

# 2D displays: human and device properties

IAT 351

Lyn Bartram

23.01.2008



## Why should we care about optics?

- 
- Hi bandwidth to the brain (70% of all receptors ,40+% of cortex, 4 billion neurons)
  - Can see much more than we can mentally image
  - Can perceive patterns (what dimensionality?)
  - What are the effects of *display resolution* and *visual acuity*?
  
  - Display resolution
    - Visualizations need to be designed according to the available display resources
  
  - Visual Acuity
    - Limitations of the human visual system



## Fundamental questions

---

- How many pixels are needed to represent information effectively?
  - Resolution
  - depth
- What's the size and brightness (visual acuity) needed for our visual system to accurately identify and interpret the visual features?

<sup>1</sup> Awant and Healey, A survey of display device properties and visual acuity for visualization

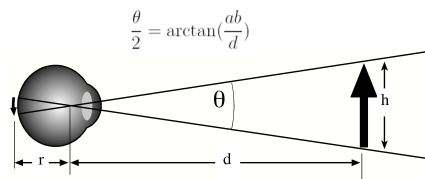
## Physical device properties

---

- Resolution
- Size
- Viewing distance
- Viewing angle
- Size and viewing distance affect the *visual angle subtended* by the viewed object
- Visibility is affected by visual angle

## Visual angle

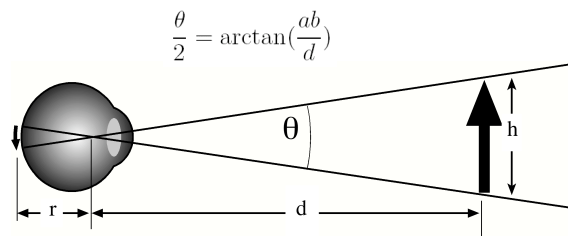
- Size and viewing distance affect the *visual angle subtended* by the viewed object
- Visibility is affected by visual angle
  - 1 arcmin = 1/60 degree of visual angle



2D Display and Optics | IAT351 | 1/23/08



## Visual Angle



the [angle](#) under which a visual [stimulus](#) appears to the [eye](#)

2D Display and Optics | IAT351 | 1/23/08



## Visual angle and FOV (field of view)

---

### Normal vision

Distinguish an object that subtends  $1/60^\circ$  at a distance of 20 ft  
FOV =  $150^\circ$  per eye

A thumbnail at arm's length = 1 degree of visual angle  
1 cm object at 57 cm = 1 degree of visual angle  
57 cm is a reasonable approximation of usual monitor viewing distance

## Resolution

---

- Number of pixels
- Sharpness depends on resolution and size
  - Small pixels are sharper than fat ones
- *Display resolution* = size x resolution
  
- Low display resolution limits information
- BUT adding pixels won't help!
- Object must subtend a minimum angle

## Physical size

---

- Large displays afford greater FOV
- Limitation on what humans can process in horizontal and vertical FOV
  - Peripheral vision is highly unacute for many visual features
- People perform better on certain spatial orientation tasks using large displays
- Wider FOV increases presence
- To a certain extent, can have higher resolution

## Display size cont.

---

- Large displays afford greater FOV
- Limitation on what humans can process in horizontal and vertical FOV
  - Peripheral vision is highly unacute for many visual features
- People perform better on certain spatial orientation tasks using large displays
- Wider FOV increases presence
- To a certain extent, can have higher resolution
- Large displays are not portable!

## Human optics

---

- The brain and eye have orders of magnitude more receptors than displays have pixels (stimuli)
- Retina has two kinds of photoreceptors:
  - Rods – intensity
  - Cones – colour
- 120 million rods, 6 million cones
- Distribution is highly non-uniform
- Fovea in the centre of the eye has the most acute vision
  - Subtends 0.5 – 2 degrees of visual angle

## Cutoff at 50 cycles/deg.

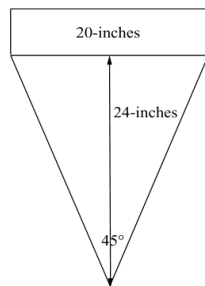
---

- Receptors: 20 sec of arc
- Pooled over larger and larger areas
- 100 million receptors
- 1 million fibers to brain
- A screen may have 30 pixels/cm – need about 4 times as much.
- VR displays have 5 pixels/cm

## Resolution of Eye

---

- Resolution of the eye ranges from 0.5 arc minute (120 cycles/degree) to 1 arc minute (60 cycles/degree) [Staad]t]



How many pixels across one scanline subtending 45° would it take to match human visual acuity?

Answer:  $120 \times 45 = 5400$  pixels

But ...

That's in the **fovea**

---

2D Display and Optics | IAT351 | 1/23/08

Introduction

Physical Resolution

Acuity

Visual Features

Conclusions



## Visual acuity

---

- Measurement of our ability to see detail
- Resolve visual phenomena to 1 arc minute of visual angle
- Roughly corresponds to spacing of receptors in the *fovea*
- Superacuties* – ability to perceive precision beyond the receptor grid
  - Vernier* (colinearity)

---

2D Display and Optics | IAT351 | 1/23/08

Introduction

Physical Resolution

Acuity

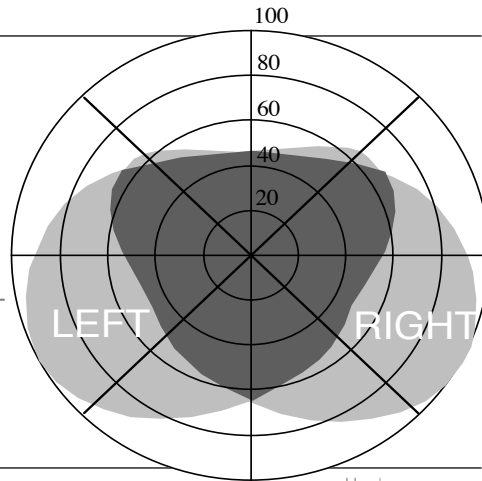
Visual Features

Conclusions



## Human Visual Field

- Area of overlap is approximately 120° with 30-35° monocular vision on each side
- Combined horizontal FOV is 180-190°
- Combined vertical FOV is 120-135°

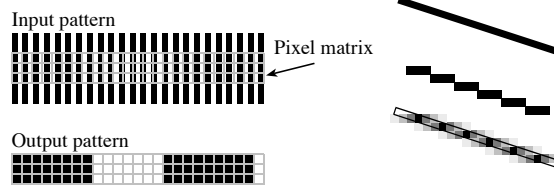


2D Display and Optics | IAT351 | 1/23/08

SIOATE SCHOOL OF INTERACTIVE ARTS + TECHNOLOGY

## Overcoming device resolution

- Binocular vision findings suggest we can use the ability of the eye to integrate information over space and time to support perception of higher-than-device resolution
- Anti-aliasing
  - Spatial
  - temporal



2D Display and Optics | IAT351 | 1/23/08

SIOATE SCHOOL OF INTERACTIVE ARTS + TECHNOLOGY

## Visual Acuity Properties

Device	Resolution	Screen Size	Distance	Angle
Phone	128 x 160	2-inches	18-inches	1,52-arc min
PDA	240 x 320 600 x 800	3,5-inches 4-inches	18-inches	1,40-arc min 0,46-arc min
Monitors	1024 x 768 1280 x 1200 1600 x 1200	17-inches 17-inches 17-inches	24-inches	1,54-arc min 1,31-arc min 1,13-arc min
Powerwall	3200 x 2400	8 x 6-feet	4-feet	2,09-arc min
Electronic ink	2550 x 3300	8.5 x 11-inches	18-inches	0,38-arc min

2D Display and Optics | IAT351 | 1/23/08



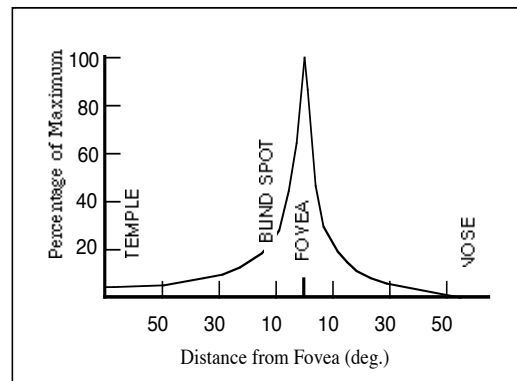
## BUT ..... Size (and angle) does matter

- Visual acuity is NOT uniform across the FOV
- Fovea subtends a small region (2 degrees)
- Parafovea covers about 6-8 degrees
- So we only resolve something clearly if we look right at it
  
- Limits effective resolution of display
- Increases fixation time
  
- Some visual features are non discriminable in the periphery

2D Display and Optics | IAT351 | 1/23/08



## Acuity Distribution



2D Display and Optics | IAT351 | 1/23/08

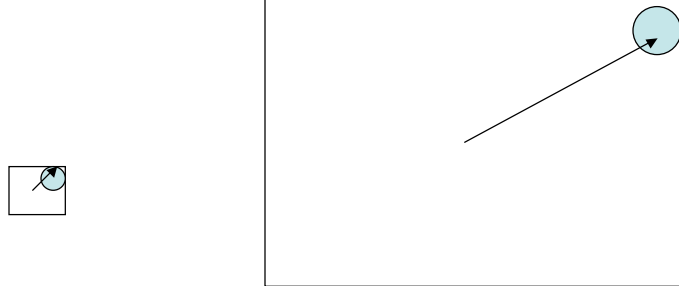


An image progressively blurred from the centre outwards simulating the progressive loss of acuity with eccentricity.

2D Display and Optics | IAT351 | 1/23/08



## How efficiently can we use each display?



- It will take approximately 2.5x as long to fixate targets at the edge of the big screen
- Head movements accompany eye movements  $> 25$  deg.

2D Display and Optics | IAT351 | 1/23/08



## How Many Pixels? Visual features

- Each visual feature needs some minimum number of pixels
  - Hue, luminance, flicker need 1 pixel
  - Orientation, size, regularity need more pixels
- Expressiveness of a single pixel is unknown
- Minimum number of pixels for certain features is unknown
- Importance
  - Help to validate a data-feature mapping
  - Characterize to what extent we saturate “visual bandwidth”
- Effectiveness of a display type will depend on what you want to show
  - Key visual features (detail? Text? Luminance? Colour?)

2D Display and Optics | IAT351 | 1/23/08



## Visual features

---

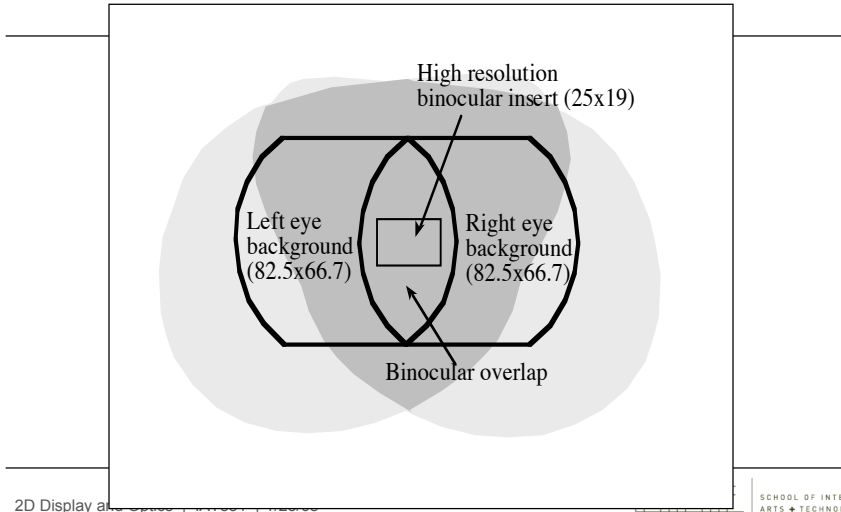
- Colour, size, position, luminance, shape, flicker, motion
- Colour (hue) visibility depends on saturation and size
  - ½ degree of visual angle
- Humans are almost colour-blind in the periphery
- Subject to interference (dithering)
- Best for low-frequency ordinal data
- NTSC: “never the same colour”

## Visual features cont.

---

- Luminance
  - Intensity or brightness of the colour
  - Evidence shows we see luminance before colour
  - We are more sensitive to luminance changes outside fovea than other static cues
- Generally, static cues like position and shape are also marginally perceptible in the periphery
- Motion a powerful visual cue across the FOV
- Conclusion: we need to fixate (foveate) most visual information to decode it
- What does that say about choosing/building displays?

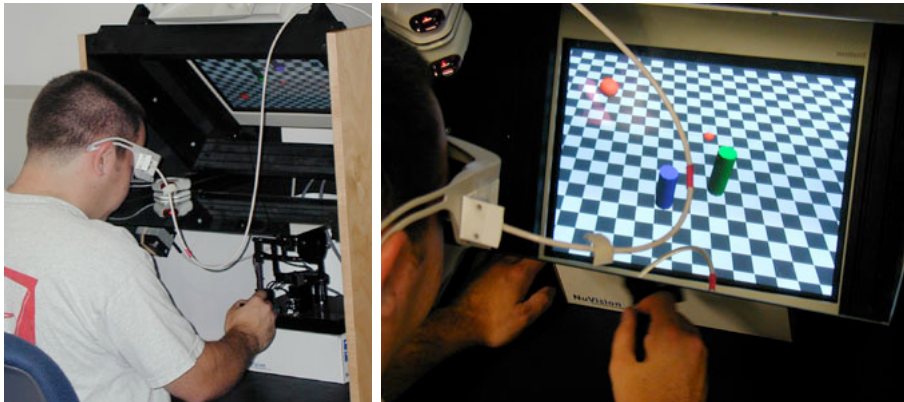
## Ultimate Display



2D Display and Optics | IAT351 | 1/23/08

SCHOOL OF INTERACTIVE  
ARTS + TECHNOLOGY

## Ultimate Display



2D Display and Optics | IAT351 | 1/23/08

SCHOOL OF INTERACTIVE  
ARTS + TECHNOLOGY

But what do we have we got to work with  
now?

A Review of 2D Display Technologies



## Display technologies

---

- Terminology of resolution etc
- Characterising factors
- Major players
- Vector vs raster displays
- CRTs
- LCDs
- Plasmas
- DLPs
- LEDs



## Device properties

- Given our understanding of visual acuity, how does it relate to the following device properties?
- Resolution, physical size and viewing distance
  - What can they render and what might we see?
  - Where do we see it?
- Luminance, clarity and eccentricity
  - How well can we see it and are there artifacts and masks?
- Physical footprint, human factors and flexibility
  - Where is it useful and usable?
- Locus \*\*
  - Where and when does it need to serve?
  - Under what conditions

## Visual Acuity Properties

Device	Resolution	Screen Size	Distance	Angle
Phone	128 x 160	2-inches	18-inches	1,52-arc min
PDA	240 x 320 600 x 800	3.5-inches 4-inches	18-inches	1,40-arc min 0,46-arc min
Monitors	1024 x 768 1280 x 1200 1600 x 1200	17-inches 17-inches 17-inches	24-inches	1,54-arc min 1,31-arc min 1,13-arc min
Powerwall	3200 x 2400	8 x 6-feet	4-feet	2,09-arc min
Electronic ink	2550 x 3300	8.5 x 11-inches	18-inches	0,38-arc min

## Key visual features vs representational context

---

- Colour
  - Luminance
  - Position
  - Shape
  - Texture
  - Motion
- Text ?
  - Detail ?
  - Density?
  - Variability?
  - Mobile?
  - Fixed ?
  - Single user
  - Multi-user?
  - There are more ..

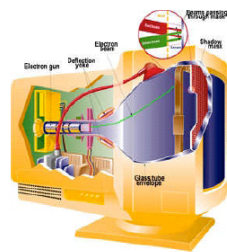
---

2D Display and Optics | IAT351 | 1/23/08



## Cathode Ray Tube (CRT)

---

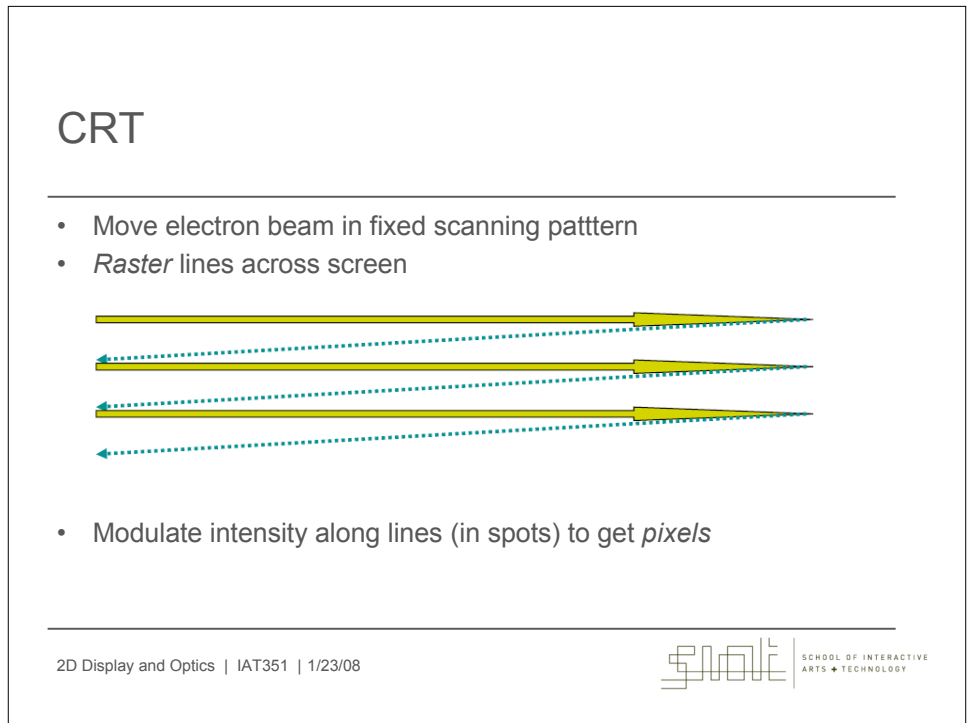
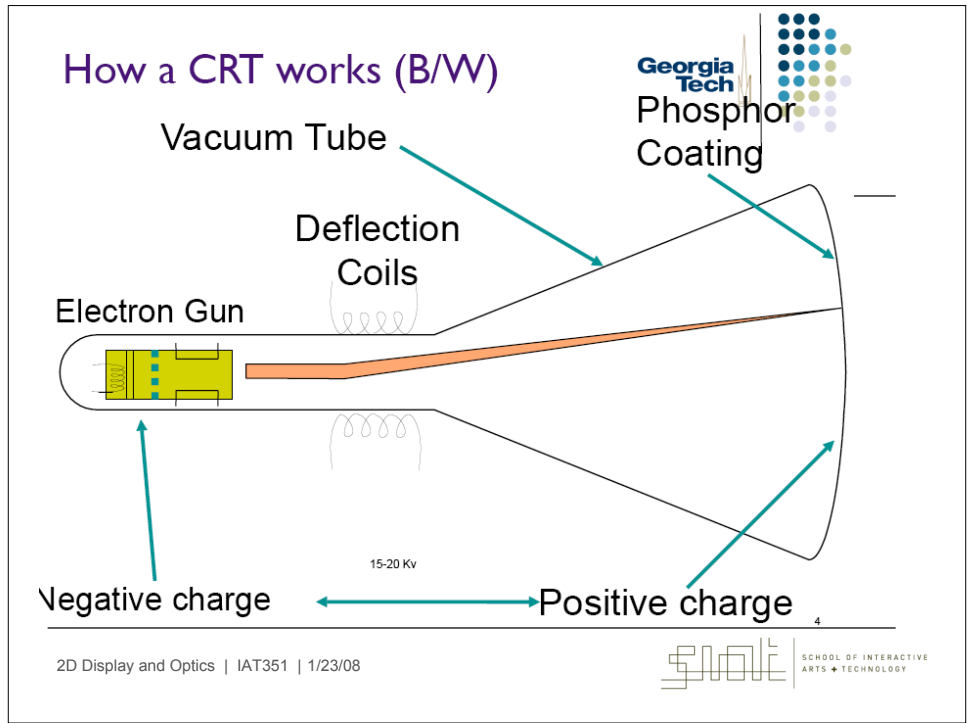


- Most common display device today
- Basic device is 100 years old
- Still dominant, although LCDs are now challenging

---

2D Display and Optics | IAT351 | 1/23/08





## Vector Displays

---



- Oscilloscopes were some of the 1st computer displays
- Used by both analog and digital computers  
Computation results used to drive the vertical and horizontal axis (X-Y) |  
Intensity could also be controlled (Z-axis)  
Used mostly for line drawings  
Called *vector*, *calligraphic* or affectionately *stroker* displays  
Display list had to be constantly updated (except for storage tubes)
- No pixelated redraw, but decay effect
  - Vector graphics are very efficient representations

---

2D Display and Optics | IAT351 | 1/23/08



## Vector vs. raster displays

---

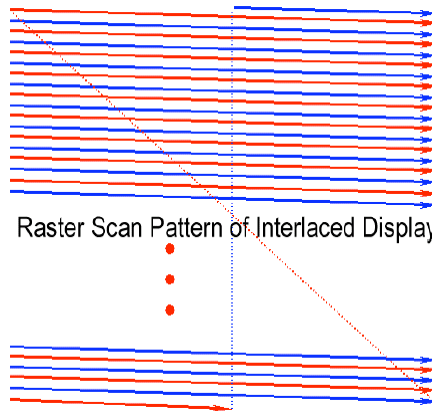
- Vectors are lines and points and geometry
- Rasters are *pixels* : an image is comprised of a discretized set of points blurred together
- All the common digital displays today are a variant of raster technology

---

2D Display and Optics | IAT351 | 1/23/08



## Raster Displays



Raster Scan Pattern of Interlaced Display

- Entire screen painted 30 times/sec
- Screen is traversed 60 times/sec
- Even/Odd lines on alternate scans (called fields)
- Interlace - a *hack* to give
  - Smooth motion on dynamic scenes
  - High Resolution on static scenes
- Optimize bandwidth

2D Display and Optics | IAT351 | 1/23/08



## Raster displays cont.

- The path of the electron beam is hardwired
- Computer has to sync painting the screen with the scanning of the display
- The computer only controls the intensity of the color at each point on the screen
- A *frame buffer* is used to store intensity variations.
  - Entire set of screen instructions needs to be in place in the time that the electron beam travels from the bottom to the top (the *vertical refresh interval*)
- *Double buffering* to prevent flicker in the redraw
- Interlacing to reduce cost of refreshing the intensity changes

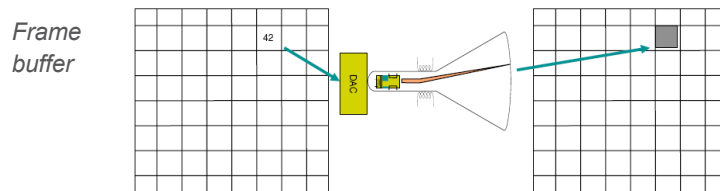
2D Display and Optics | IAT351 | 1/23/08



## Frame buffer

---

- Pixels are determined by 2D array of intensity values in memory
- Each memory cell controls 1 pixel



- All drawing done by placing values in memory

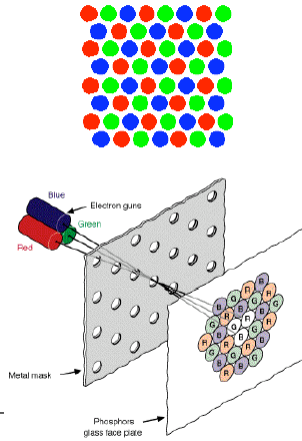
## How do we add colour?

---

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

## Colour video is much more complicated!

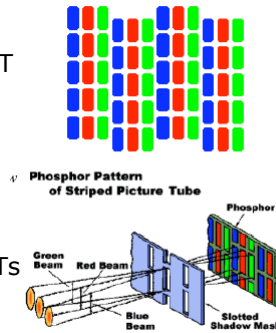
Delta Electron Gun Arrangement



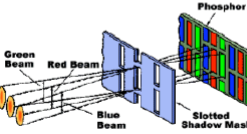
2D D

- Requires precision geometry
- Patterned phosphors on CRT face
- Aligned metal shadow mask
- Three electron guns
- Less bright than monochrome CRTs

In-line Electron Gun Arrangement



Phosphor Pattern of Striped Picture Tube



SIAATE | SCHOOL OF INTERACTIVE ARTS + TECHNOLOGY

## Colour Frame Buffer

- Frame buffer now has 3 values per pixel
  - Each value drives one electron gun
  - Can only see  $2^8$  gradations of intensity for each R,G,B
  - 1 byte  $\Rightarrow$  24 bits/pixel  $\Rightarrow$  full colour

2D Display and Optics | IAT351 | 1/23/08

SIAATE | SCHOOL OF INTERACTIVE ARTS + TECHNOLOGY

## Other display technologies: LCD

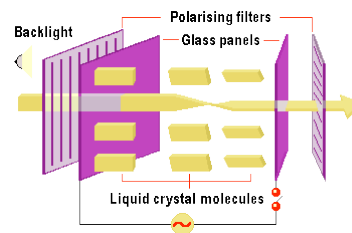
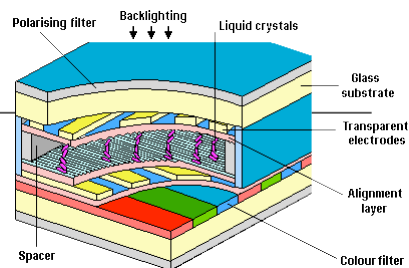
- Liquid Crystal Display
- Discovered in 1888 by Reinitzer
- Uses material with unusual physical properties: liquid crystal
  - Rest state: rotates polarised light 90 degrees
  - Voltage applies: passes light through
- Two kinds
  - Reflective and backlit
  - Active matrix (TFT)

2D Display and Optics | IAT351 | 1/23/08



## Passive LCDs cont.

- Reflective displays use ambient light
  - Can't be seen in the dark
- Transmissive displays use backlight
  - Overwhelmed by ambient light
- Poor for dynamic information
- Imprecise and limited colour
- Good for limited information (microwaves, watches)
- Slow response time and imprecise voltage control make them poor choices for computer screens
- <http://electronics.howstuffworks.com/lcd7.htm>



2D Display and Optics | IAT351 | 1/23/08



## Active LCDs (TFT)

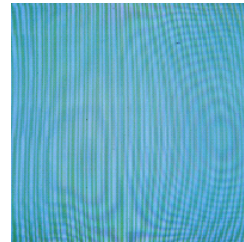
---

- Grid of transistors and capacitors
- Only the capacitor at the designated pixel gets the charge
- Applies it to the LC
- Adjusting the voltage applied controls how much the crystal untwists, permitting variable light pass-through
  - = gray levels! 256
- Delivers true colour (24 bit)
- BUT lots of transistors - 2,359,296 for 1024x768
- Limits display size
- Usually get a few bad pixels

## Disadvantages of the CRT+raster display.

---

- Requires screen-sized memory array
- Discrete spatial sampling (pixels)
- Moire patterns result when shadow-mask and dot-pitch frequencies are mismatched
- Straight lines don't appear straight at edge of screen because of tube curvature



---

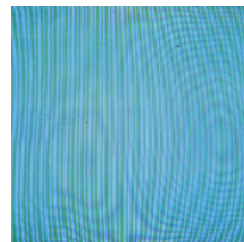
2D Display and Optics | IAT351 | 1/23/08



## Disadvantages of the CRT+raster display.

---

- it sucks up too much electricity
- its single electron beam design is prone to misfocus
- misconvergence and colour variations across the screen
- its clunky high-voltage electric circuits and strong magnetic fields create harmful electromagnetic radiation
- it's simply too big
- Limit on practical size < 40 "
- Screen burn-in on phosphor



---

2D Display and Optics | IAT351 | 1/23/08



## Advantages of the CRT

---

- Best black-level and Dynamic Range of all the display technologies
- Highest color and gray-scale accuracy
- Most accurate Gamma
- Perfectly smooth gray-scale with no false contouring
- Excellent accuracy and low noise at the dark-end of the gray-scale
- Supports a wide range of resolutions
- Image rescaling not necessary
- No motion artifacts
- Widest viewing angles
- Least artifacts of all the display technologies
- Gaussian beam profile produces a very smooth image

---

2D Display and Optics | IAT351 | 1/23/08



## LCD Advantages

---

- exceptionally sharp, high contrast images, including fine text and graphics – at NATIVE resolution
- Brightest of all the display technologies
- Highest resolution of all the flat panels (but the LCD4000 is only 1280 x 768)
- LCD panel intensity is controlled by an analog signal, which allows it to produce a smooth intensity-scale that is free of dithering noise and artifacts, especially at the dark-end of the scale
- Image noise resulting from poor quality video signals was less apparent due to the slower pixel response times
- Low reflection of ambient light due to the panel's polarizers and color filters
- The thinnest, lightest displays available
- Perfectly quiet for normal viewing (but on some models fans turn on at the brightest backlight settings)
- Lower power consumption than CRTs

---

2D Display and Optics | IAT351 | 1/23/08



## LCD Disadvantages

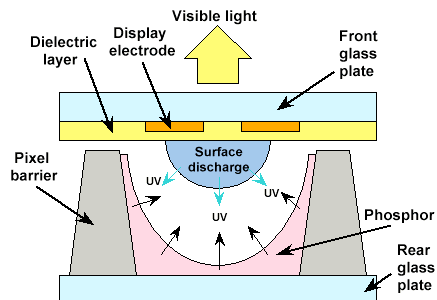
- Relatively bright black-level
- Brightness and color saturation generally decrease as the viewing angle increases; hue errors that increase with viewing angle
- Black-level generally increases with viewing angle
- Slowest response time of all the displays leads to motion flicker, smear and artifacts
- Lowest pixel fill factor or aperture ratio of the technologies, which often results in visible pixelation and the Screen Door Effect due to visible gaps between pixels. Less noticeable at higher resolutions and greater viewing distances
- Possible uneven light distribution from the backlight
- Fixed native resolution. Rescaling required for other resolution formats
- Bad pixels are common
- Expensive .. .Not so much anymore ...

2D Display and Optics | IAT351 | 1/23/08



## Plasmas

- Basic idea: a matrix of tiny fluorescent lights
- Excite the gas (plasma) in the tubes to emit light



2D Display and Optics | IAT351 | 1/23/08



## Plasmas

---

- intended for large format displays
- Combination of LCD and CRT approaches
  - LCD: uses x,y grid of electrodes
  - CRT: uses a phosphor (emissive)
- Basically fluorescent tubes
- High-voltage discharge excites gas mixture
- Upon relaxation UV light is emitted
- UV light excites phosphors
- Large viewing angle since the phosphors emit light uniformly
- Very bright
- Currently the most effective technology for non projected large displays

## Plasmas advantages

---

- Direct-view plasma displays produce exceptionally sharp, high contrast images, including fine text and graphics
- Excellent color saturation
- Widest viewing angle of all the flat panels
- Some models have a very dark black-level
- Very fast pixel response time
- Largest direct-view display technology available
- The thinnest displays available.
- Long life

## Plasma disadvantages

---

- Large pixel pitches
  - Hard to make high resolution plasmas
- Large power consumption
- Spatial and temporal dithering produce noise and false contouring in dark images.
- Pixelated image with Screen Door Effect due to noticeable gaps between pixels. Less noticeable at higher resolutions and greater viewing distances
- Fixed native resolution. Rescaling required for other resolution formats
- Fan Noise
- Very heavy.
- fragile

---

2D Display and Optics | IAT351 | 1/23/08



## Other interesting/cool technologies

---

- Digital light projectors (DLP)
  - Memory bits stored as electrical charge in cells
  - Insulating layer with mirror has an angle that is changed by exciting the cell
  - Light bouncing off the mirror forms a picture
  - 3 chips (RGB) or projector rotating colour wheel provides colour
  - Currently only available as projection technology
- Direct retinal display (HIT Lab, University of Washington)
  - 3 colour lasers scan image directly onto retina
  - Very high contrast, all in focus
  - Potential for very high and adaptive resolution
  - Has to be head mounted

---

2D Display and Optics | IAT351 | 1/23/08



## Frame-buffer based systems

---

- Used in all these technologies
- 3 values/pixel : R,G,B
- Matches receptor (cone) mechanisms in the eye
- 8-bits each is pretty good - but there are complications
  
- Eye's perception (as we have seen) is not linear
- Different displays have different dynamic ranges
  - Different colours different devices!
  - Need to compensate

## Gamma correction

---

- Response of all parts understood (or measures)
  
- Uniform perceived colour
- Normally table driven:
  - 0..255 linear intensity scale
  - 0..N out to drive guns (1024 or 2048 typical)
- Most systems don't do gamma correction, so
  - Knowing the RGB value does not tell you what COLOUR you will get!

## What if we don't have 24 bits?

- 16 bits/pixel
  - 5 RGB with 1 left over
  - Decent range ( $2^5$ , 32 gradations, decent range)
- Unfortunately we often only get 8
  - 3 G, 3B, 2R
  - Not enough
  - Use a "trick" instead

## Colour Lookup Tables (CLUTs)

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



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

## Palettes

---

- 8 bits/pixel with CLUT
- Gives a “palette” of 256 different colours ( $2^8$  selection)
  - Chosen from 16M ( $2^{24}$  generated)
- Can do a lot better than uniform distribution by picking a good palette for the image to be displayed
  - Nice algorithms for doing this

---

2D Display and Optics | IAT351 | 1/23/08



## Drawing

---



- Draw and redraw and undraw operations
  - Rubber banding a line over complex background
- Once you have drawn a shape on the raster/FB, how do you undraw?
  - Redraw everything under, then redraw previous state (expensive)
  - “Save-under”: restore previous state - issues?
  - Use XOR bit manipulation of colours ( $X \oplus B \oplus B == A$ )
  - Simulate bit planes with CLUT tricks
    - Used for special cases like cursors

---

2D Display and Optics | IAT351 | 1/23/08



## Higher level imaging models

---

- Simple pixel/raster model is somewhat impoverished
- Not very device independent
  
- Stencil and paint model
  - All drawing modeled as placing paint on a surface through a “stencil”
  - Closed curves, straight lines
  - Original model used only opaque paint (from hardcopy devices)
  - Current systems now support paint combining with paint underneath
    - Translucency
    - “alpha” values

## Stencil and paint models

---

- Advantages
  - Resolution and device independence
  - Don't need to know size of pixels
  - Can support full transformations (rotate and scale)
  
- Disadvantages
  - Slower
  - Interactive response dictated by redraw time
  - Harder to implement
  
- Becoming the model for screen-based approach (Java, .Net)

## Object-oriented abstractions for drawing

---

- Most modern systems provide uniform access to all graphical output capabilities and devices
- Treated as abstract drawing surface
  - “Canvas” abstraction
  - Macintosh: graffPort
  - Windows: device context
  - Xwindows: GC (Graphics Context)
  - **Java: Graphics/Graphics 2D classes**
    - Implements these abstractions in almost truly platform independent way

## Object-oriented abstractions for drawing

---

- Abstraction provides set of drawing primitives
- Hide low- level details
  - Graphics/bitmap operations
  - Device dependence
- Might be drawing on
  - Window, direct-to-screen, in-memory bitmap, printer
- Key point is that you write code that does not have to know which one

## Object-oriented abstractions for drawing

---

- Generally don't want to depend on details of device but sometimes need to know some aspects (limitations)
  - Size
  - Can it be resized, and how much?
  - Colour depth
  - Pixel resolution (for fine details)
- As a UI designer, you need to be sensitive to properties of each one and context of use, e.g.
  - Visibility (a mobile backlit screen)
  - Position (peripheral vs central)

---

2D Display and Optics | IAT351 | 1/23/08



## java.awt.Graphics

---

- Particular drawing abstraction
- Fairly typical raster-oriented model
- More recent version: Graphics2D

---

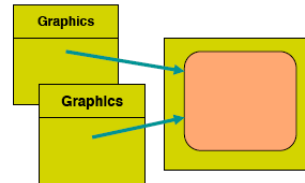
2D Display and Optics | IAT351 | 1/23/08



## java.awt.Graphics

---

- Gives indirect access to drawing surface (device)
- Contains
  - Reference to screen
  - Drawing state (graphics context)
    - Current clipping rectangle (what area to draw)
    - Colours of objects
    - Font
    - Etc.
  - Multiple Graphics instances may reference the same underlying drawing surface but hold different state information



---

2D Display and Optics | IAT351 | 1/23/08



## Fonts and drawing strings

---

- Font provides description of the shape of a collection of chars
  - Called *glyphs*
  - Information about how to advance after drawing glyph
  - Aggregate information for whole collection
- More recent formats (OpenType™) can specify lots more
  - Alternates
  - ligatures

ff affect

ffi affine

ffl afflict

---

2D Display and Optics | IAT351 | 1/23/08



## Fonts

---

- Typically specified by
  - Family or typeface (courier, helvetica, geneva, ....)
  - Size (in points)
  - Style ( **bold**, *italic*, plain, ....)
- See `java.awt.Font`

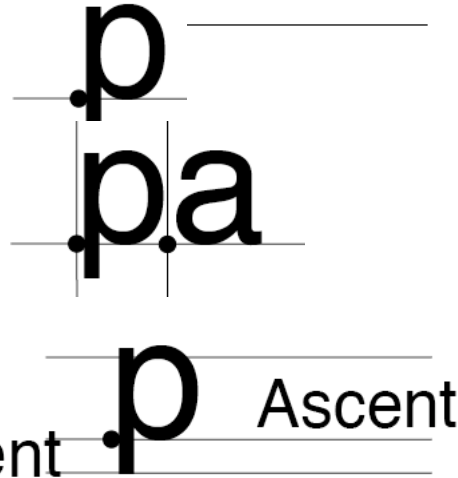
## FontMetrics

---

- Objects that allow you to measure characters, strings and properties of whole fonts
- `java.awt.FontMetrics`
- Get it by using
  - `FontMetrics fm = new FontMetrics (Graphics.getFontMetrics() );`

## FontMetrics

- Reference point and baseline
- Advance width
  - Where reference point of next glyph goes along baseline
- Ascent and descent



2D Display and Optics | IAT351 |

## Drawing fonts

- Sometimes easier to use `drawString()` method but font family gives you full control over appearance

2D Display and Optics | IAT351 | 1/23/08

## Graphics primitives

---

- Point
- Line
- Curve
- Rectangle
- Ellipse/circle
- arc

---

2D Display and Optics | IAT351 | 1/23/08



- 
- <http://java.sun.com/docs/books/tutorial/2d/geometry/examples/ShapesDemo2D.java>
  - Demo code for drawing each of these shapes
  - Can fill, change line (stroke) appearance and texture objects

---

2D Display and Optics | IAT351 | 1/23/08



# Images

---

- `Java.awt.image.BufferedImage`