Evolution from Vector to Raster

History:

- **Vector**
  - **Drive a oscilloscope with x-y deflections**
  - **Calligraphic or line drawing display ('50s)**
  - **Phosphors decay, must be refreshed: *display list***
  - **Future laser-based displays?**
- **Raster**
  - **Motivated by television ('30s)**
  - **Refresh monitor from framebuffer ('70s)**
  - **Advantage: images very general (tv,text,movies)**
  - **Disadvantage: original cost of memory, low-level**

Resolution

World is continuous, digital media is discrete ...

Three aspects:

- **Color and intensity resolution:** $\Phi(\lambda)$
  - ■ **Physical limits: color "pigments," 1-bit vs n-bit tones**
  - ■ **Human limits: just-noticable-differences, trichromaticity**
- **Spatial resolution: (x,y)**
  - ■ **Physical limits: controllable pixel size, framebuffer size**
  - ■ **Human limits: photoreceptor density + optics**
- **Temporal resolution: t**
  - ■ **Physical limits: film transport, channel bandwidth**
  - ■ **Human limits: neuronal response time**

Perceptual Resolutions

Experiments

- Resolving lines pairs, sinusoidal gratings
  - Max 50-60 cycles per degree
- Hyperacuity
  - 5 arcsecs for very fine line position judgements!

Photoreceptor mosaic

- Foveal (1deg.) vs. peripheral
- Two types of photorceptors
  - Rods: 100 million total, 1μ diameter
  - Cones: 3 subtypes (L,M,S), 5 million total
    1-10μ diameter (fov.-per.),
    Fovea res: 10 arcmins (S), 0.5 arcmins (L,M) spacing

Image Resolutions in Practice

Television

NTSC	640x480x8b	1/4 MB
GA-HDTV	1920x1080x8b	~2MB

Workstations

Bitmapped display	960x1152x1b	~1 Mb
Color workstation	1280x1024x24b	5 MB

Laserprinters

300 dpi	(8.5″x300)(11″x300)	1.05 MB
2400 dpi	(8.5″x2400)(11″x2400)	~64 MB

Film (line pairs/mm)

- 35mm (diagonal) slide (ASA25~125 lp/mm) = 3000
  3000 x 2000 x 3 x 12b ~27 MB

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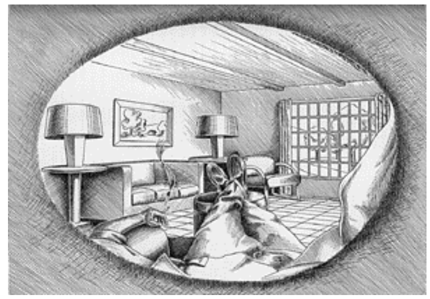
Field of View

Visual field

Monocular: 160° (h) x 135° (v)

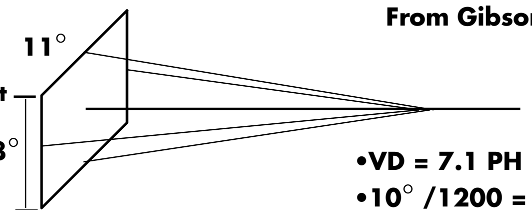
Binocular: 200° (h) x 135° (v)

Wide field of view creates a sense of immersion



From Gibson 1968

Conventional Television



- VD = 7.1 PH
- 10° /1200 = 0.5 arcmin

Aspect Ratio

Frame aspect ratio (FAR) = horizontal/vertical size

TV	4:3	
HDTV	16:9	
Page	8.5:11 ~ 3:4	
35mm Film	3:2	
Panavision	2.35:1	(2:1 anamorphic)
Vistavision	2.35:1	(1.5 anamorphic)

Pixel aspect ratio (PAR) = FAR vres/hres

Nuisance in graphics if not 1

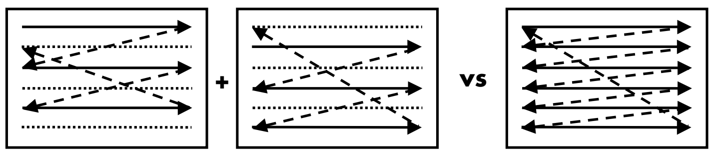
Refresh Rates and Bandwidth

Critical flicker fusion rate

- high ambient light, large field: - 80 Hz
- low ambient light: 20-30 Hz

Frames per second (FPS)

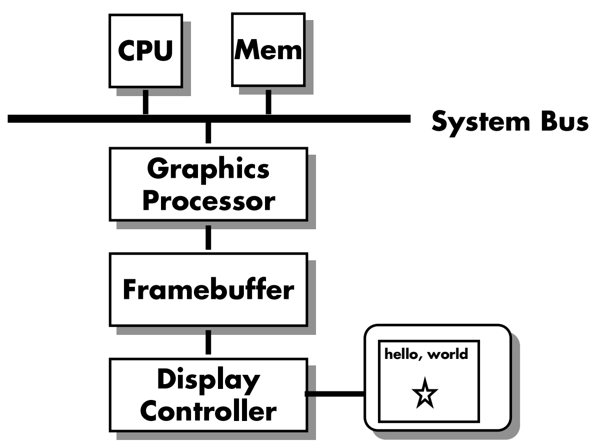
Film (double framed)	24 FPS
TV (interlaced)	30 FPS x 1/4 = 8 MB/s
Workstation (non-interlaced)	75 FPS x 5 = 375 MB/s



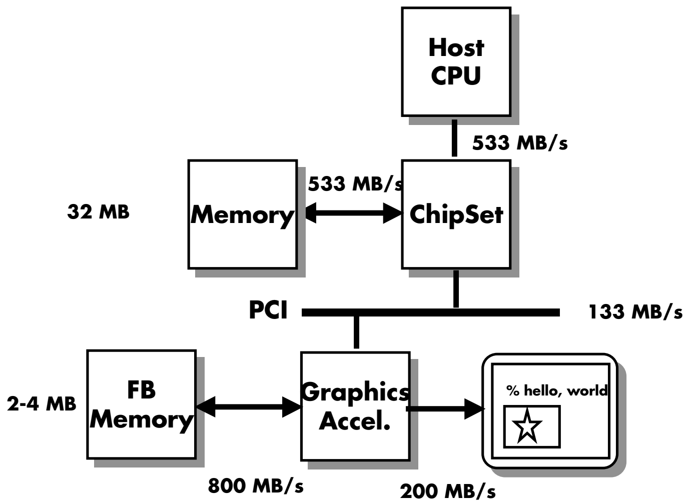
Interlaced

Non-Interlaced (Progressive Scan)

Raster Graphics Architecture



Home PC



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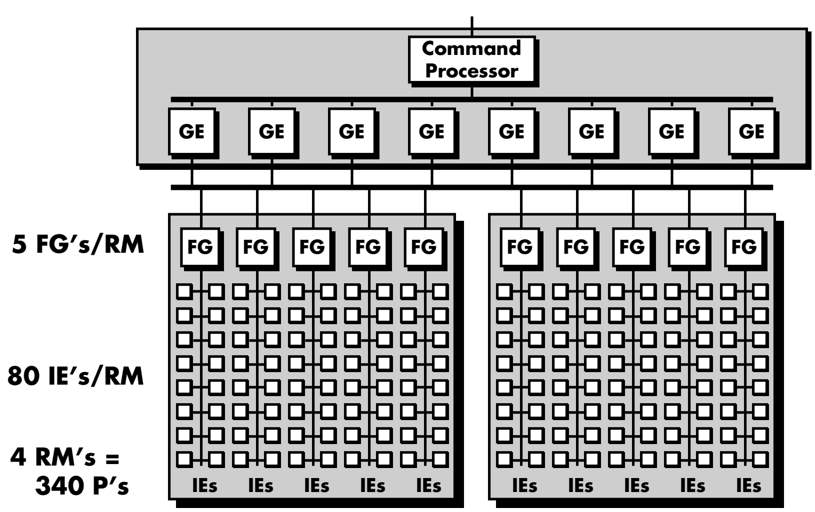
SGI Reality Engine



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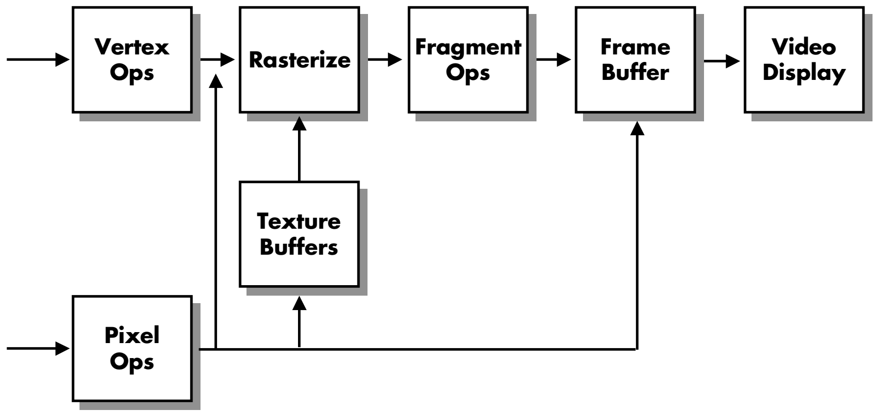
OpenGL Architecture



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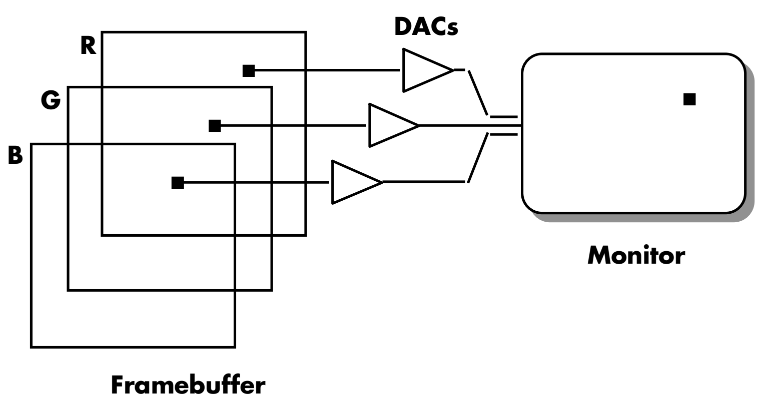
RGB Framebuffer



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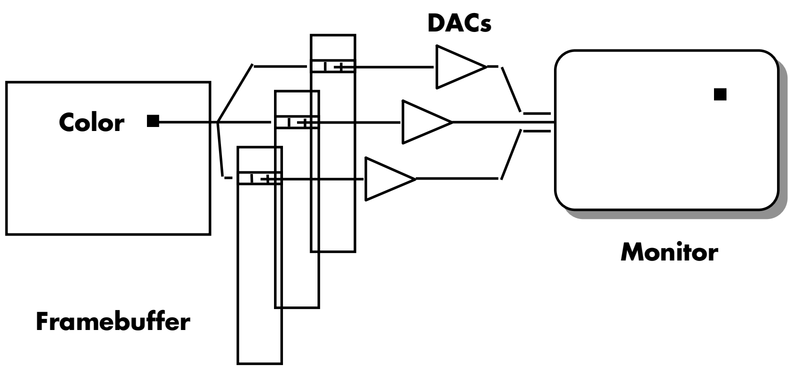
Color Index Framebuffer



Buffers

- Single and double buffering: Front and Back
- Z-Buffer
- Texture Map Buffer
- Window ID Buffer
- Accumulation Buffer
- Stencil Buffer
- Stereo: Left and Right