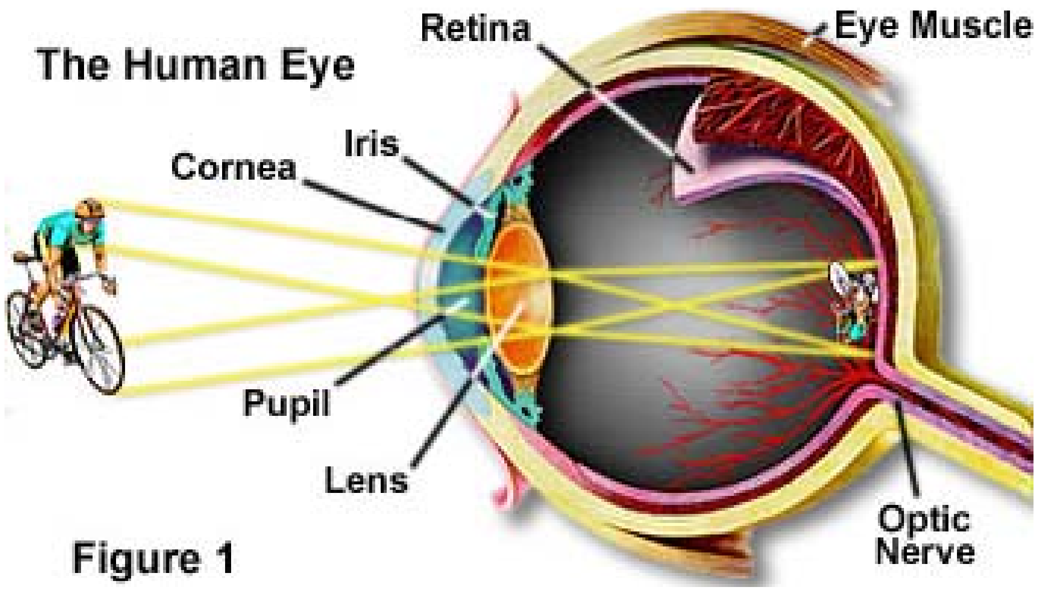
Real-Time Rendering

Perception Issues



What for?

- We want to exploit human visual system
  - Try not to draw what cannot be perceived
  - A lot can be faked …
- We want good quality, even in real time
  - Know key aspects of quality
  - Avoid artifacts
- Topics:
  - Intensity, gamma correction
  - Motion, flicker
  - Latency
  - Resolution

Intensity and Brightness

- Eye has nonlinear response to intensity
- Intensity I: physical intensity
- Brightness B: perceived intensity
- Psychophysical models:
  - Relation of
    - small increments of Brightness (d**B**)
    - small increments of Intensity (d**I**)
  - … give differential equation
  - … allow calculating **B** = f(**I**)

Psychophysics

- Weber's law: describes threshold intensity
  - Minimum visible contrast is 1%
    $d\mathbf{I}/\mathbf{I} = 0.01$
- Weber-Fechner law: generalization
  - $d\mathbf{B} = k \cdot d\mathbf{I} / \mathbf{I} \rightarrow \mathbf{B} = k \cdot \ln(\mathbf{I} / \mathbf{I_0})$
  - For Intensity: k ~ 100.5
- Steven's law: more accurate
  - $d\mathbf{B}/\mathbf{B} = k \cdot d\mathbf{I} / \mathbf{I} \rightarrow \mathbf{B} = c \cdot \mathbf{I}^k$
  - For Intensity: k ~ 0.4

Gamma Correction

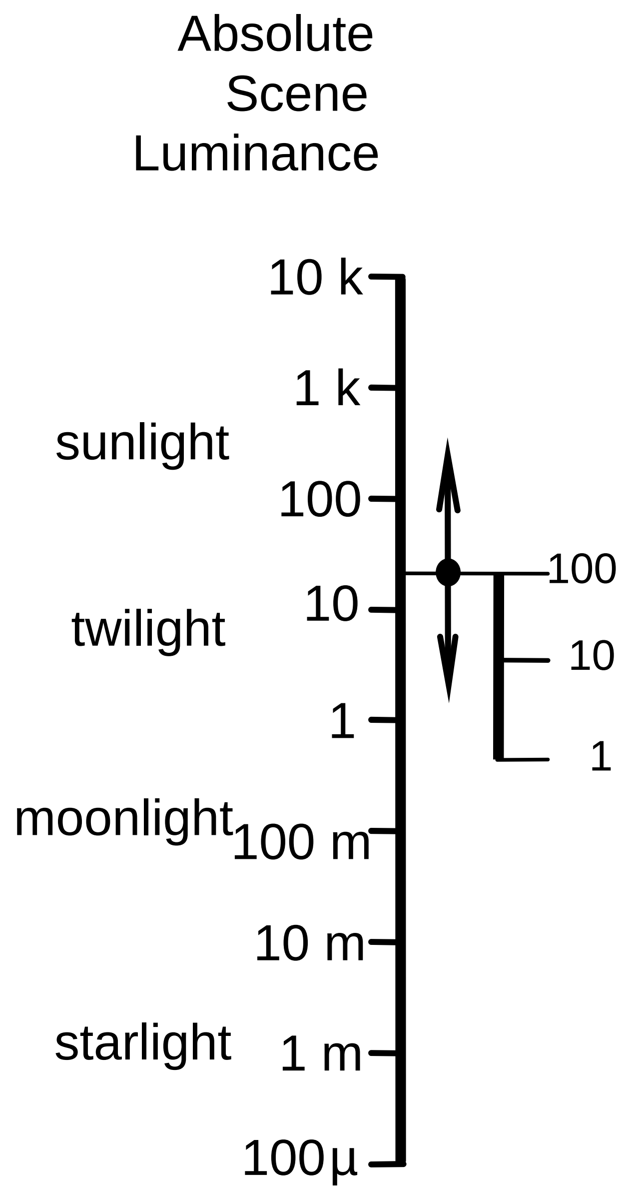
- CRT has nonlinear response to input signal
  - Intensity = a · Voltage^{gamma} + b
- Requires correction for physical signals (I)
- Lucky coincidence: combined response is near-linear
  - 0.4 · 2.5 ~= 1.0
  - Suggests: if colors are stored gamma-corrected

  → best use of available precision
  - 9 bit (460 levels) good for ~100:1 contrast ratio
    - Proof: Weber-Fechner law
  - Contrast ratio:
    - Ratio of white/black at certain adaptation level

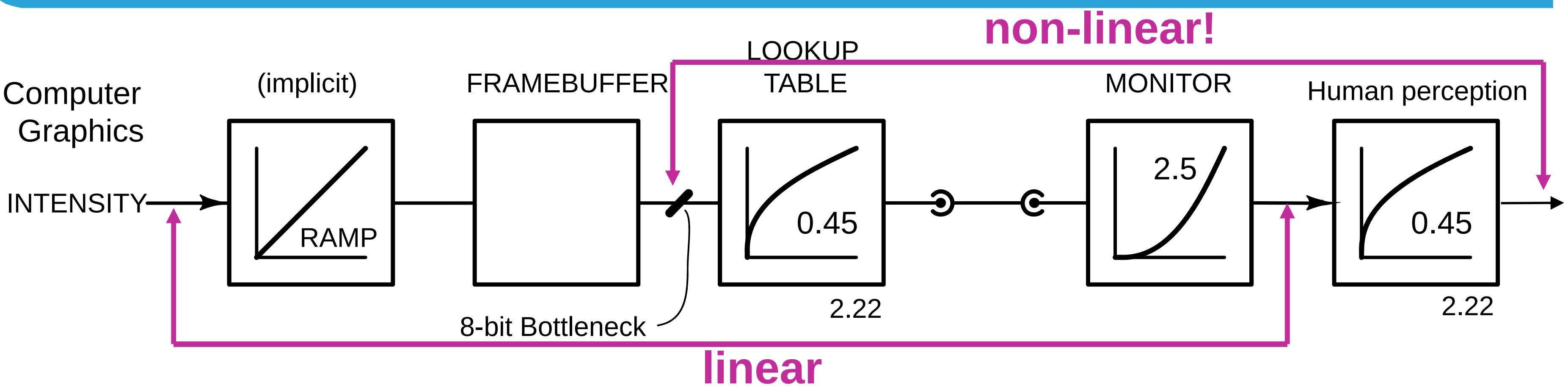
Intensity and Brightness

- Eye adaptation…
  - Contrast 100:1
  - (But: doesn't consider local adaptation!)

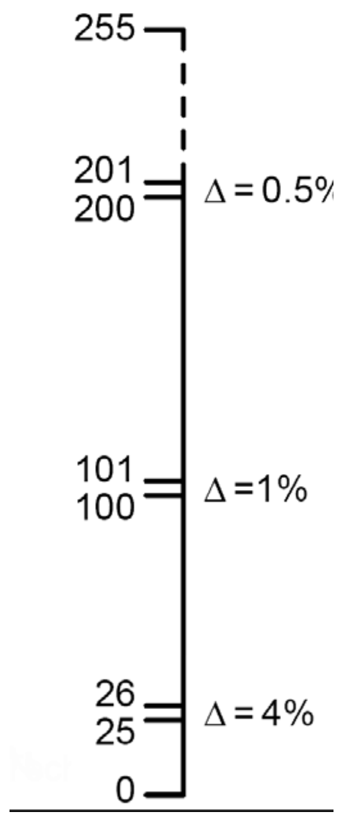
  → Need HDR displays!



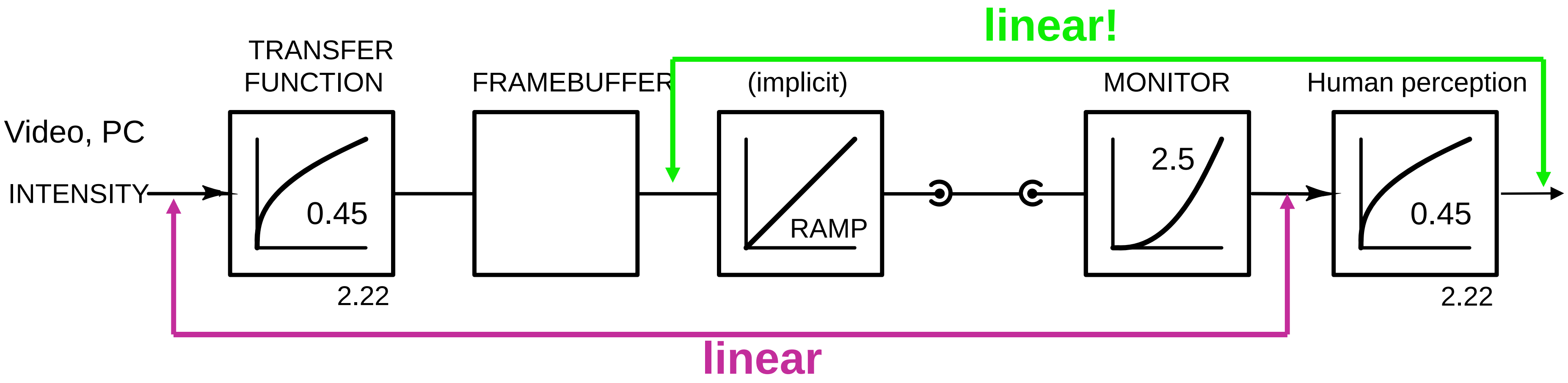
Store Image Linear in Intensity



- Native arithmetic format
  - for shading, blending
- Requires conversion during display
- Banding below „best gray“ (100)
- Textures need to be in linear space
- Practically unused today



Store Image Linear in Brightness



- Best use of available storage precision
- 256 levels (8 bit) are not bad (60 suffice)
- Requires conversion for each pixel operation
- Typical in video/image processing (MPEG)
- Images can be used w/o modification

Experiment

What is half **intensity** of white?

255 0

Experiment

What is half **intensity** of white?

255 186 128 0

= white/2

- Humans perceive intensity in a nonlinear way
  - We perceive brightness as linear

- Physics happens in linear intensity

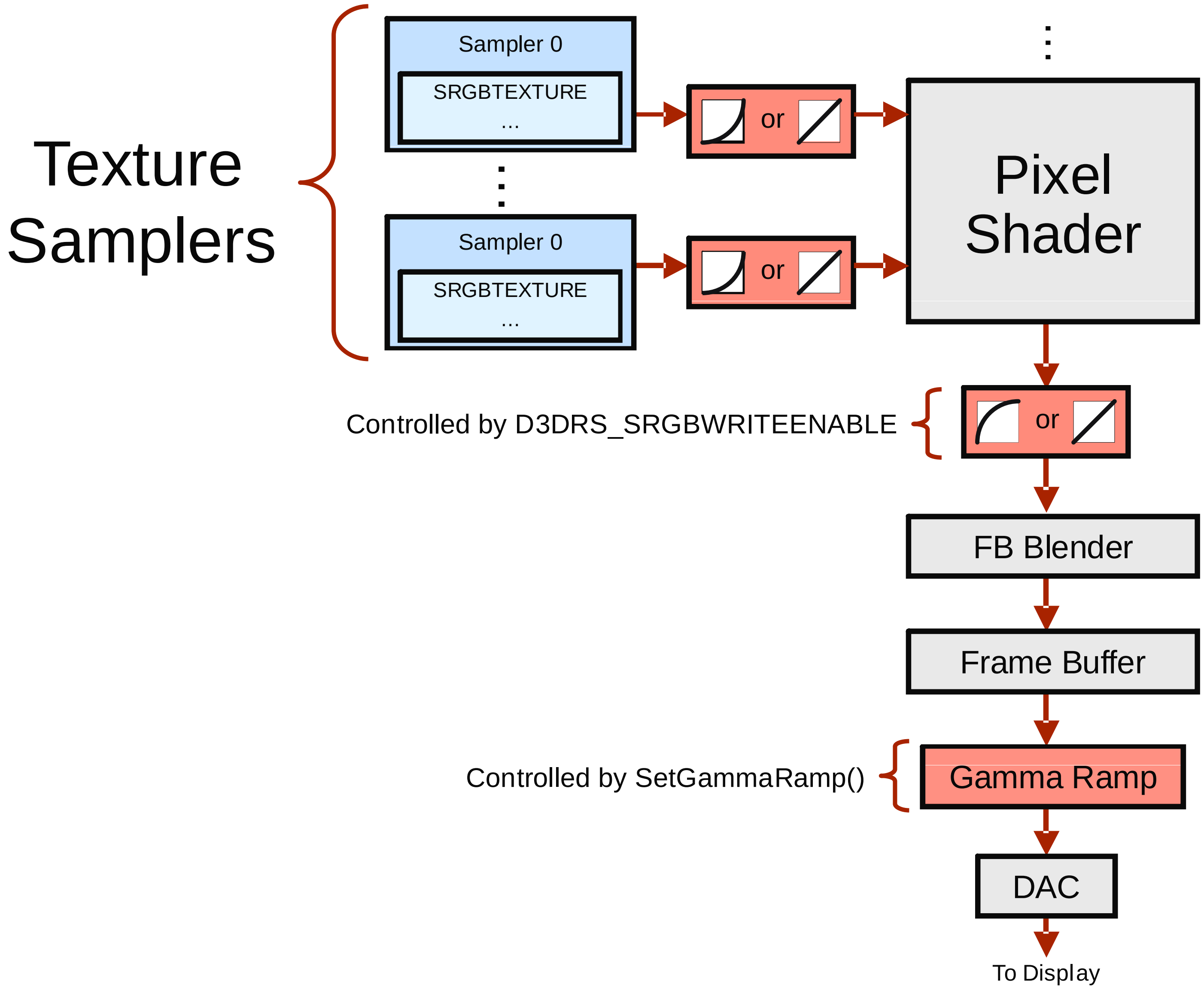
Gamma on the PC

- Uses Brightness coding (Gamma=2.2)
  - Instead of 2.5, due to bright surroundings
  - Every image, texture, browser color…
  - Linear RGB-ramps are perceptually uniform
  - But it's a hack for 3D graphics
  - **Not physically correct if used without gamma correction**

Gamma on the PC

- sRGB: color space with gamma=2.2
- DirectX9/10: better approach
  - converts sRGB-textures to linear on the fly!
  - all shading happens in linear space (correct!)
  - can write sRGB-values to framebuffer!
- DirectX10: adds correct blending!
- Beware of SGIs, MACs, …
  - use different definitions of gamma
  - have default gamma in hardware-LUT
- Read Poynton's Gamma FAQ!

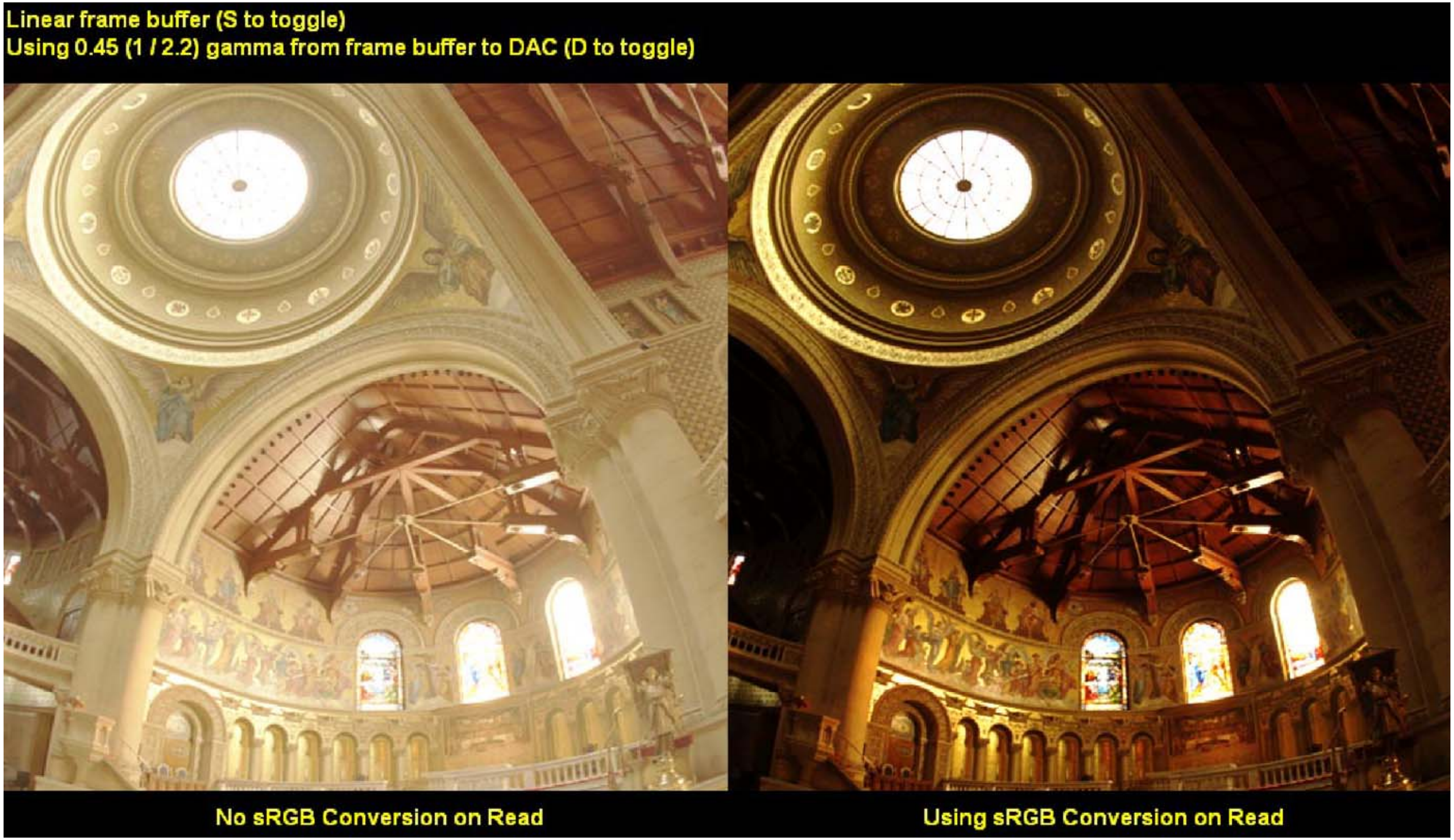
DirectX 9 sRGB and Gamma



DirectX 10/OpenGL 2.0 and Gamma

- Finally, correct gamma throughout the pipeline!
  - “de”-gamma before
    - Texture reads
    - Frame buffer blends (new!)
    - Multisampling (new!)
- OpenGL
  - **`EXT_framebuffer_sRGB`**
  - **`EXT_texture_sRGB`**

sRGB Example



High Dynamic Range Displays

- Human adaptation ~100:1
  - Typical display: 100-500cd/m2, contrast 500:1
- BUT: eyes adapt locally → need HDR display
- Contrast ratio: 200.000:1
- Brightness: 3.000cd/m2

→ Black level: 0,015cd/m2

- Additional LED backlights

Motion

- Eye is sensitive to motion and change
  - Rule: Avoid substantial frame-to-frame changes (e.g., popping for levels of detail, low frame rate)

- Animation
  - Usually no flicker detection above 85 Hz
  - Animations at >60 Hz interpreted as continuous
  - Experiment on limits of visual system:
    Pilots can detect changes at 1/220th of a second

Motion – Movies

Movies: only 24 Hz, but:

- Use motion blur
- Afterimages due to
  - dark room, bright projector
  - whole frame refresh
- Higher contrast
- Pay attention to fast camera pans:
  - look blurry
  - double images
- Newer IMAX: 48 Hz

Motion – Artifacts

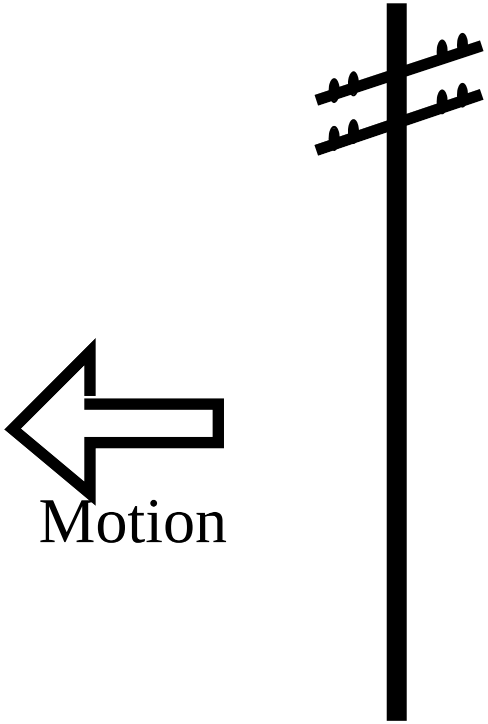
Eye/brain combination tracks motion

- Separation if colors are displayed sequentially (e.g., some projectors)
- Low framerate artifacts
  - Strobing/Stuttering

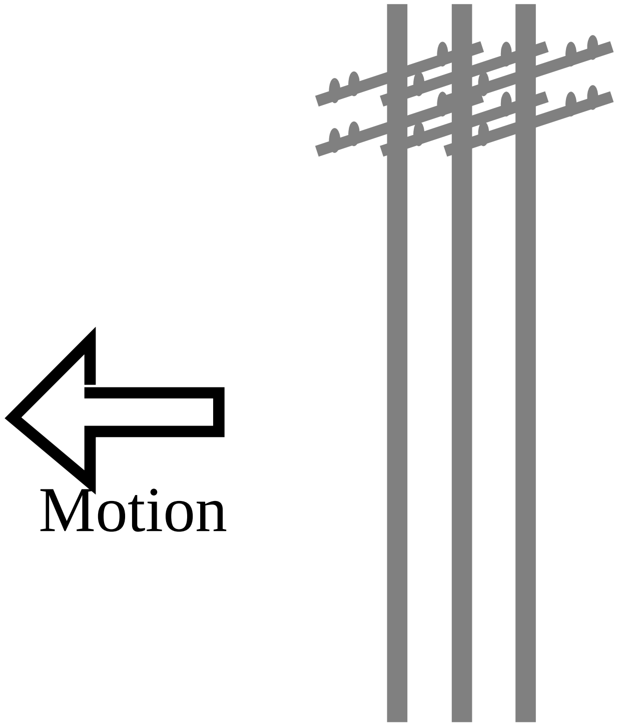
    Motion blur would help
  - Frame rate variations (very noticeable!)
  - Interlacing artifacts (combing)
  - Image doubling (repeated images)

Image Doubling

- Render and refresh rates differ
  - e.g., render at 20 Hz, monitor at 60 Hz!



Refresh Rate = Update Rate

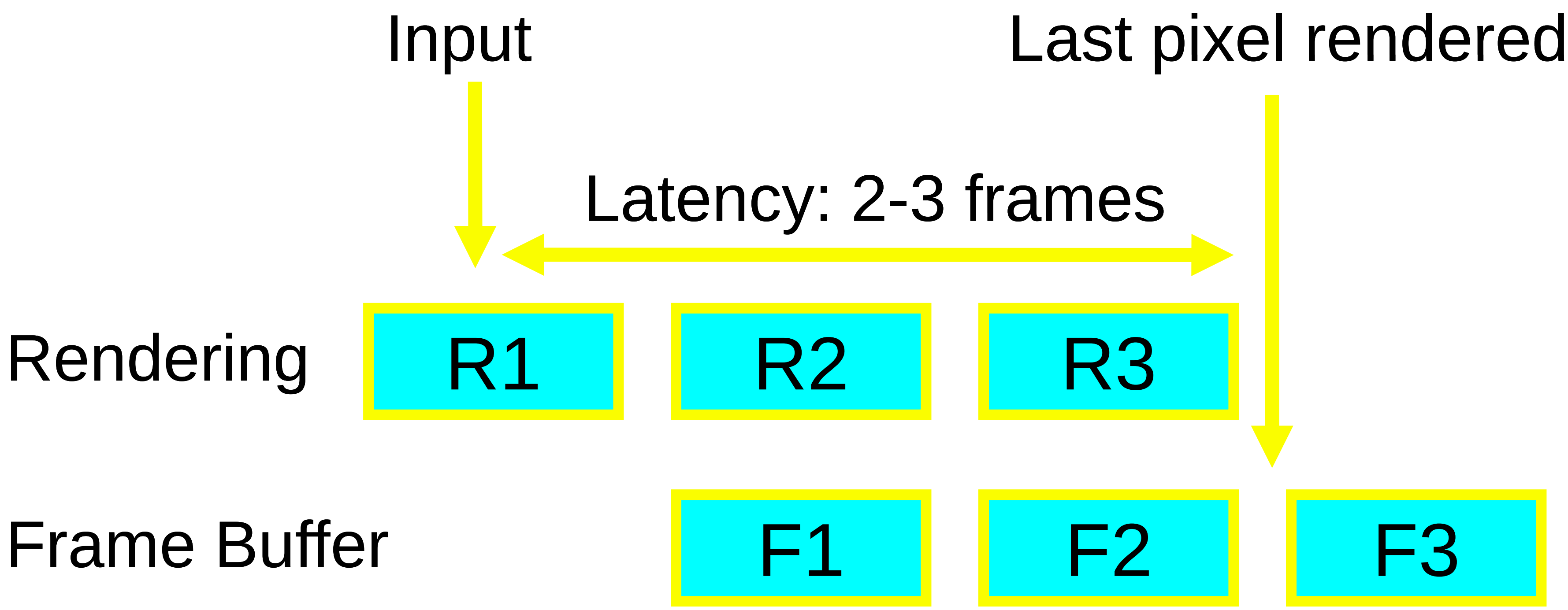


Refresh Rate = 3 * Update Rate

Ghosting Artifacts

Latency

- Time from input to last pixel of display
- In a double-buffered display:



Latency

- Critical system issue
- Here: “total system latency”
- Sometimes different definitions
- 3 frames ~ 50ms at 60 Hz
- Can even be up to 4 frames
  - If graphics card buffers commands in queue
- Human latency thresholds
  - Hand-eye (fixed display) is ~100ms
  - Head-eye (HMD) is ~10ms

Resolution ("Visual Acuity")

- Eye resolution not evenly distributed
  - Foveal resolution is ~20x peripheral
  - Flicker sensitivity higher in periphery (rods!)
- Static and dynamic resolutions differ
- One eye can compensate for the other
- Limit: about 0.5-1 arc minute
- 1600x1200 21"-screen at 60 cm:
  1.4 arc minutes