Evolution from Vector to Raster Graphics

History:

- **Vector**
  - **Drive a oscilloscope by supplying x and y deflections**
  - **Calligraphic or line drawing display ('50s)**
  - **Phospors decay, thus must be refreshed: *display list***
  - **CRT memory!**
- **Raster**
  - **Motivated by television ('30s)**
  - **Refresh monitor from framebuffer ('70s)**
  - **Advantage: images very general (tv,text,movies)**
  - **Disadvantage: original cost of memory, low-level**

Copyright © Pat Hanrahan

Raster Graphics

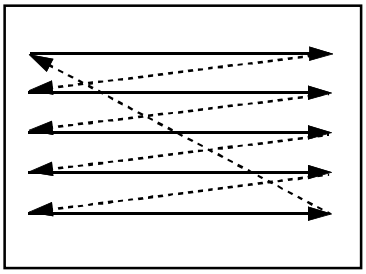
ras.ter \'ras-t<e>r\ n (ca. 1934)

[G, fr. L raster, rastrum rake, fr. radere to scrape]

:a scan pattern (as of the electron beam in a cathode-ray tube) in which an area is scanned from side to side in lines from top to bottom;

:a pattern of closely spaced rows of dots that form the image on a cathode-ray tube (as of a television or computer display)

From *Websters*



Copyright © Pat Hanrahan

Image Resolution

Three aspects:

- **Spatial resolution**
  - **Physical limits: controllable "pixel" size**
  - **Human limits: photoreceptor density + optics**
- **Color and intensity resolution**
  - **Physical limits: color "pigments", 1-bit vs n-bit tones**
  - **Human limits: brightness and color sensitivity**
- **Temporal resolution**
  - **Physical limits: film transport, channel bandwidth**
  - **Human limits: neurons, flicker fusion rate>30Hz**

World is continuous, digital media is discrete

Copyright © Pat Hanrahan

Image Resolutions in Practice

NTSC TV	**640x480x8b**	**1/4 MB**
SUN Bitmapped Display	**960x1152x1b**	**<1MB**
SGI Indigo2 XZ	**1280x1024x24b**	**5MB**
Laser printed page		
300dpi	**(8.5"x300)(11"x300)**	**1.05MB**
2400dpi	**(8.5"x2400)(11"x2400)**	**~64MB**
Film (line pairs/mm)		
35mm slide (ASA 25)	**35mm x 125lp/mm = 4375**	
	4500 x 3000 x 3 x 12b	**~64MB**

Copyright © Pat Hanrahan

Aspect Ratio

Frame aspect ratio (FAR) = horizontal/vertical size

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

Pixel aspect ratio (PAR) = FAR hres/vres

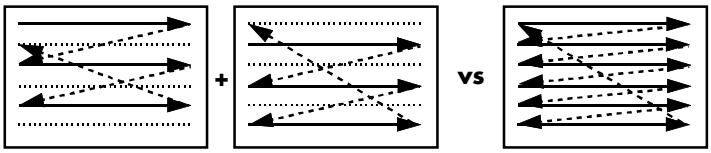
Nuisance in graphics if not 1

Copyright © Pat Hanrahan

Refresh Rates and Bandwidth

Frames per second (FPS)

Film (double framed)	**24 FPS**
TV (interlaced)	**30 FPS x 1/4 = 8 MB/s**
Workstation (non-interlaced)	**~70 FPS x 5 = 350 MB/s**



Interlaced **Non-Interlaced**

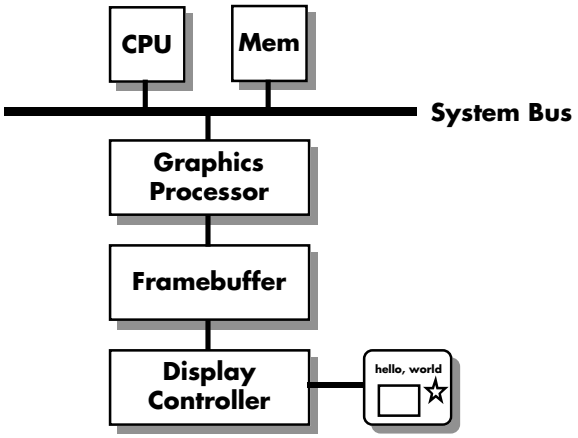
Copyright © Pat Hanrahan

Monitors

1. Vertical/Horizontal Deflection, Accelerate and focus e's
2. Non-linear voltage to luminance
3. Color and intensity
   - R, G, B "phosphors"
   - Shadow mask: inline, trinitron, delta
4. Resolution
   - Pitch: .26 - .31mm
   - Resolution: 72-96 dpi
5. Persistence
   - <1ms, but may be longer

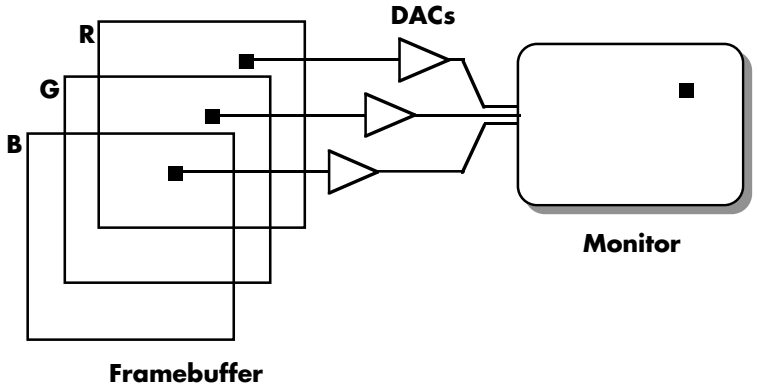
Copyright © Pat Hanrahan

Raster Graphics System Architecture



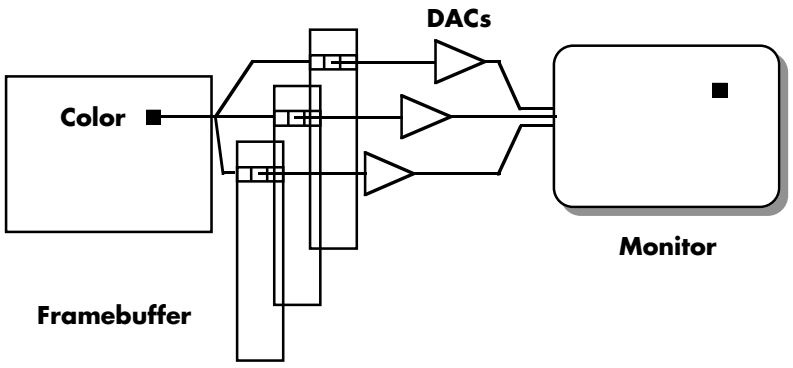
Copyright © Pat Hanrahan

RGB Framebuffer



Copyright © Pat Hanrahan

Color Index Framebuffer



Copyright © Pat Hanrahan

Color Mapping

Applications

- **Apply function: gamma, invert, solarize**
- **Pseudocolor: blue to yellow to red ramp**
- **Animation by numbers, cycling**
- **Bit-plane extraction**
- **...**

Copyright © Pat Hanrahan

Framebuffers and Memory

Frame buffer decouples

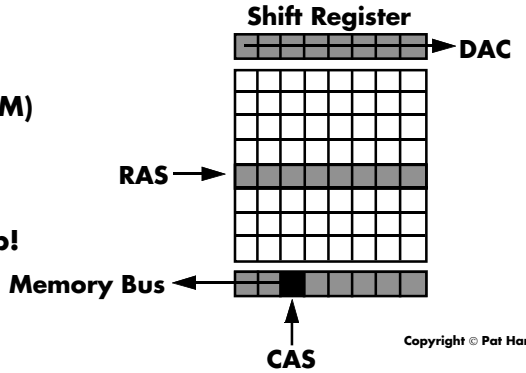
- **High bandwidth drawing**
- **High bandwidth display refresh**

One solution:

Video RAM (VRAM)

Memory crisis:

1 image<<1 chip!



Copyright © Pat Hanrahan