The eye, displays and visual effects

Week 2
IAT 814
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Visible light and surfaces

- Perception is about understanding patterns of light.
- Visible light constitutes a very small part of the electromagnetic spectrum.
- Humans can perceive light only in the range of 400 to 700 nanometers.
  - At wavelengths shorter than 400nm are ultraviolet light and X-rays.
  - At wavelengths longer than 700nm are infrared light, microwaves, and radio waves.
- Surface perception is primary interface with objects in the world (Gibson)
  - Ambient optical array
  - Optical flow
- World is an information display
- How do get similar information from dots on a screen?

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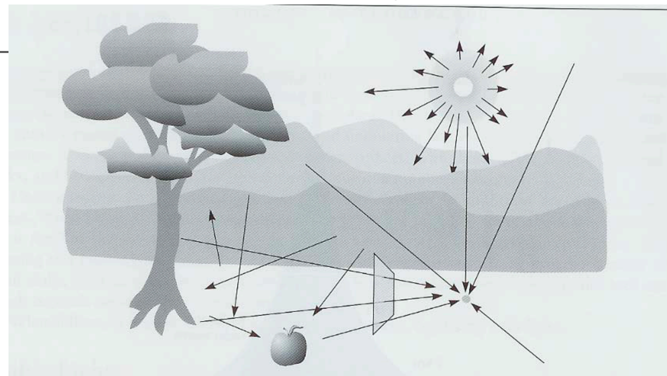
The ambient optical array



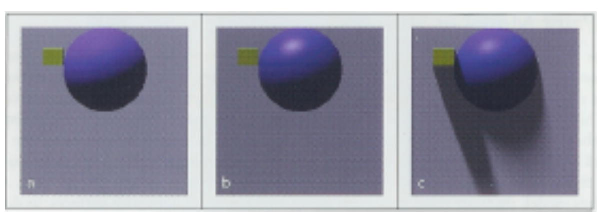
The Ambient optical array is a term that describes the array of light that arrives from all directions at some designated point in the environment. Simulating the appearance of the bundle of rays that would pass through a glass rectangle is one of the goals of computer graphics

Textured Surfaces and Texture Gradients

- Surface **texture** is one of the fundamental visual properties of an object.
- The texture of an object helps us see where an object is and what shape it has.
  - Orientation, shape and spatial layout
- Texture gradient of ground is important in space perception
- Even subtle texture needed for 3D
- Texture can be used for information -
  - Subtle texturing exceeds pixel capacities of most displays

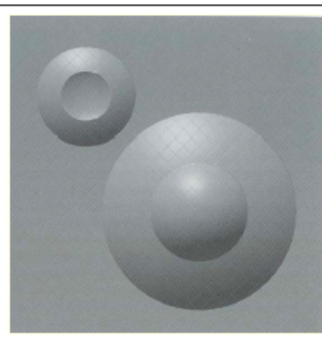
The paint model of surfaces

- Surfaces in nature are endlessly varied and complex.
- Microtextures give irregular patterns of reflection, so the amount and color of reflected light can vary with both the illumination angle and the viewing angle.
- This is a simple model that approximates many common materials.
- Shape from shading
- Simplified model may be embedded in our visual systems
  - Explanation of why these models work so well.



- a) Lambertian shading only.
- (b) Lambertian shading with specular and ambient shading.
- (c) Lambertian shading with specular, ambient, and cast shadows.

- Glossy leaves. The highlights are the colour of the illuminant.

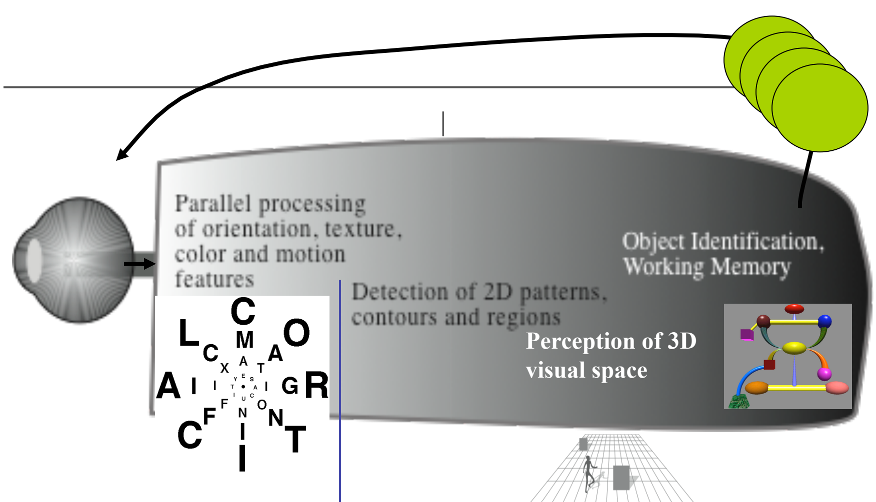


- Specular light reveals the details of surface structure but relies on viewpoint

How the eye works

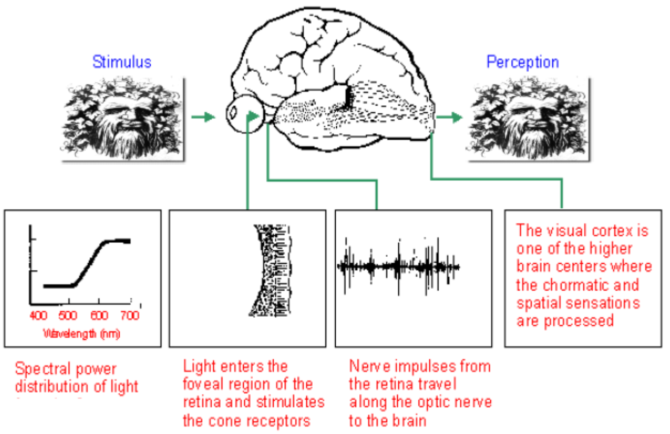
- The human eye, like a camera, contains the equivalents of a lens, an aperture (the pupil), and a film (the retina).
  - The lens focuses a small, inverted picture of the world onto the retina.
  - The iris performs the function of a variable aperture, helping the eye to adjust to different lighting conditions.
- Some people find it difficult to understand how we can see the world properly when the image is upside down.
- The right way to think about this is to adopt a computational perspective.
- We do not perceive what is on the retina; instead, our brains compute a percept based on sensory information. Inversion of the images is the least of the brain's computational problems.

The machinery



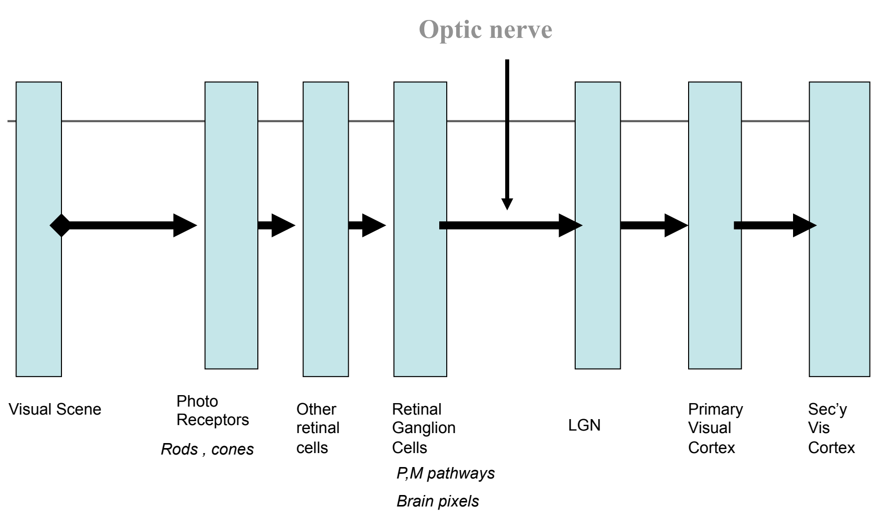
- Perceptual features

Visual Stages of Perception



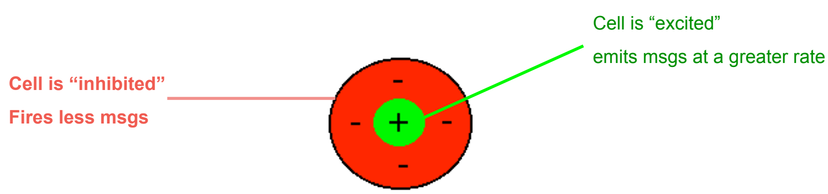
The visual stages from the stimulus to the perception of the external world

(Adapted from Wright, 1964)

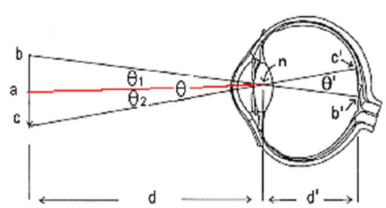


Receptive fields

- The area of the retina that results in a neuron being stimulated
- Can be the result of a pattern
- Edges and lines
- http://psych.hanover.edu/Krantz/receptive/
- Used to explain a variety of brightness and contrast effects



Visual angle and FOV



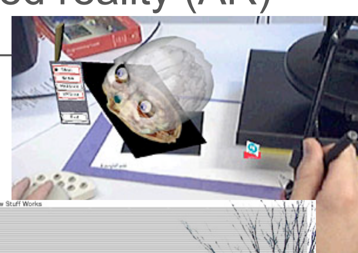
$$\frac{\theta}{2} = \arctan(\frac{ab}{d})$$

- Visual angle
  - Angle subtended by an object on the eye of an observer
- Normal vision
- Distinguish an object that subtends 1/60° at a distance of 20 ft
- FOV = 150° per eye

Depth of focus

- Eye contains compound lens
- Diopters define focal length of lens
- Range of diopters is the range over which the lenses in the eye can adapt
  - Oculomotor control to change the shape of the lenses
  - Flex diminishes with age
  - Reduces focal capacity
- Depth of focus is the range over which objects are in focus when the eye(lens) is adjusted for a particular distance
  - Eye focused at infinity: 3m--infinity
  - At 50 cm (monitor) : 7cm in front to 10 cm behind in focus
- Important for VR displays
- Hard to model depth of focus effects

Depth of focus: augmented reality (AR)



- Augmented-reality systems involve superimposing visual imagery on the real world so that people can see a computer graphics-enhanced view of the world.
- Easier to perceive both when same depth of focus
  - Set focal plane of virtual at real depth
- Different focal depths enforce perceptual distinction and enable selective attention (HUDs)
  - Problems with distance estimation

Depth of focus: Virtual Reality (VR)

- Virtual-reality (VR) displays block out the real world, unlike the see-through augmented-reality displays discussed previously.
- Ideally, objects on which the user fixates should be in sharp focus, while objects farther away or nearer should be blurred to the appropriate extents.
- Helmet mounted displays (HMDs) set screen at 2m
  - 1.2 - 6m is depth of focus
- Need *image blur* to model out of focus effect
- Depth of focus simulation is difficult and computationally expensive
- Large pixels and low resolution in VR displays prevent effective image blur

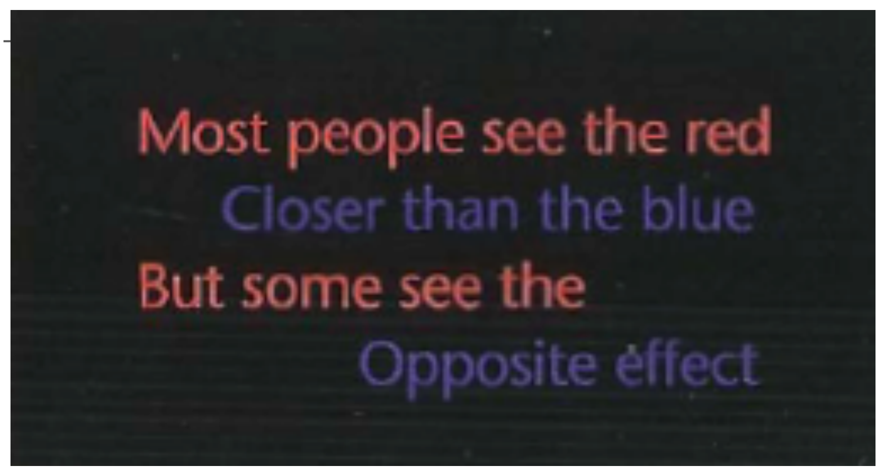
Depth of focus: flat displays

- simulating depth of focus using a flatscreen display is a major technical problem.
- It has two parts;
  - simulating optical blur
  - simulating the optical distance of the virtual object.
- There is also the problem of knowing what the user is looking at so that the object of attention can be made sharp while other objects are displayed as though out of focus.
- Eye tracking for adaptive focus rendering

Chromatic aberration

- The human eye is not corrected for chromatic aberration.
- Chromatic aberration means that different wavelengths of light are focused at different distances within the eye.
- Short-wavelength blue light is refracted more than long-wavelength red light.
- The chromatic aberration of the eye can give rise to strong illusory depth effects

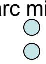
Chromostereopsis



Visual Acuities

- Visual acuities are measurements of our ability to see detail.
- give us an idea of the ultimate limits on the information densities that we can perceive.
- Most of the acuity measurements suggest that we can resolve things, such as the presence of two distinct lines, down to about 1 minute.
  - 1 degree = 60 arc minutes = 360 arc seconds
- This is in rough agreement with the spacing of receptors in the center of the fovea.

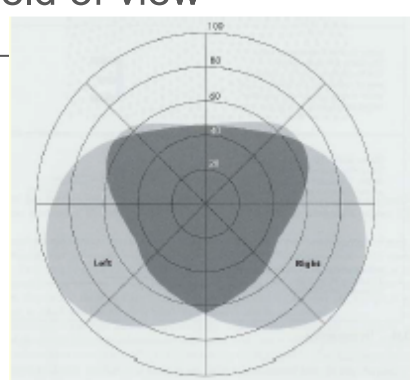
Visual acuities

Type	Description
Point acuity (1 arc minute) 	The ability to resolve two distinct point targets.
Grating acuity (1-2 arc minutes) 	The ability to distinguish a pattern of bright and dark bars from a uniform grey patch.
Letter acuity (5 arc minutes)	The ability to resolve a letter. The Snellen eye chart is a standard way of measuring this ability. 20/20 vision means that 5-minute target can be seen 90% of the time.
Stereo acuity (10 arc seconds)	The ability to resolve objects in depth. The acuity is measured as the difference between two angles for a just-detectable depth difference.
Vernier acuity (10 arc seconds)	The ability to see if two line segments are collinear.

Acuity distribution over the visual field

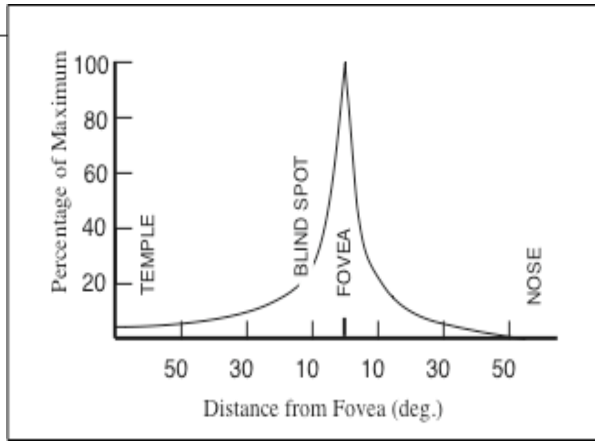
- If we look directly ahead and hold our arms straight out to either side, then we can just see both hands when we wiggle our fingers.
- This tells us that both eyes together provide a visual field of a bit more than 180 degrees.
- The fact that we cannot see our fingers until they move also tells us that motion sensitivity in the periphery is better than static sensitivity.
- Binocular viewing improves acuity by 7% as compared with monocular viewing.
- roughly triangular region of binocular overlap within which both eyes receive input.

Visual field of view



- Acuity outside of the fovea drops rapidly, so that we can only resolve about one-tenth the detail at 10 degrees from the fovea.

Acuity Distribution



"Brain pixels"

- Brain pixels = image units used by brain to process space
- Retinal ganglion cells are neurons that send information from the eyeball up the optic nerve to the cortex.
- Each one pools information from many rod and cone receptors.
- In the fovea, a single ganglion cell may be devoted to a single cone; in the far periphery each ganglion cell receives information from thousands of rods and cones.
- one nerve fiber (axon,) from each ganglion cell, and there are about a million axons in each optic nerve.

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P and M pathways

- Ganglion cells from the retina to the lateral geniculate nucleus (LGN)
- parvocellular P (small neurons)
  - Slow-conducting
  - colour
  - Detailed shape
- Magnocellular M (big neurons)
  - Fast
  - Gross shape
  - Luminance
  - motion

Visual efficiency of displays

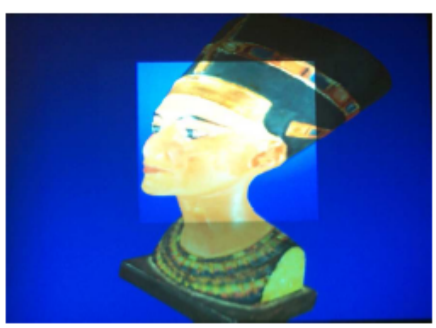
- How many brain pixels are stimulated by a display?
- There are two types of inefficiency that occur when we view displays.
- At the fovea there are many brain pixels for each screen pixel.
  - higher-resolution screens would definitely help foveal vision.
- However, off to the side, the situation is reversed; there are many more screen pixels than brain pixels.
- We are, in a sense, wasting information, because the brain cannot appreciate the detail and we could easily get away with fewer pixels.

Brain pixels and the optimal display

- Even though a conventional monitor covers only about 5-10% of our visual field when viewed normally, it stimulates almost 50% of brain pixels.
- Thus even if we could have very high-resolution, large screens, we would not be getting very much more information into the brain - given a single viewing position.
- Computer screens are currently about the right size for most tasks.
- However, large screens certainly have their uses in supporting many viewers.
  - Better match in periphery of SP to BP

Dual-Resolution Stereoscopic Display with Scene-Adaptive Fovea Boundary

G. Godin, J.-F. Lalonde, L. Borgeat. NRC Ottawa



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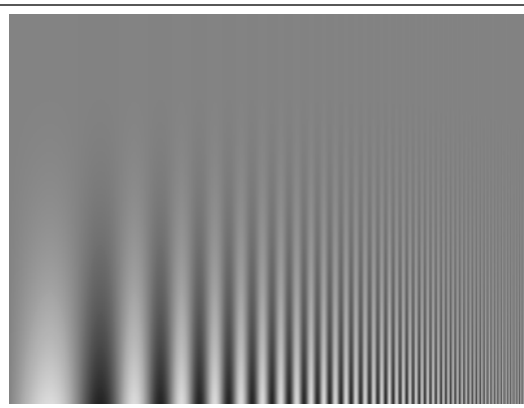
Human Spatial Acuity

- Spatial modulation sensitivity function
  - Measures sensitivity of vision to range of contrast that can be detected and how this varies with *spatial frequency*
- Spatial frequency: A measure of how rapidly a property changes in space.
  - A commonly used form of visual stimulus consists of vertical bars where the lightness varies according to a sinusoidal function. In this simple case the spatial frequency of the stimulus is just the frequency of the function used to generate the pattern.
  - In general stimuli with fine detail including sharp edges have **high spatial frequency** while those where the stimulus properties change more slowly in space have **low spatial frequency**.

Spatial contrast sensitivity function



Spatial resolution sensitivity

- Spatial sensitivity falls off at high and low frequencies
  - Most sensitive to 2-3 Hz (cycles per degree)
  - Don’t see low frequency variation - non-uniform monitors
- Varies with age
- Most tests of visual acuity - such as letter or point - are tests of **high-frequency** resolution
- Increasingly apparent that **low-frequency** resolution is extremely important
  - Pilot performance measures (Ginsburg 82)
  - Icon discrimination (Queen 2007)

Spatial frequency filtering

- The visual system maintains a set of scales that we associate with distance. If we see an object thought to have great size—say, a building—but that takes up little space on the retina (i.e. it looks very small), we immediately “perceive” it as being far away rather than perceiving it as a miniature building.
- The perception of scale is actually based on the encoding of visual spatial frequency (Schyns & Olivia, 1994).
- This is interesting because you can encode images in specific spatial frequencies (Schyns & Olivia, 1999).

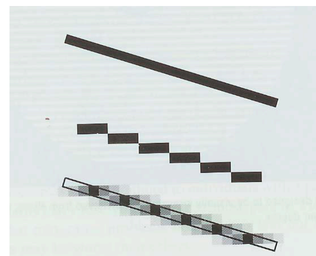
Spatial frequency filtering

Spatial frequency filtering

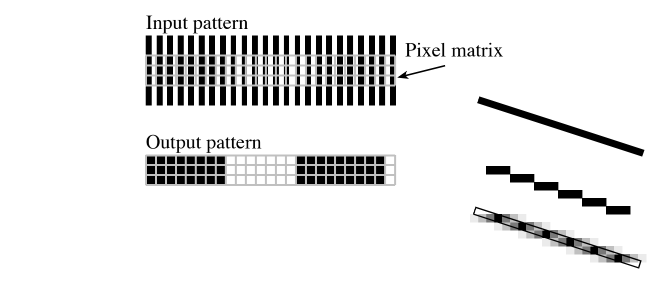
- This phenomenon is based on our inability to perceive high frequency information from greater distances
- if the image has no distinctive low frequency component, it simply disappears when viewed from a distance.
- Matt Queen http://www.boxesandarrows.com/view/icon_analysis
- Where does this apply??
  - Consider icon design

Aliasing

- Aliasing can cause all kinds of unwanted effects.
- Patterns that should be invisible because they are beyond the resolving power of the human eye can become all too visible.
- Anti-aliasing consists of computing the average of the light pattern that is represented by each pixel.
- Proper anti-aliasing can be a more cost-effective solution than simply increasing the number of pixels in the display.
- Aliasing can sometimes be useful
  - Horizontality
  - Small misalignments (vernier acuity)



Anti aliasing



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Temporal requirements

- 50-Hz flicker is about the limit of resolution that most of us can perceive.
  - The 50-75-Hz refresh rate of the typical monitor.
- temporal aliasing artifacts are common in computer graphics and movies.
  - “reversing wagon wheel”.
  - pronounced when the image update rate is low
- some visualization systems have objects updated only about 10 times per second even though the screen is refreshed at 60Hz or better.
  - A poor example of adaptive rendering!
- Use motion blur to compensate
- Expensive to compute