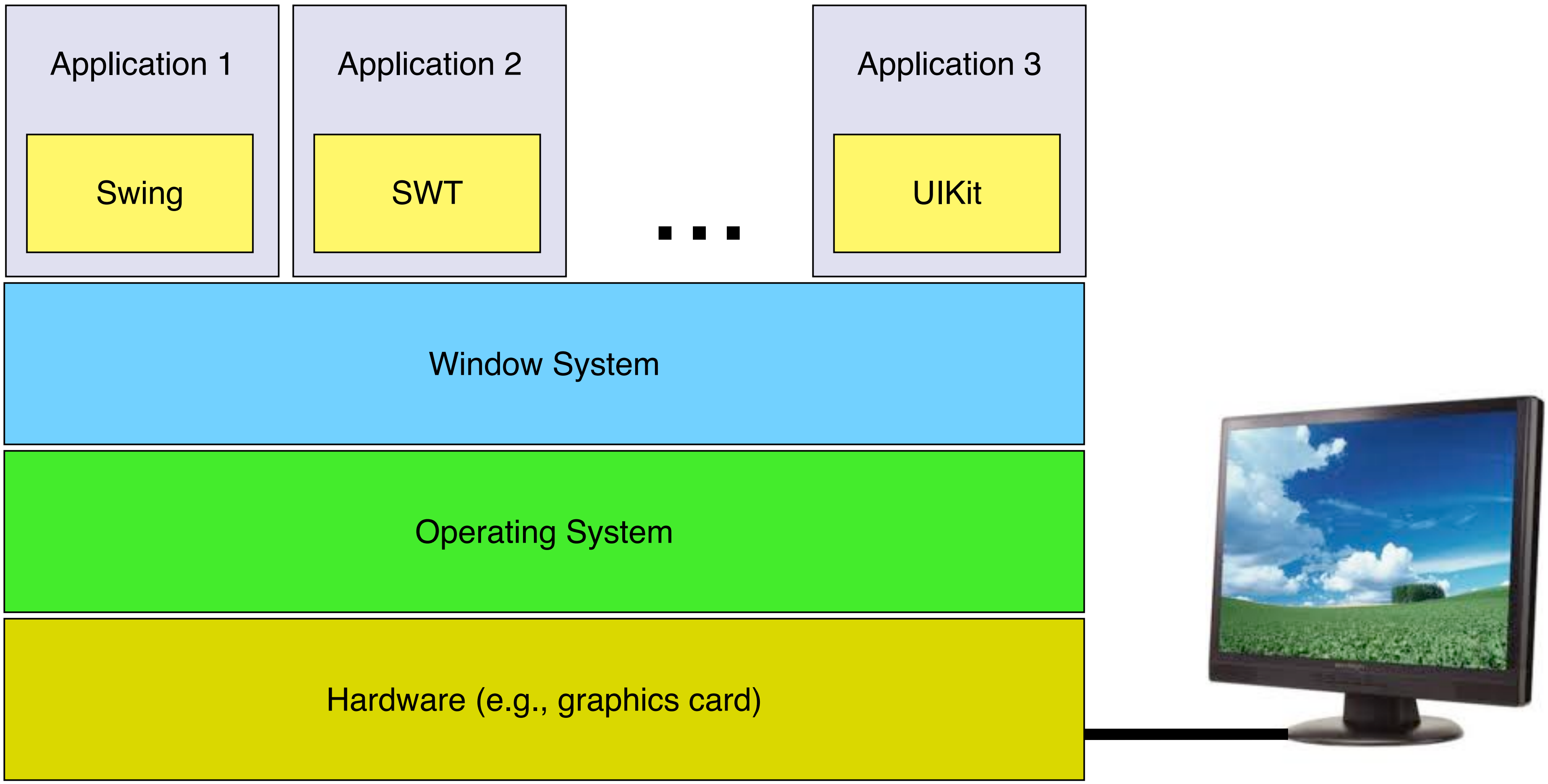
Output: Hardware

Output System Layers



Output Hardware

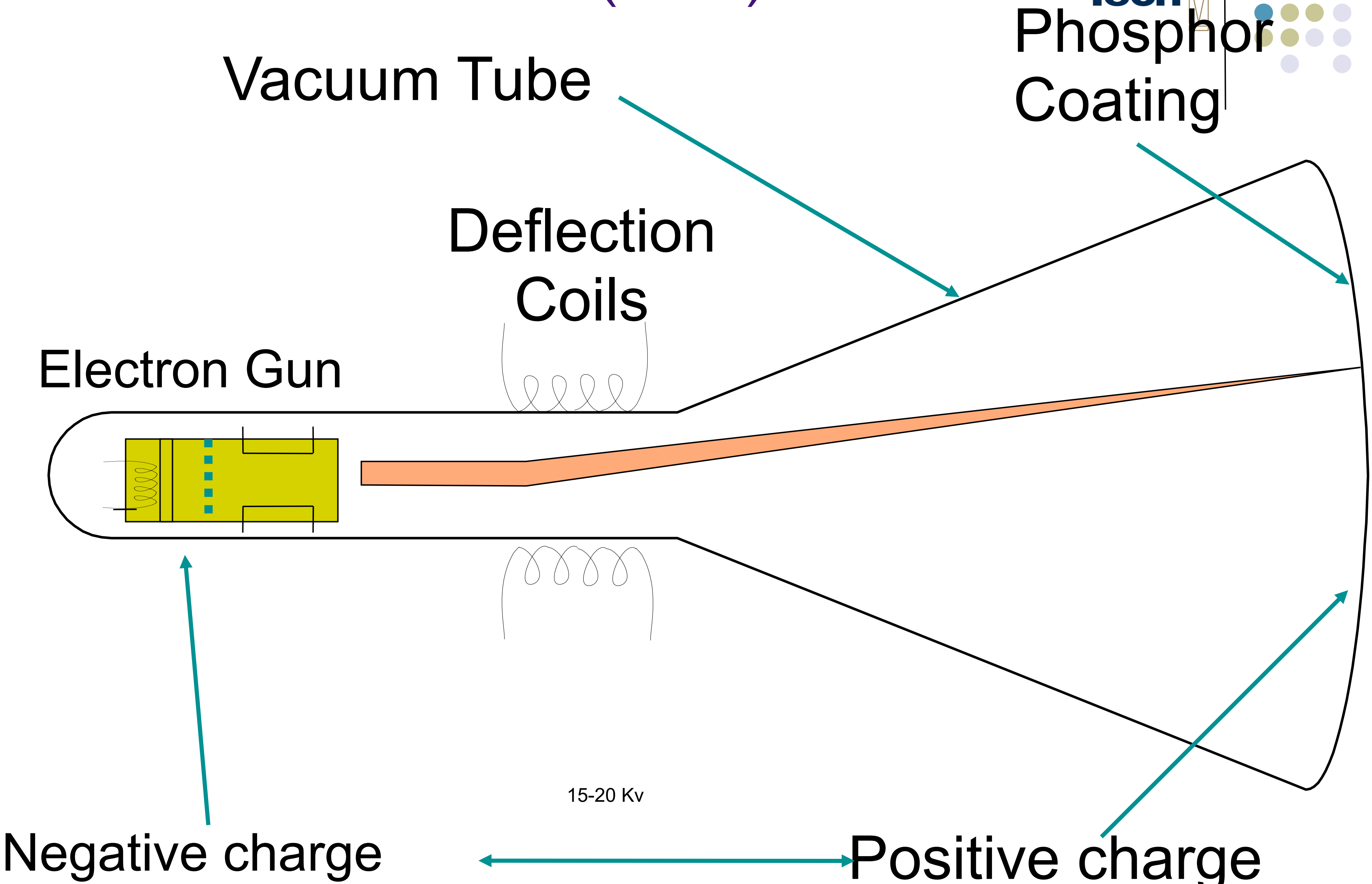
Start with some basics: display devices

- Just how do we get images onto a screen?
- Most prevalent device: CRT
  - Cathode Ray Tube
  - AKA TV tube

Cathode Ray Tubes

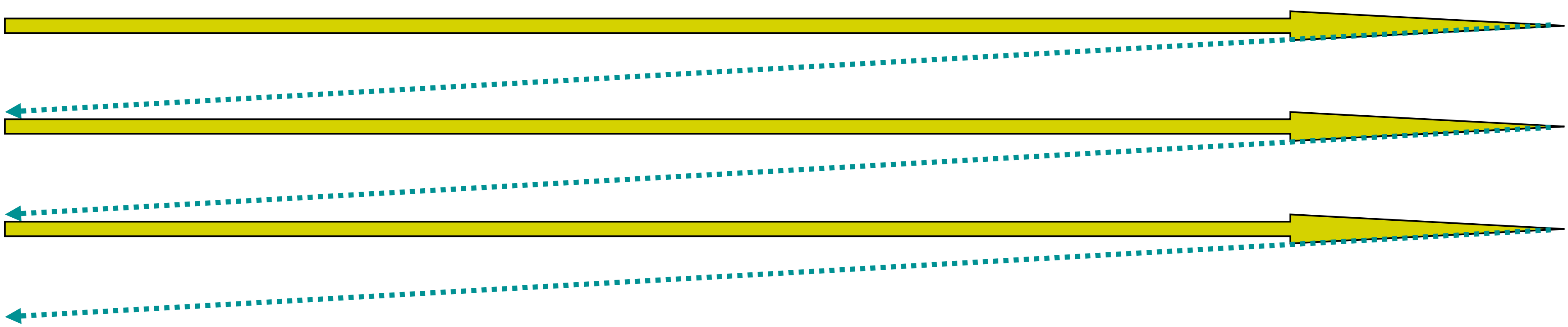
- Cutting edge 1930's technology
  - (basic device actually 100 yrs old)
  - Vacuum tube (big, power hog, …)
  - Refined some, but no fundamental changes
- But still dominant
  - Because TVs are consumer item
  - LCD's just starting to challenge

How a CRT works (B/W)



Move electron beam in fixed scanning pattern

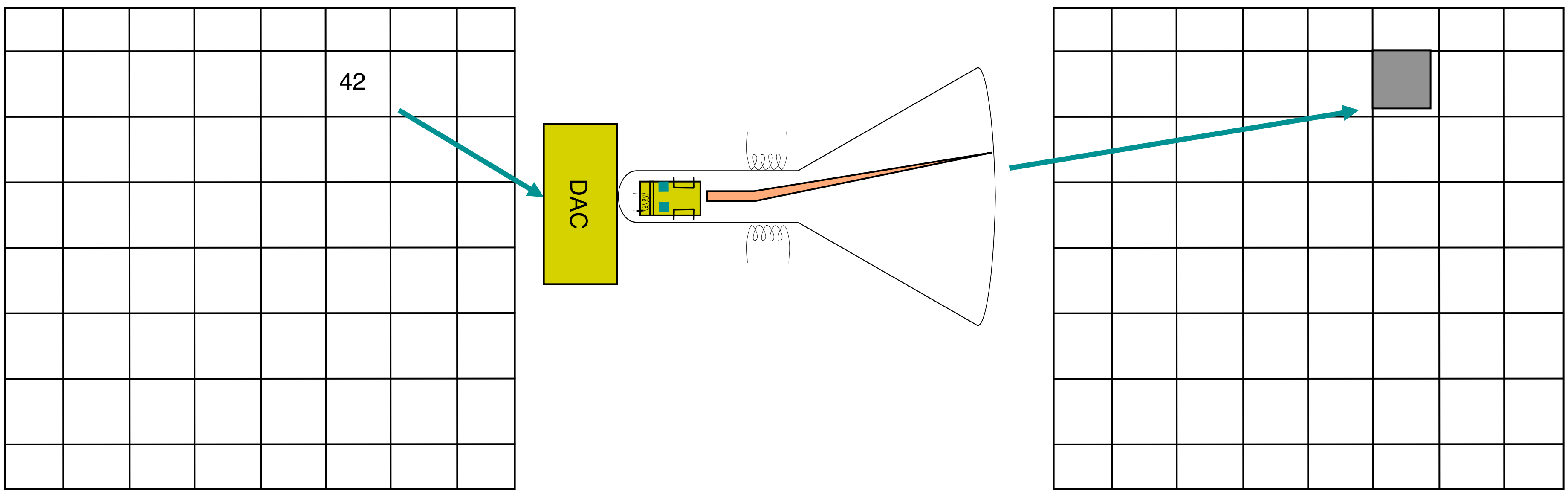
- "Raster" lines across screen



- Modulate intensity along line (in spots) to get pixels

Pixels determined by 2D array of intensity values in memory

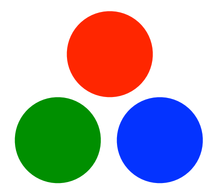
- "Frame buffer"
  - Each memory cell controls 1 pixel



  - All drawing by placing values in memory

Adding color

- Use 3 electron guns
- For each pixel place 3 spots of phosphor (glowing R, G, & B)
- Arrange for red gun to hit red spot, etc.
  - Requires a lot more precision than simple B/W
  - Use “shadow mask” behind phosphor spots to help



Color frame buffer

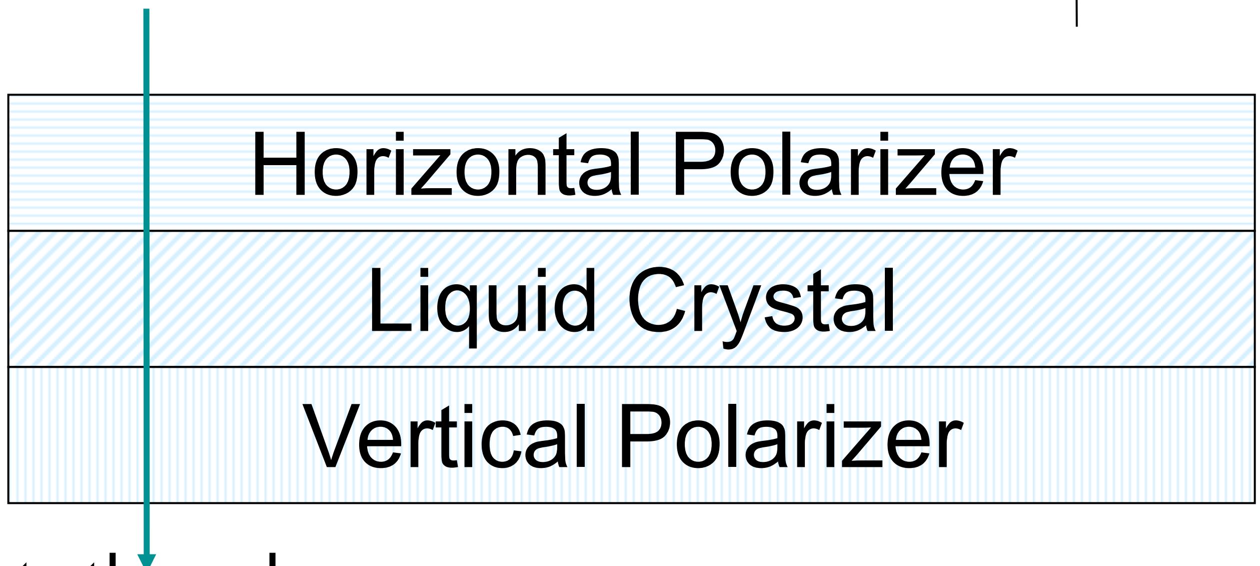
- Frame buffer now has 3 values for each pixel
  - each value drives one electron gun
  - can only see ~ 2^8 gradations of intensity for each of R,G,&B
  - 1 byte ea => 24 bits/pixel => full color

Other display technologies: LCD

- Liquid Crystal Display
- Discovered in 1888 (!) by Reinitzer
- Uses material with unusual physical properties: liquid crystal
  - rest state: rotates polarized light 90°
  - voltage applied: passes as is

Layered display

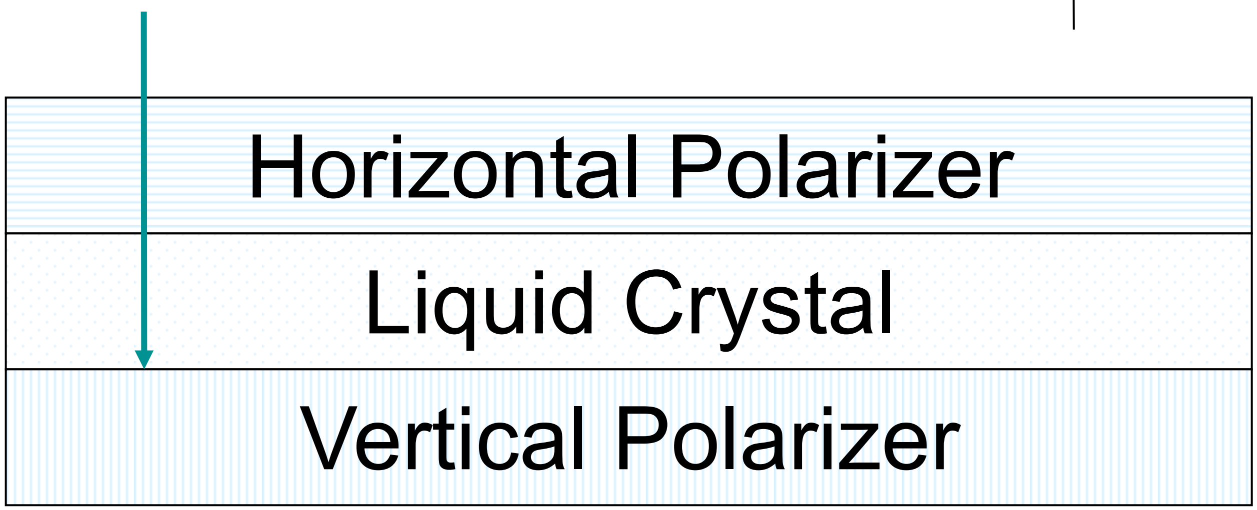
- Layers



- In rest state: light gets through
  - Horizontally polarized, LC flips 90°, becomes vertically polarized
  - Passes through

Layered display

- Layers



- In powered state: light stopped
  - Horizontally polarized, LC does nothing, stopped by vertical filter

Lots of other interesting/cool technologies

- Direct retinal displays
  - University of Washington HIT lab
- Set of 3 color lasers scan image directly onto retinal surface
  - Scary but it works
  - Very high contrast, all in focus
  - Potential for very very high resolution
  - Has to be head mounted

All these systems use a frame buffer

- Again, each pixel has 3 values
  - Red, Green Blue
- Why R, G, B?
  - R, G, and B are particular freq of light
  - Actual light is a mix of lots of frequencies
  - Why is just these 3 enough?

Why R, G, & B are enough

- Eye has receptors (cones) that are sensitive to (one of) these
  - Eye naturally quantizes/samples frequency distribution

- 8-bit of each does a pretty good job, but… some complications

Complications

- Eye's perception is not linear (logarithmic)
- CRT's (etc.) do not respond linearly
- Different displays have different responses
  - different dynamic ranges
  - different color between devices!
- Need to compensate for all of this

Gamma correction

- Response of all parts understood (or just measured)
- Correct: uniform perceived color
  - Normally table driven
    - 0…255 in (linear intensity scale)
    - 0…N out to drive guns
      - N=1024 or 2048 typical

Unfortunately, gamma correction not always done

- E.g., TV is not gamma corrected

➡Knowing RGB values does not tell you what color you will get!

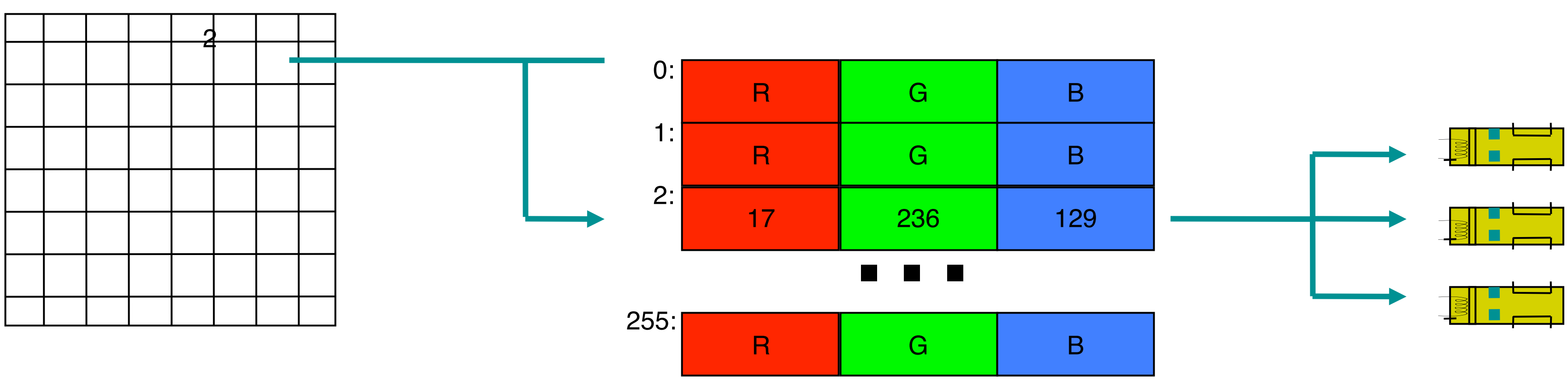
- For systems you control: do gamma correction

24 bits/pixel => “true color,” but what if we have less?

- 16 bits/pixel
  - 5 each in RGB with 1 left over
  - decent range (32 gradations each)
- Unfortunately often only get 8
  - 3 bits for GB, 2 for R
  - not enough
  - Use a “trick” instead

Color lookup tables (CLUTs)

- Extra piece of hardware
  - Use value in FB as index into CLUT
    - e.g. 8 bit pixel => entries 0…255



  - Each entry in CLUT has full RBG value used to drive 3 guns

Palettes

- 8 bits / pixel with CLUT
  - Gives "palette" of 256 different colors
  - Chosen from 16M
  - Can do a lot better than uniform by picking a good palette for the image to be displayed (nice algorithms for doing this)

Imaging Models

What does the hardware "look like" to the higher levels of software?

Software models of output (Imaging models)

- Start out by abstracting the HW
  - *What does the hardware "look like" to the higher levels of software?*
- Earliest imaging models abstracted early hardware: vector refresh
  - stroke or vector (line only) models
- "Display list" containing end points of lines to be drawn
  - System just cycles through the display list, moving the electron gun between endpoints
  - Arbitrarily positionable electron gun, rather than the "sweep" pattern seen in raster imaging.

Vector models

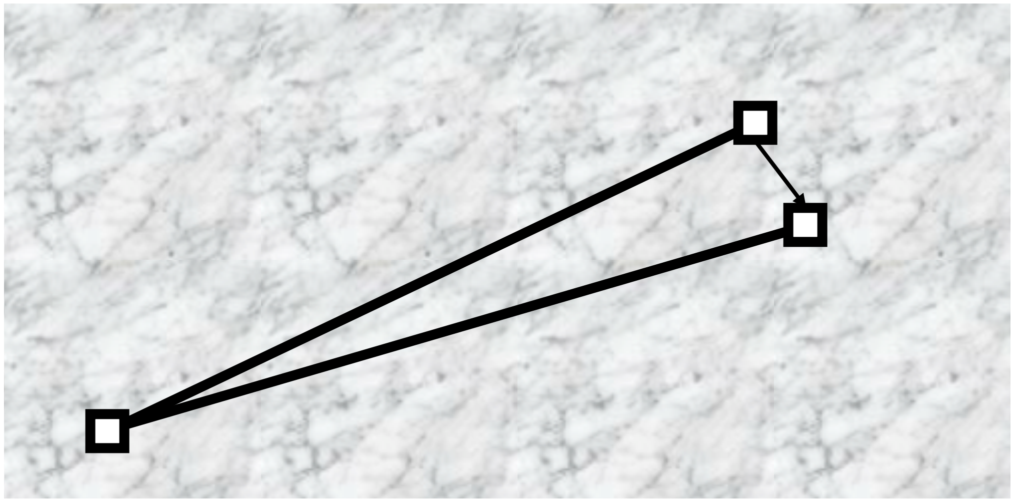
- Advantages
  - can freely apply mathematical xforms
    - Scale rotate, translate
    - Only have to manipulate endpoints
- Disadvantages
  - limited / low fidelity images
    - wireframe, no solids, no shading

Current dominant: Raster models

- Most systems provide model pretty close to raster display HW
  - integer coordinate system
  - 0,0 typically at top-left with Y down
  - all drawing primitives done by filling in pixel color values (values in FB)

Issue: Dynamics

- Suppose we want to "rubber-band" a line over complex background



- Drawing line is relatively easy
- But how do we "undraw" it?

Undrawing things in raster model

- Ideas?

(red, su, xo, pal, fwd)

Undrawing things in raster models

- Four solutions:
- 1) Redraw method
  - Redraw all the stuff under
  - Then redraw the line
- Relatively expensive (but HW is fast)
  - Note: don't have to redraw all, just "damaged" area
- Simplest and most robust

(back)

How to undraw

- 2) “Save-unders”
  - When you draw the line, remember what pixel values were “under” it
  - To undraw, put back old values
  - Issue: (what is it?)

How to undraw

- 2) “Save-unders”
  - When you draw the line, remember what pixel values were “under” it
  - To undraw, put back old values
  - Issue: what if “background” changes
- Tends to either be complex or not robust
  - Typically used only in special cases

(back)

How to undraw

- 3) Use bit manipulation of colors
  - Colors stored as bits
  - Instead of replacing bits XOR with what is already there
    - A ^ B ^ B == ?

How to undraw

- 3) Use bit manipulation of colors
  - Colors stored as bits
  - Instead of replacing bits XOR with what is already there
    - A ^ B ^ B == A (for any A and B)
  - Draw line by XOR with some color
  - Undraw line by XOR with same color

Issue with XOR?

- What is it?

Issue with XOR

- Colors unpredictable
  - SomeColor ^ Blue == ??
    - Don’t know what color you will get
    - Not assured of good contrast
      - Ways to pick 2nd color to maximize contrast, but still get “wild” colors

Undraw with XOR

- Advantage of XOR undraw
  - Fast
  - Don't have to worry about what is "under" the drawing, just draw
- In the past used a lot where dynamics needed
  - May not be justified on current HW

(back)

How to undraw

- 4) Simulate independent bit-planes using CLUT "tricks"
  - Won't consider details, but can use tricks with CLUT to simulate set of transparent layers
  - Probably don't want to use this solution, but sometimes used for special cases like cursors (back)

Higher level imaging models

- Simple pixel/raster model is somewhat impoverished
  - Integer coordinate system
  - No rotation (or good scaling)
  - Not very device independent

Higher level imaging models

- Would like:
  - Real valued coordinate system
    - oriented as Descarte intended?
  - Support for full transformations
    - real scale and rotate
  - Richer primitives
    - curves

Stencil-and-Paint

Higher level imaging models

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Stencil and paint model

- All drawing modeled as placing paint on a surface through a "stencil"
  - Stencil modeled as closed curves (e.g., splines)
- Issue: how do we draw lines?

Stencil and paint model

- All drawing modeled as placing paint on a surface through a "stencil"
  - Modeled as closed curves (splines)
- Issue: how do we draw lines?
  - (Conceptually) very thin stencil along direction of line
  - Actually special case & use line alg.

Stencil and paint model

- Original model used only opaque paint
  - Modeled hardcopy devices this was developed for (at Xerox PARC)
- Current systems now support "paint" that combines with "paint" already under it
  - e.g., translucent paint ("alpha" values)

Stencil and paint examples

- In *most* cases, implemented at a much higher layer than the raw hardware (e.g., in the Window System or Toolkit, which we'll talk about soon...)

- Postscript is based on this approach
  - Implemented in printer's hardware (often)
- NeXTstep: Display Postscript
  - Brought same imaging model used for hardcopy output to interactive graphics
- Mac OS X
  - Derived from NeXTstep, uses DisplayPDF as its imaging model
- Windows, starting with Vista
  - Aero
- New Java drawing model (Java2D) provides a stencil-and-paint imaging model, implemented completely in the Toolkit

Stencil and paint pros and cons

- Advantages
  - Resolution & device independent
    - does best job possible on avail HW
    - Don't need to know size of pixels
  - Can support full transformations
    - rotate & scale

Stencil and paint pros and cons

- Disadvantages
  - Slower
    - Less and less of an issue
    - But interactive response tends to be dominated by redraw time
  - Much harder to implement

Stencil and paint pros and cons

- Stencil and paint type models generally the way to go
  - But have been slow to catch on
    - Market forces tend to keep us with old models
    - Much harder to implement
  - Finally became mainstream around 2006