

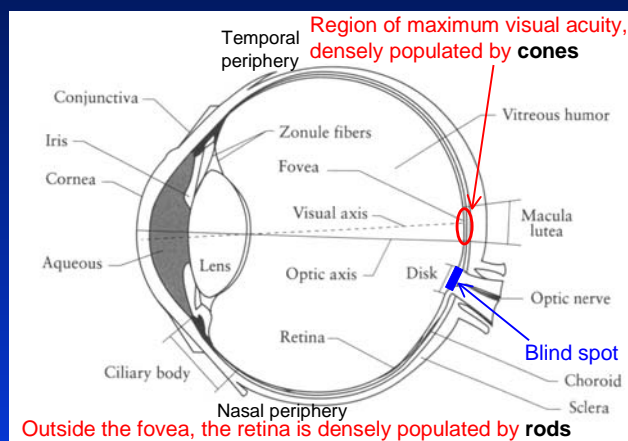
Display Technology

- The Human Visual System
- Graphics Display Technology
- Raster System Architecture

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The Human Visual System



Base image from *Principles of Digital Image Synthesis*, Vol. 1, page 6, by Andrew Glassner, Morgan Kaufmann Publishers, Inc.

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Retina

- Thin, extensive layer covering about 200° on the back of the eye
- Covered by basic types of photoreceptors: **cones** and **rods**
- Fovea
 - Region of maximum visual acuity (about 1 to 2° of visual angle)
 - Contains only cones, about 147,000 per linear millimeter
- Outside the fovea, the retina is most populated by rods

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Photoreceptors



- Cones
 - Primarily responsible for color perception
 - There are three kinds of cones (different pigments and chemistry)
 - Red cones or L-cones, more sensitive to Long wavelengths (red light)
 - Green cones or M-cones, more sensitive to Medium wavelengths (green light)
 - Blue cones or S-cones, more sensitive to Short wavelengths (blue light)
- Rods
 - Highly sensitive, are responsible for vision under dark-dim conditions (intensity and black and white vision)

Illustration courtesy of Webvision (<http://webvision.med.utah.edu/photo2.html#cones>)

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Density of Photoreceptors

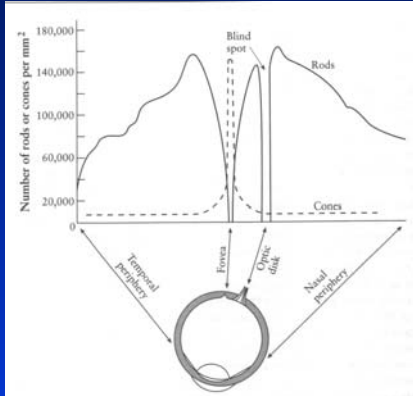
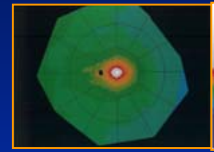


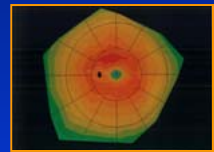
Image from *Principles of Digital Image Synthesis*, Vol. 1, page 10, by Andrew Glassner, Morgan Kaufmann Publishers, Inc.

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Cones in the entire retina



Rods in the entire retina

Images courtesy of Christine Curcio

Photoreceptors Response

Actually, violet, not blue, and yellow, not red!!

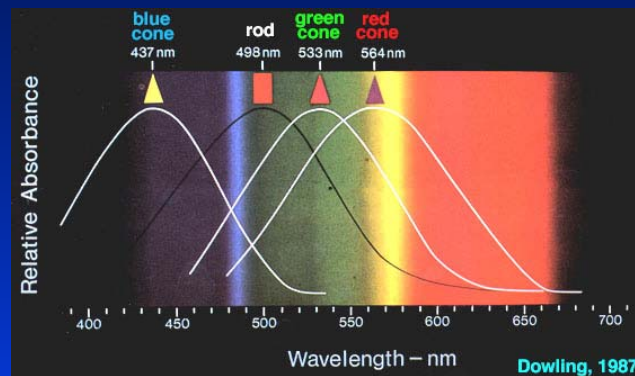


Image by Dowling, 1987. Reproduced from Webvision (<http://webvision.med.utah.edu/photo2.html#cones>)

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Trichromatic Vision

- The existence of cones with three different wavelength sensitivity is the basis of color perception in our visual system
- Colors can be specified as a linear combination of red, green and blue light

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Graphics Display

- Most common technologies:
 - Cathode Ray Tubes (CRTs)
 - Raster Displays vs Vector Displays
 - Liquid-Crystal Displays (LCDs)
 - Passive vs Active

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Cathode Ray Tubes (CRTs)

- Electron beam hits a phosphor-coated screen
- Used on most TV sets and computer displays

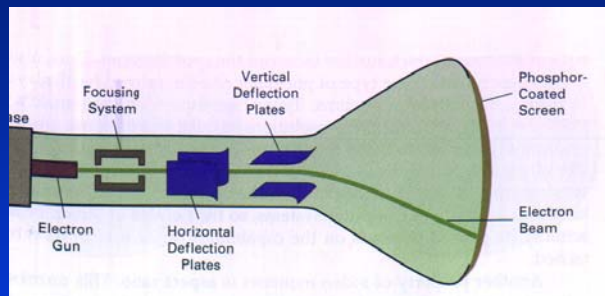


image from Computer Graphics C Version, 2nd Ed., page 39, by
Hearn and Baker, Prentice Hall

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CRTs (Cont.)

- Related Concepts
 - **Phosphorescence**: light emitted by the coating phosphor dots
 - **Phosphor Persistence**: time from the removal of the excitation until phosphorescence has decayed to 10% of the initial light output
 - **Refresh Rate**: Number of times per second the image is redrawn (typically 60Hz)
 - **Critical Fusion Frequency (CFF)**: refresh rate above which a picture stops flickering and fuses into a steady image (increases with image intensity and ambient room lighting, and varies with observer)
 - **80 to 90 Hz**: refresh rate required to eliminating flicker for 99% of viewers of high intensity images

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Vector Displays

- Picture stored as a list of line-drawing commands
- Electron beam directed only to parts of the screen where lines should be drawn
- Advantages
 - Produce higher resolution and smoother line drawing than raster graphics
- Disadvantages
 - No support for arbitrary color images (two layers and beam intensity)
 - Refresh time is dependent of scene complexity

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Raster Displays

- Image as a matrix of dots called *pixels*
- Image to be displayed is stored in a *frame buffer*
- Refresh time is independent of scene complexity
- Color produced using three electron guns and groups of three-color phosphor dots (**RGB**)
- Metal mask used to stop beams from hitting wrong dots
- Prone to spatial aliasing (jagged lines)

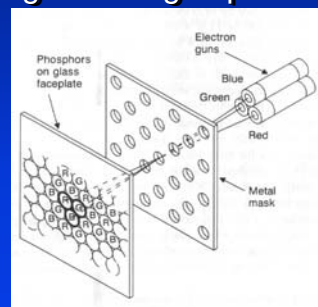


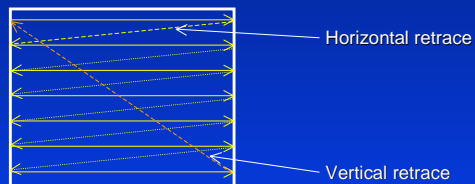
image from Computer Graphics *Principles and Practices*, 2nd Ed.,
page 159, by James Foley et al, Addison Wesley

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Raster Displays (Cont.)

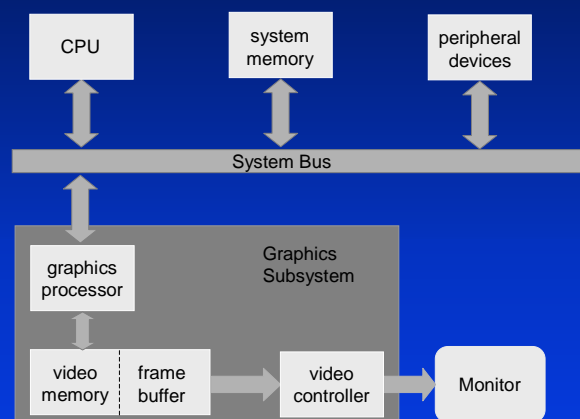
- Related Concepts
 - **Interlace Refresh**: the beam sweeps all odd rows and then all even rows or vice-versa
 - **Horizontal Retrace**: the return of the electron beam to the left next scan line
 - **Vertical Retrace**: the return of the electron beam to the top left corner of the screen to begin the next frame



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Raster System Architecture



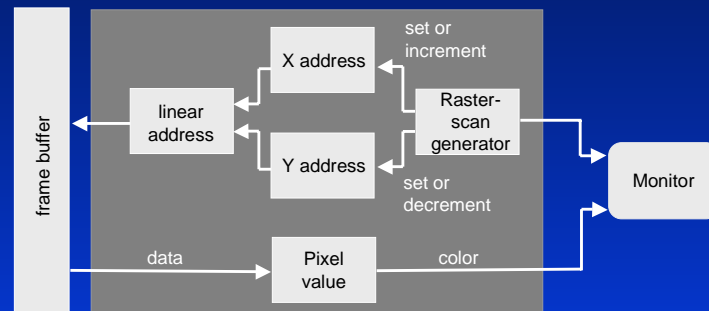
Frame buffers of modern graphics systems use 32 bits per pixel (R, G, B, alpha) and maximum number of pixels of 1280 x 1024 or higher ($4 \times 1280 \times 1024 = 5\text{MB}$)

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Video Controller

- Logical Organization



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Liquid-Crystal Displays (LCDs)

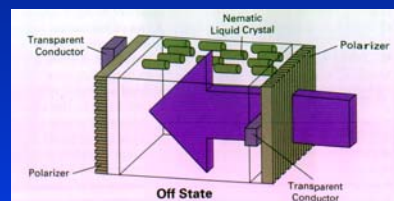
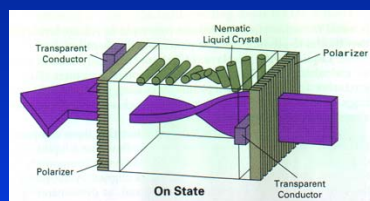
- Low cost
- Low weight
- Small size
- Low power consumption

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Liquid-Crystal Displays (LCDs)

- Long crystalline molecules arranged in spiral, change polarized light by 90°
- In an electric field, molecules line up blocking the light
- A reflective layer (and back lighting) is used in the back



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LCDs (Cont.)

- A dark spot at point (x,y) is created via matrix addressing
- Passive-matrix LCD
 - Horizontal and vertical grid wires are used for addressing
 - Display refreshed one row at a time, in raster-scan fashion
- Active-matrix LCD
 - Use a (thin-film) transistor to control the voltage at each pixel location
 - Faster state change and brighter colors (no decay)
 - State stored in the transistor memory; no refresh needed
 - Support for color

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