Comp/Phys/Mtsc 715


Example Videos

• Volume Illustration of Muscle from DT-MRI
• Flowing volumetric surfaces
• Visual Queries for Neurobiology

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
- 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

Radiosity Example

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

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 ($\theta$)
  - Color of the surface
- Specular also depends on view direction (angle of incidence = angle of reflection) ($\alpha$)
  - 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

Ware Recommends: (2/2)
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

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 a noisy image
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 (even moonlight)
  - 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
• 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

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
You can’t always believe your eyes…

Lines with the background removed

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Chevreul Illusion

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Mach Bands and Receptor Fields

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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.

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 = Voltage^1.33
- True control of luminance requires careful monitor measurement and calibration.
Adaptation, Contrast, and Lightness Constancy

- 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

Contrast and Constancy

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

- Corrects for background intensity differences
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
  - 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

3D Surface Perception – Whether we want it or not!
Application: Can we make an Interval Grayscale Map?

- Just-noticeable-difference (JND): Weber’s Law
  - $\delta L/L$ is constant at threshold ($\delta$ 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, $Y/Y_n > 0.01$
- 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...

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
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 \(\rightarrow\) large luminance contrast
  – Subtle gradations \(\rightarrow\) make use of crispening

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

“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
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](http://www.vassg.hu/cornell_teapot.htm)
• Anti-Aliasing example: [http://www.richleader.com/bargainbinreview_FSAA.htm](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