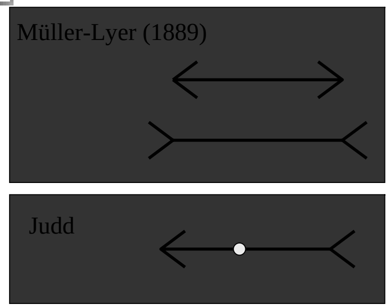


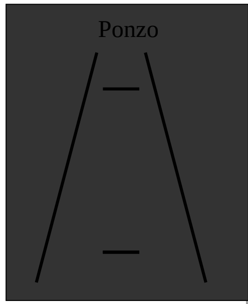
Amodal completion and size illusion

- **Apparent size is changed by amodal completion [Kanizsa 79]**

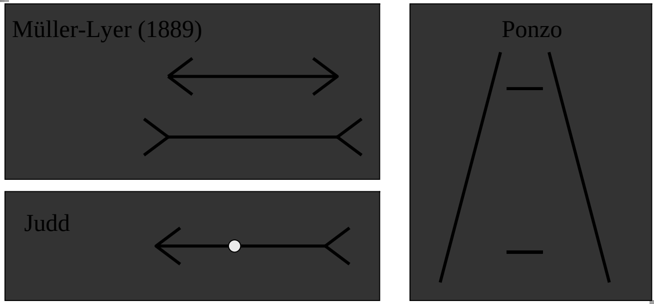


Geometrical illusions





Geometrical illusions



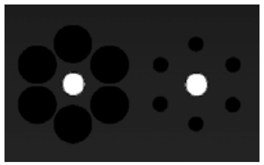
Geometrical illusions

Titchener (1898)

Delboeuf (1892)

Geometrical illusions

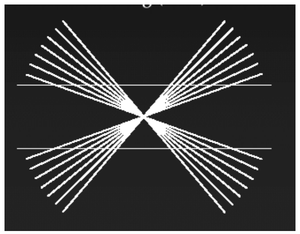
Titchener (1898)



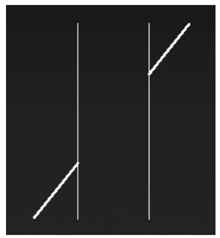
Delboeuf (1892)

Geometrical illusions

Herring (1861)



Poggendorf (1860)



Geometrical illusions

Herring (1861)

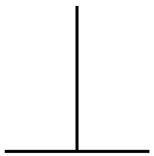
Poggendorf (1860)

Geometrical illusions

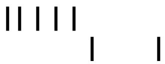
Zoellner Jastrow

Geometrical illusions

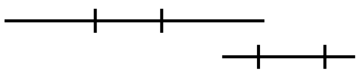
Horizontal-
vertical illusion



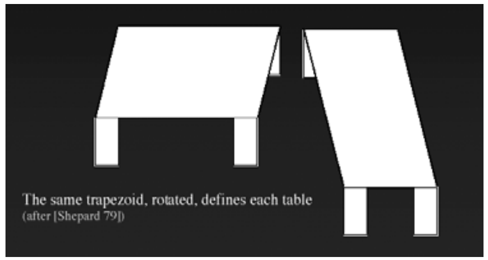
Opel-Kundt illusion



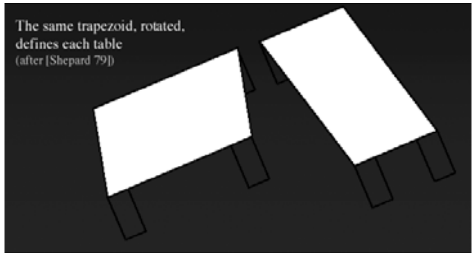
Divided-line illusion



Geometrical illusions



Geometrical illusions



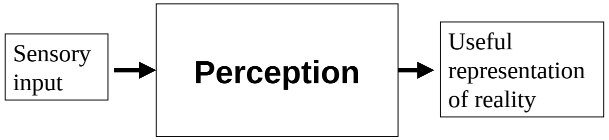
Summary

- What we perceive depends not only on what we see but also on context, interpretation, and many other conscious and subconscious factors
- The path from stimulus to recognition is complex and not well-understood
- As visualization developers we need to be aware of the factors influencing peoples' ability to perceive information in images, so that we can design images that convey information in an optimal way

Auditory perception

- Why auditory?
- Difference between auditory & visual perception
- Basic auditory perception
- Interactions with vision

Perception (reminder)



Visual/auditory differences & similarities

- Constancies
  - Vis: size
    - Irrespective of perspective in image
  - Aud: timbre
    - Recognize same voice in quiet / noisy environment
      - ➔ Speaker / voice recognition

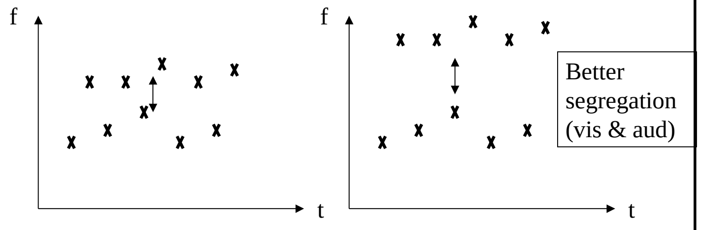
For our application

- Regions grouped appropriately
  - Vision
  - Audition

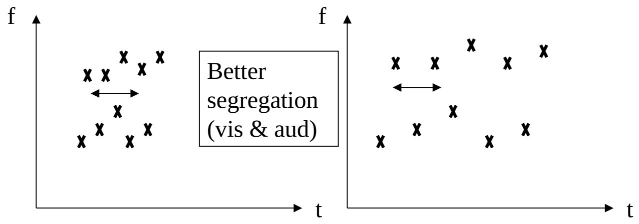
Comparison: scene analysis in vision & audition

1. Auditory streaming and apparent motion

Better segregation w/greater frequency separation



Better segregation w/higher speed

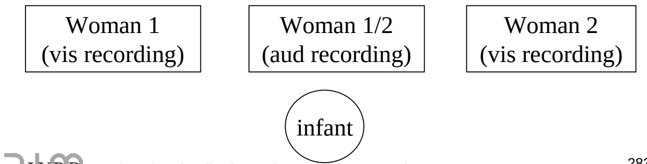


Gestalt grouping

Vision	Audition
Distance: space separation	"Distance": time / frequency separation
Similarity: visual	Similarity: timbre
Apparent motion	Stream segregation
Spatial motion	Melodic motion: as freq separation between high and low tones, must slow sequence down (can't keep up with rapid changes)

Interaction with vision

- **Vis/aud sync "built in"**
  - **E.g., infant experiment: aud in sync w/only one vis. Infant sync correctly**
  - **Infant reduces time looking at video if sound lags > 400 msec after vis**



Interaction with vision

- **Humans use each sense to correct scene-analysis decisions of other sense**
- **E.g., lip-reading, not only by deaf**
- **Experiment:**
  - **Aud: "ga-ga"**
  - **Vis: "ba-ba"**
  - **Eyes open ➔ blend of sounds perceived**
  - **Eyes closed ➔ correct sounds perceived**
- **Eye "wins" over ear**
  - **Justification: sound can bounce off walls, vision, not.**

Eye's advantage over ear

- Parallel vs. sequential

Ear's advantage over eye

- Sound can bend around large obstructions
- Light cannot
- ➔ Best strategy: combine info from both

Sound perception parameters

- Loudness
- Pitch
- Sound recognition
- Interaural differences
- Localization

Loudness

- Magnitude estimates
- Intensity discrimination

Pitch

- Frequency
  - Absolute vs. relative
- Variations with intensity
- Doppler shift
- Relationship to timbre

Sound recognition

- What the source is
  - Auditory perception of texture
- Localization
  - Where sound originates
- Interaural differences
  - Time ➔ localization of low frequencies
  - Intensity ➔ localization of high frequencies

Mislocalization errors

- Ear / eye contradiction
  - E.g., movie speakers location vs. screen
  - Ventriloquism
  - Pseudophone (tubes that switch left-right ears' sound)
- Eyes win over ears
- With eyes closed, ears win

Avoiding mislocalization

- Head movements
- Pinnas: bounce off sound various times ➔ time/frequency differences ➔ better localization
  - Blocked ➔ reduces localization

Conclusions

- Sounds can be used to
  - Reinforce vision
  - Increase dimensionality
  - Disambiguate
- But need to pay attention to possible interferences, inconsistencies

Multi-view Visualization

- Why 'multi-view'
- Handling multiple views
  - User Issues
  - Coordinating Views
  - Designer issues

Why Multi-view

a 'View'

- a particular visual representation of a data set
- different views reveal different aspects of data
  - complex (e.g., multidimensional, heterogeneous) data sets typically require multiple complementary views
  - complex problems may require multiple views of multiple data sources

Multiple Views

- Multiple view system
  - two or more different views to support investigation of a single conceptual entity
- Possibilities
  - SS: single data model/single data source
  - SM: single data model/multiple data sources
  - MS: multiple data models/single data source
  - MM: multiple data models/multiple data sources

Examples

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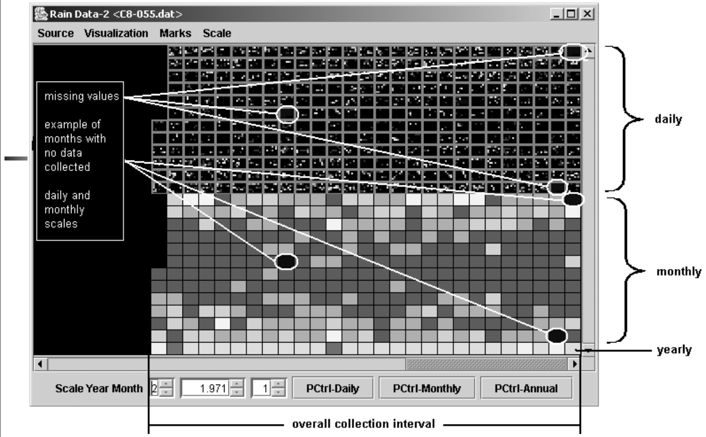

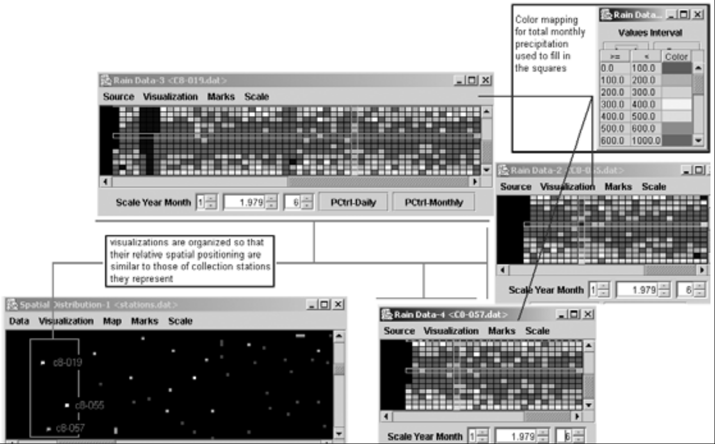

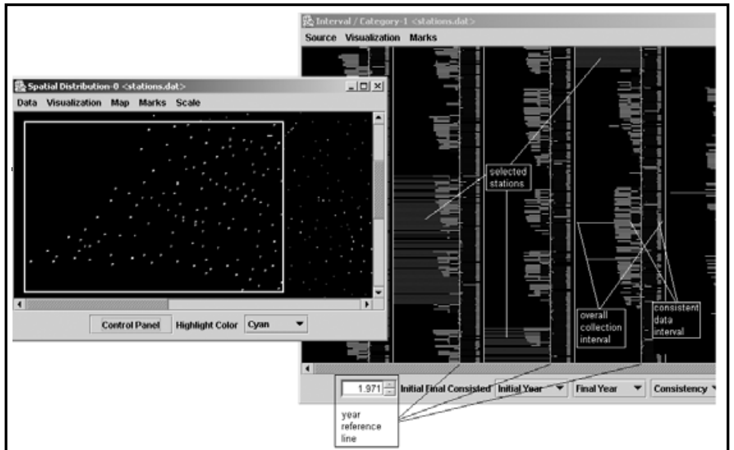

User Issues

- Cognitive overhead
  - Additional interaction
  - Window layouting
  - Context switching
  - Memory load
  - Comparison
  - Learning curve
- Coordination

Coordinating views

- Coordinate content, appearance and behaviour of the views
- Goal
  - to make apparent the relationship between the contents of different windows

Coordinating views

- Typical approach
  - coordinate user interactions, but...
- Other coordinations possible
  - visualization parameters, color maps, viewing parameters...

Coordinating views

- Typical interactions
  - navigational slaving
  - linked brushing
  - details on demand
  - ...
- “Coupling” function

Striving for flexibility

- Need for a systematic approach towards multiple view coordination
  - Generality, flexibility
- Data, task and user dependence
- Coordination models

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Snap-Together

- Chris North & Ben Shneiderman
  http://www.cs.umd.edu/hcil/snap/
  http://infovis.cs.vt.edu/snap/
  - visualizations defined on data schemas, rather than on specific databases
  - coordination of user actions on views of relational data
  - data centric approach

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Snap-Together Perspectives

- Conceptual model
  - formalization of coordinated multiple view vis's in terms of relational data model
- User interface
  - composition of custom multiple-view vis's
- System architecture
  - web-based component architecture, run time integration of diverse data source and vis tools

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Other Models

- More generic approaches
  - View Coordination Architecture, Pattison & Phillips 2001
  - Abstract Coordination Model, Boukhelifa & Rodgers 2003

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Coordination Models

- Common to all
  - Component-based, extensible, dynamically configurable software architectures

Designer Issues

- Impact on system requirements
  - computing power
  - display space
  - implementation complexity

Guidelines for Designers

- Source: Baldonado et al. Proceedings of Advanced Visual Interfaces, 2000
- Eight design guidelines
  - when and how
  - targeted at system designers/evaluators of single user systems

Guidelines for Designers

- Source: Baldonado et al. Proceedings of Advanced Visual Interfaces, 2000
- When to use multiple views
  - Rule of diversity
  - Rule of complementarity
  - Rule of decomposition
  - Rule of parsimony

Guidelines for Designers

- Source: Baldonado et al. Proceedings of Advanced Visual Interfaces, 2000
- How to use multiple views
  - Rule of space/time resource optimization
  - Rule of self-evidence
  - Rule of consistency
  - Rule of attention management

Summarizing

- Benefits
  - different aspects of a single data source
  - integrate info from multiple data sources
- Cost
  - extra complexity (user and designer)
  - additional work to handle this...

Evaluation and verification

- Overview
  - Why run experiments?
  - Experiment design
  - Case study design
  - Analyzing data
  - Case study analysis
  - Validity of experiments

Why run experiments?

- Vis method technically possible, but better?
- Objective comparisons
- Notice small, subtle differences
- Believe unexpected effects

Experiment design

- Experiment: a procedure ...
- Operations definition ...
- Measurement definition ...

Experiment: a procedure ...

- Manipulate active independent variable
- Measure changes in dependent variable
- Under controlled conditions

Operations definition …

- Specify operations to manipulate variables

Measurement definition …

- Specify procedures to measure variables

Hypothesis

- State expected relationship between
  - Input condition
  - Output behavior
- Null hypothesis
  - There is no relationship
- Hypothesis must be ...

Hypothesis must be ...

- Explicit
- Empirically testable
- Formulated prior to testing

Variability

- Maximize effects of experimental variables …
- Minimize effects of extraneous variation ...

Maximize effects of experimental variables ...

- Extreme values
- Multiple values

Minimize effects of extraneous variation ...

- Subjects
  - Characteristics
  - Learning
- Procedural variations
  - E.g., trial order
- Environment

Minimize extraneous effects

- Hold extraneous variables constant
- Balance effects of extraneous variables
- Randomize extraneous variables
- Incorporate extraneous variables as independent variables

Between-subjects design

- Different subjects ==> diff. treatments
  - Subjects exposed to 1 level of variable
- To minimize effects of subject differences
  - Randomize assignment of subjects to treatments
- Advantages …
- Example: N = 4…

Advantages ...

- Subjects not influenced by other treatments
- Fewer learning effects

Example: N = 4

		Treatments	
		A	B
Subjects	1	Va1	
	2	Va2	
	3		Vb3
	4		Vb4

	Treatments	
	A	B
1	Va1	
2	Va2	
3		Vb3
4		Vb4

Within-subjects design

- All subjects exposed to all levels of each independent variable
- To minimize mult. treatment effects
  - Hold conditions constant
  - Balance conditions
- Advantages …
- Example: N = 4 ...

Advantages ...

- More data per subject
- Possibly greater sensitivity
- Can study interactions

Example: N = 4

		Treatments	
		A	B
Subjects	1	[redacted]	Vb1
	2	[redacted]	Vb2
	3	[redacted]	Vb3
	4	[redacted]	Vb4 = Vb1

		Treatments	
		A	B
Subjects	1	[redacted]	[redacted]
	2	[redacted]	[redacted]
	3	Va3	Vb3
	4	Va4	Vb4

Overview

- Why run experiments?
- Experiment design
- Case study design
- Analyzing data
- Case study analysis
- Validity of experiments

Case study: Optimal Color Scales

- "Optimal Color Scales 101" ...
- Hypothesis …
- Design
  - Procedure and image data …
  - Task …
  - Subjects ...

"Optimal Color Scales 101" ...

- Maximize some measure(s)
- Subject to constraint(s)
- E.g., Linearized Optimized Color Scale (LOCS)
  - Max. Perceived Dynamic Range (PDR)
    - Just Noticeable Differences (JND)
    - Constraints

Hypothesis ...

- Better detection w/ scale that maximizes PDR (#JNDs)

Procedure and image data ...

- Test color vision
- Training session …
- 4 test sessions per subject ...

Training session ...

- 20 images
- Feedback

4 test sessions per subject ...

- 100 images
- Ea. subject S, scale S1, S2, S3, S1
- Partially-counterbalanced
  - Random assignment of subjects to scale order

Task ...

- 1. Detection
  - {Normal, Abnormal}
- 2. Confidence
  - {Likely, PRobably, POssibly}
- Yields ...

Yields ...

- ==> 6 categories
  - {LN, PRN, PON, POA, PRA, LA}
- ==> 5 binary decision criteria
- Receiver (Relative) Operating Characteristics (ROC) curve
  - Area under curve ≈ performance

Subjects ...

- 6 subjects
  - 2 physicians
  - 1 Ph.D. student
  - 2 Post doctoral researchers
  - 1 System administrator
- 1 discarded

Overview

- Why run experiments?
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Basic statistics

- Measures of tendency
  - Mean, median
- Measures of variability
  - Range, variance, standard deviation

Statistical hypothesis testing

- Basic procedure
  - Compute test statistics
  - Accept or reject null hypothesis
- p-value …
- Possible errors ...

p-value ...

- Given that the null hypothesis is true
  - I.e., no relationship
- Probability of obtaining a test statistic as extreme or more extreme than that observed

Possible errors ...

- Type I: reject true null hypothesis (false positive)
- Type II: fail to reject false null hypothesis (false negative)

Overview

- Why run experiments?
- Experiment design
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- Analyzing data
- Case study analysis
- Validity of experiments

Results

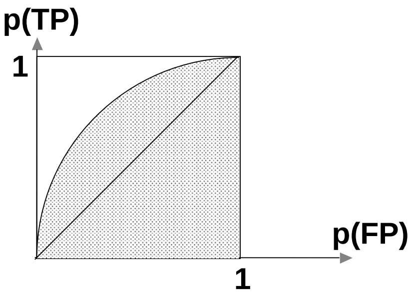
- For each subject, each session
  - ==> 6 categories
    - [LN, PRN, PON, POA, PRA, LA]
  - ==> 5 binary decision criteria ...
  - ROC curve …
- Results …

5 binary decision criteria …

- Divide categories into [N] [P] (Lenient to Stringent):
  - [LN] [PRN, PON, POA, PRA, LA] (L)
  - [LN, PRN] [PON, POA, PRA, LA]
  - [LN, PRN, PON] [POA, PRA, LA]
  - [LN, PRN, PON, POA] [PRA, LA]
  - [LN, PRN, PON, POA, PRA] [LA] (S)

ROC curve ...

- Area under curve represents performance



Results ...

Reader	LinGray		Scale Heated-Object	LOCS	
1	0.921, 0.031	0.925, 0.031	0.791, 0.048	0.799, 0.045	
2	0.945, 0.027		0.882, 0.047	0.913, 0.032	0.910, 0.036
3	0.920, 0.029		0.836, 0.041	0.893, 0.039	0.811, 0.053
4	0.639, 0.058		0.478, 0.063	0.605, 0.060	0.652, 0.061
5	0.918, 0.030		0.664, 0.057	NA	NA

- (Area, Standard deviation)
- NA: no result from prog.

Overview

- Why run experiments?
- Experiment design
- Case study design
- Analyzing data
- Case study analysis
- Validity of experiments

Validity of experiments

- Statistical conclusion validity ...
- Internal validity ...
- Construct validity ...
- External validity ...

Statistical conclusion validity ...

- Correct decisions about null & alternate hypothesis?
- Data variability
  - Simulated vs. real data

Internal validity ...

- Observed effect due to manipulations of independent variable?
  - Procedure confounded results?
  - Automation

Construct validity ...

- Measured qualities indicate conceptual variable?
  - Task meaningful? representative?
    - Simple task for simpler tools
- Questions with clear right answer

External validity ...

- Results generalized to larger population?
  - Subject pool representative of target population?
    - Naive
    - Experts

Case study critique

- Task: Blob detection vs. other
  - Simulated blobs
- LOCS development
  - Color context
  - Uniform color space?
  - Math vs. perceptual modeling of L, H, S
- Objective vs. anecdotal results

Summary

- Why run experiments?
- Experiment design
- Case study design
- Analyzing data
- Case study analysis
- Validity of experiments

Conclusion

- Motivation
- Foundations of vision & color
- Visual perception
- Auditory perception
- Cognitive issues
- Perception in image
  - Generation
  - Understanding
- Multi-view visualization
- Evaluation and verification

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