Comp/Phys/Apsc 715

Graphics System, Human Visual System Characteristics, and Illusions:
Lighting, Surface Perception, Texture, Acuities,
Receptive Fields, Brightness Illusions, Simultaneous Contrast, Constancy

Example Videos

- Volume Illustration of Muscle from DT-MRI
- Flowing volumetric surfaces
- Visual Queries for Neurobiology
  - Link to folder (open queries_divx.avi with VLC)

Pop Quiz!

- What is magic about Red, Green, Blue?
- What is the human visual system especially good at?
- What is the human visual system especially poor at?
- What visual channel is used for shape detection?

What happens in the world?

- Ambient Optical Array (Gibson, 1986)== Plenoptic Function = f(x,y,z, ϕ,θ, λ)
  - Describes intensity of light passing all locations, in all directions, at all wavelengths
  - Is zero inside opaque objects
  - Takes forever to simulate
- We only need a sampling of this function!
  - Passing through center of projection of the eye(s)
  - Coming from pixels on the screen
  - At three wavelengths ("red", "green", and "blue")
- This sampling is what computer graphics is about

What's the big deal?

How about just drawing the correct number of photons from objects in space?

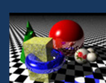
- Works for photorealism!
  - It would take forever to compute…
  - Display devices have limited ranges
- We're interested in displaying data
  - Deviations from photorealism cause distortion
  - Perceptual machinery tuned for real world can drastically affect perception of quantitative data

What happens in the computer?

- One or two screens stand in for 3D world
- Ideal display would match human capabilities
  - "Retina" display (+brightness…)
- Understand human perceptual system
  - to harness bandwidth and pattern matching (what's the best display to provide?)
  - to fool it (what cheats can we get away with?)

Different CG methods to render the environment

- Ray tracing
  - Optics: Traces paths from eye through screen

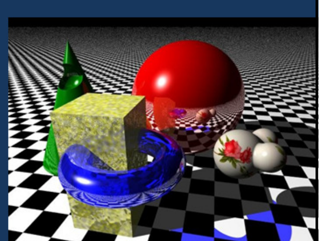


- Radiosity
  - Solves the heat-transfer equation for light

- Scan conversion
  - Cheap trick, fast to compute
  - Simplified lighting model implemented in hardware

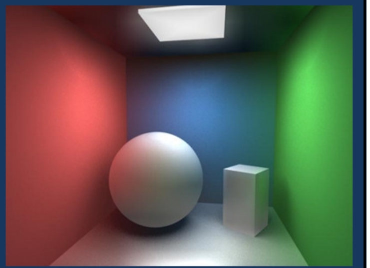
Ray Tracing Example

- Specular reflection
- Precise shadows
- Complex lighting
- Many minutes
  - In 1990



Radiosity Example

- Diffuse light
- Color washing
- Soft shadows
- Several hours
  - In 1990

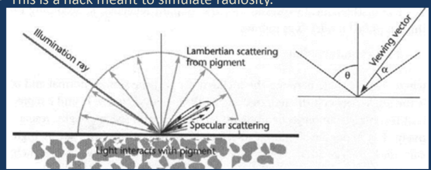


Scan Conversion Example

- Ambient, diffuse, and specular
- No reflections
- No shadows
- 30 frames/second
- Hardware + tricks

Scan Conversion Lighting Model

- Diffuse depends on incident light angle (θ)
  - Color of the surface
- Specular also depends on view direction (angle of incidence = angle of reflection) (α)
  - Color of the light
- Ambient term independent of light & view
  - This is a hack meant to simulate radiosity.



Ware Recommends: (1/2)

- Glossy paint model
  - Lambertian (diffuse reflection)
  - Specular (mirror reflection)
  - Ambient (everything glows)
  - Add textures
  - Add shadows
- Hardware support
  - All but shadows standard in OpenGL/DirectX
  - Shadows can be done using tricks

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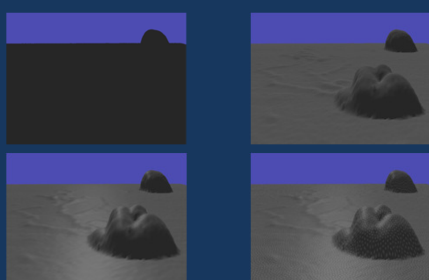
Ware Recommends: (2/2)



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Why does this model work?

- It may be the model that the brain uses for shape estimation
  - A more complex model may actually impede understanding of the surface
- Lambertian (diffuse) and texture better for overall shape perception
- Specular better for small details, if the lighting is just right
- Shadows indicate relative heights of objects, distances

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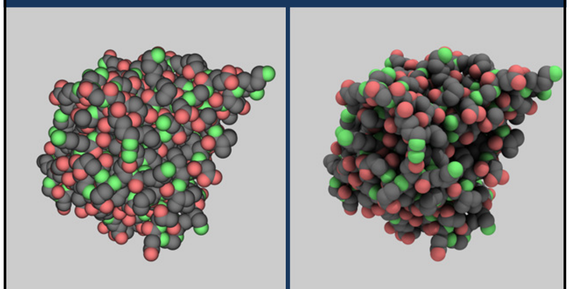
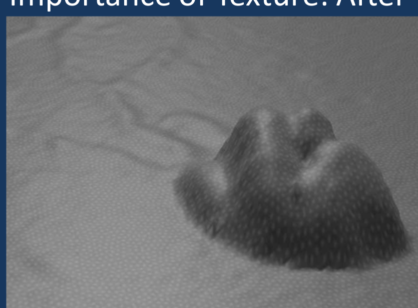
The importance of shadows



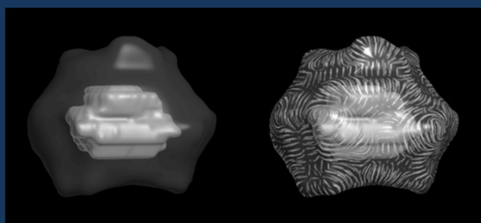
Importance of Texture: Before

Importance of Texture: After



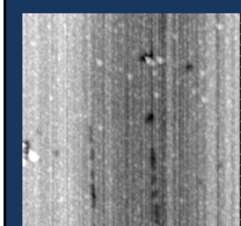
Importance of Texture 2: Transparency

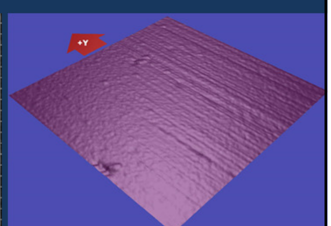
- Victoria Interrante



3D Not always the best display

- Small features in noisy data



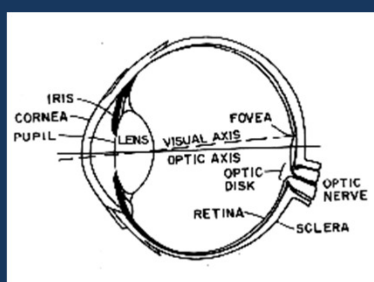


What is the human visual system tuned for?

- Understanding the environment
  - Navigation
  - Seeking food or avoiding foe
  - Tool use (object shape perception)
- Perception of *surfaces* in the environment
  - Independent of lighting conditions
  - Usually textured
  - Usually not planar

Physiology: Eye

- Cornea
- Iris
- Lens
- Retina
  - (fovea)
- Optic nerve
  - (blind spot)

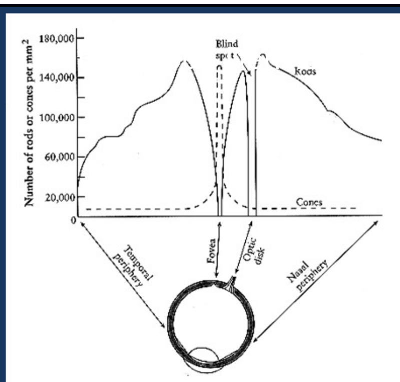


Chromatic Aberration in the Lens System

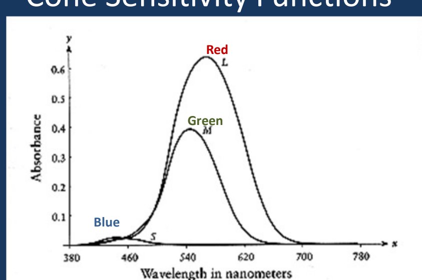
- Most People See the Red
- Closer than the Blue
- Green – where is it?
  - But some see the
  - Opposite effect
- Careful with this slide: Brightness effect?

Physiology: Receptors

- Rods
  - active at low light levels (night vision)
  - only one wavelength sensitivity function
  - 100 million rod receptors and nothing on…
- Cones
  - active at normal light levels
  - three types: sensitivity functions peaks at different wavelengths (“red”, “green”, “blue”)
  - 6 million cone receptors
  - Concentrated in the center of vision (fovea)



Cone Sensitivity Functions



- Glassner ‘95, p. 16.

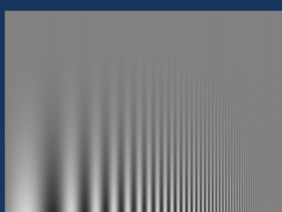
Acuities: Boiled way down

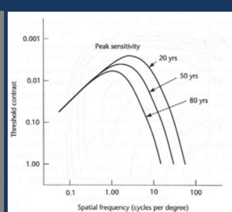
- Human visual acuity in the fovea (central 2 degrees) is better than the display resolution (thus the name “retina display” when it became equal)
- Outside the fovea, it is much worse than the display resolution
- Can tell vernier acuity much more precisely (1/10 pixel) – two lines not quite aligned

- Can integrate over space, time, and stereo to do better (and to improve effective display resolution)

Spatial Contrast Sensitivity Function

- Peak sensitivity at around 1-3 cycles/degree
- Much more sensitive to contrast than hue

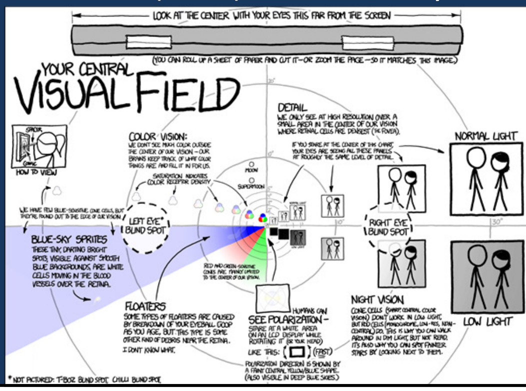




Cutoff at 50 cycles/deg.

- Receptors: 20 sec of arc (180 per degree)
  - Pooled over larger and larger areas
  - 100 million receptors
  - 1 million fibers to brain
- A screen may have 30 pixels/cm – need about 4 times as much.
- VR displays have 5 pixels/cm

XKCD (1080) view of the eye



What brightness do we see?

- Receptors respond to absolute levels, but that's not what we perceive
- Neurons early in the system behave like change meters (in space and time)
- True for other stimuli (not just brightness)

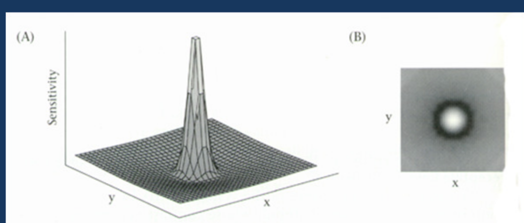
- Tuned to see surfaces independent of overall illumination level
- Can attempt to do otherwise in displays encoding non-shape information with brightness changes, but this leads to inaccuracies

Neurons

- Signal each other by increasing or decreasing firing rate relative to background
- Can receive input from hundreds or thousands of other neurons
  - Some increase firing rate
  - Some decrease firing rate
  - *Receptive field* describes the weighting
- We'll look at one type of receptive field and illusions that it causes

Center-surround Receptive Fields

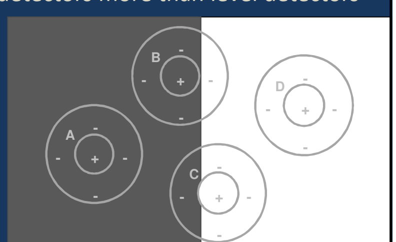
- Retinal ganglion cells
  - Can be on-center-off-surround or off-center-on-surround



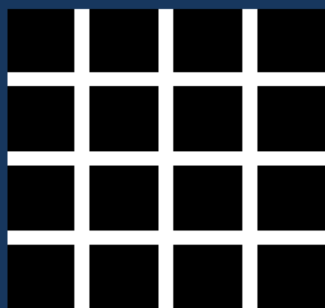
Center-surround Receptive Fields

- Act as edge detectors more than level detectors

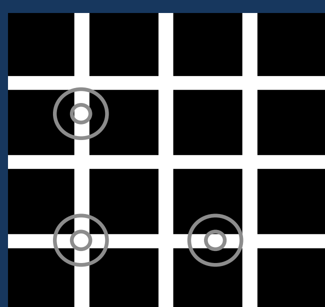
A: mid-low
B: lowest
C: highest
D: mid-high



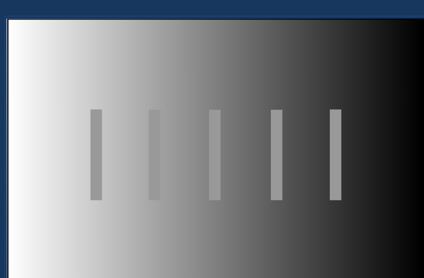
Hermann Grid Illusion

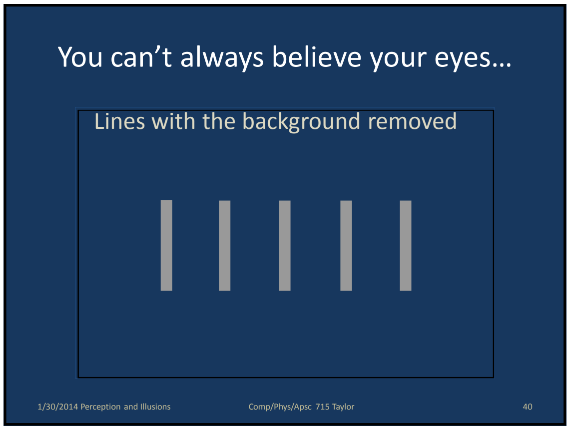


Hermann Grid w/ Receptive Fields



Simultaneous Contrast




You can't always believe your eyes…
Lines with the background removed
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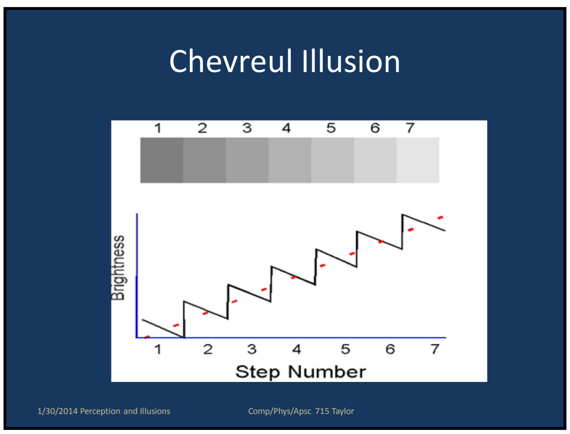
Chevreul Illusion
1 2 3 4 5 6 7
Brightness
1 2 3 4 5 6 7
Step Number
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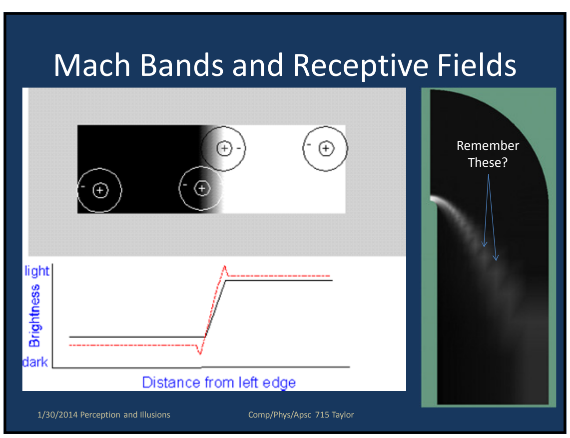
Mach Bands and Receptive Fields
light
Brightness
dark
Distance from left edge
Remember These?
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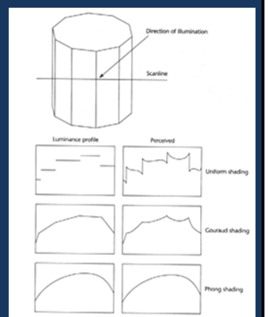
Illusions and Rendering

- Shading Illusions
- Uniform
  - Chevreul
- Gouraud
  - Mach bands



Why do we care?

- Visual artifacts in computer graphics
  - Uniform, Gouraud shading
    - Chevreul, Mach Bands
    - Hardware acceleration
  - Phong interpolation helps
    - Hardware acceleration becoming more common
- Harness to enhance edges
  - Highlight objects so they stand out
- Errors when reading grayscale maps
  - Up to 20% of the entire scale [Ware88]
  - Value read depends on nearby values

Luminance, Brightness, Lightness

- Physical
  - Luminance: Number of photons coming from a region of space
- Perceptual:
  - Brightness
    - Amount of light coming from a glowing source
  - Lightness
    - Reflectance of a surface, paint shade

Luminance

- Amount of light hitting the eye, weighted by the sensitivity of the photoreceptors to each wavelength (R&G).

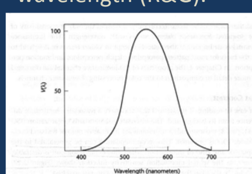
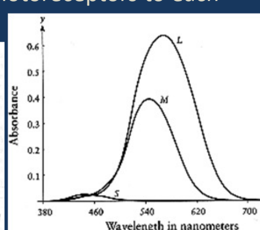
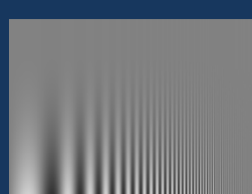


Figure 3.12 The CIE $V(\lambda)$ function representing the relative sensitivity of the human eye to light of different wavelengths.



Finer Detail Requires More Luminance Difference

- Text: at least 3:1
  - 10:1 preferred
- Generalizes to data
  - Detection of detail requires more contrast



More detail → More contrast

Brightness

- Perceived amount of light coming from a glowing object
- Stevens power law
  - Brightness ≈ Luminance^n
  - n = 0.333 for patches of light, 0.5 for points
  - Applies to many other perceptual channels
    - Loudness (dB), smell, taste, force, friction, etc.
- Enables high sensitivity at low levels without saturation at high levels
- Just-noticeable difference depends on value

Monitor Gamma Correction

- Attempt to make linear change in voltage map more closely to linear perceptual difference.
- Luminance ≈ Voltage^γ
- γ ranges from 1.4 through 3
  - γ=3 cancels n=0.33 Stevens' function:
    - Brightness ≈ $(\text{Voltage}^3)^{0.33}$ ≈ Voltage
- True control of luminance requires careful monitor measurement and calibration

Adaptation, Contrast, and Lightness Constancy

- Luminance is completely unrelated to perceived brightness or lightness
- Luminance is completely unrelated to perceived brightness or lightness
- Luminance is completely unrelated to perceived brightness or lightness
- brightness or lightness
- Luminance is completely unrelated to perceived brightness or lightness

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Adaptation: Overall Light Level

- Factor of 10,000 difference: sunlight to moonlight
  - Still can identify different-brightness materials
  - Absolute amount of light from surface irrelevant
- Adaptation to change in overall light level
  - Factor of 2 hardly noticeable
  - Iris opens and closes (small effect)
  - Receptors photobleach at high light levels (large effect)
  - Can take time to regenerate when entering dark areas
  - Eventually switch to rods

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Contrast and Constancy

- Concentric opponent receptive fields react most strongly to differences in light levels
- Item relative to surround

- Corrects for background intensity differences

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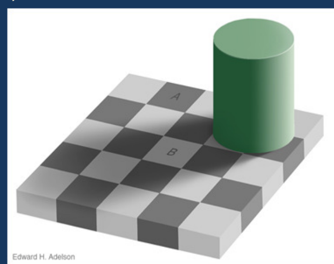
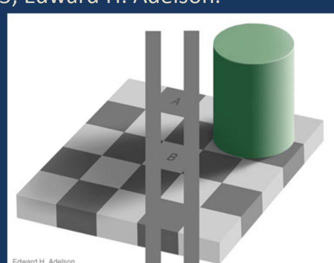
Visual System Interprets 3D Shape

- ©1995, Edward H. Adelson.



Visual System Interprets 3D Shape

- ©1995, Edward H. Adelson.

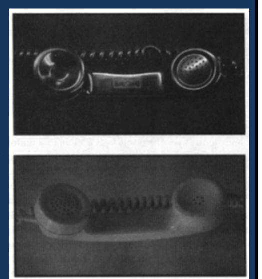


What you see depends on what you think you're looking at…

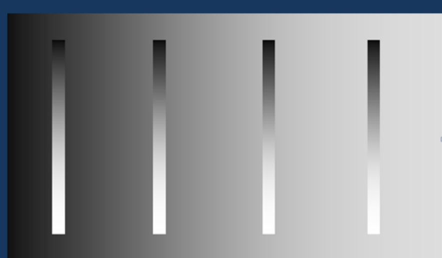
- Real paper in real office with real lamp
  - Very convincing
- Photograph of the same scene
  - Not so convincing
- CRT display of same scene
  - Even less convincing
- Studies of immersive vs. non-immersive displays show different perceptions of aspect ratio, slope
  - Even when images on retina are the same
  - Note incorrect perspective when viewing a picture or movie

Other Factors in Surface Lightness Perception

- Direction of illumination and surface orientation
  - Shape-from-shading information factored out
- Lightest object in the scene is a reference white
  - Other objects scaled accordingly
- Ratio of specular to nonspecular reflection

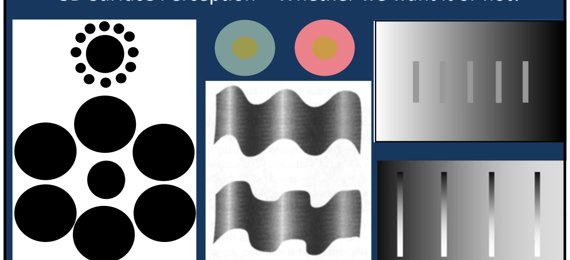


Crispening



What's Going On In There?!?!

3D Surface Perception – Whether we want it or not!



More Available Online

- http://www.purveslab.net/seeforyourself
- "Visuelle Welt" http://www.psychologie.uni-konstanz.de/abteilungen/kognitive-psychologie/various/demo-programs/viwo-visual-illusions
- http://www.csc.ncsu.edu/faculty/healey/PP/index.html
- http://www.qualitylogoproducts.com/lib/optical-illusions.htm

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Application: Can we make an Interval Grayscale Map?

- Just-noticeable-difference (JND): Weber's Law
  - δL/L is constant at threshold (δ around 0.005)
  - Applies when looking at small differences
- CIE uniform grayscale standard
  - Rated large differences in intensity to produce scale
  - $L = 116(Y/Y_n)^{1/3} – 16$, Y_n = ref white, $Y/Y_n > 0.01$
- Unavoidable Effects
  - Contrast/constancy: Surround affects perception
  - Crispening: Surround affects JND
  - Adaptation: Overall light level affects perception
- Therefore, take 'Uniform' with a *big* grain of salt…

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Conclusions (1/2)

- Visual system is a *difference* detector
  - Don't rely on it for absolute intensity measurement
  - Enables seeing patterns despite background
- Grayscale not a good method to code data
  - Various effects describe here
  - *Waste of resources* needed for luminance/shape (described later)
- Choose background based on goal
  - Object detection → large luminance contrast
  - Subtle gradations → make use of crispening

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Conclusions (2/2)

- Several illusions result from these effects
  - Be familiar with them and on the lookout
  - Test visualization formally, not just "by eye", if you want to provide quantitative data
- Provide rich visual display
  - Aim at realistic, not impoverished display
  - Take advantage of effects rather than fighting them

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"The Lesson"

- Visualization is not good at representing precise, absolute numerical values
- Visualization is good at displaying patterns of differences or changes over time, to which the eye and brain are extremely sensitive

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References:

- Importance of texture 2: Victoria Interrante
- Not always the best model: UNC nanoManipulator
- Receptor mosaic picture: [Frisby79], copied from Ware figure 2.15
- Graphics sampling and reconstruction: [Taylor94]
- Interpolation and Lighting Tricks: UNC nanoManipulator

References:

- Scan Conversion Example: David Ebert lecture
- Physiology (eye, receptors), Cone sensitivity, Rod/cone density: Penny Rheingans lecture
- Raytracing example: Donald W. Hyatt at Thomas Jefferson High School for Science and Technology using POV-Ray
- Radiosity example: http://www.vassg.hu/cornell_teapot.htm
- Anti-Aliasing example: http://www.richleader.com/bargainbinreview_FSAA.htm
- Importance of texture: UNC nanoManipulator system

References:

- Most of the material: Information Visualization
- Simultaneous Contrast, Center-surround Receptive Fields, Human Visual Characteristics, Communication between Receptors, Illusion examples: Penny Rheingans
- Mach Bands, Intensity Illusion: David Ebert