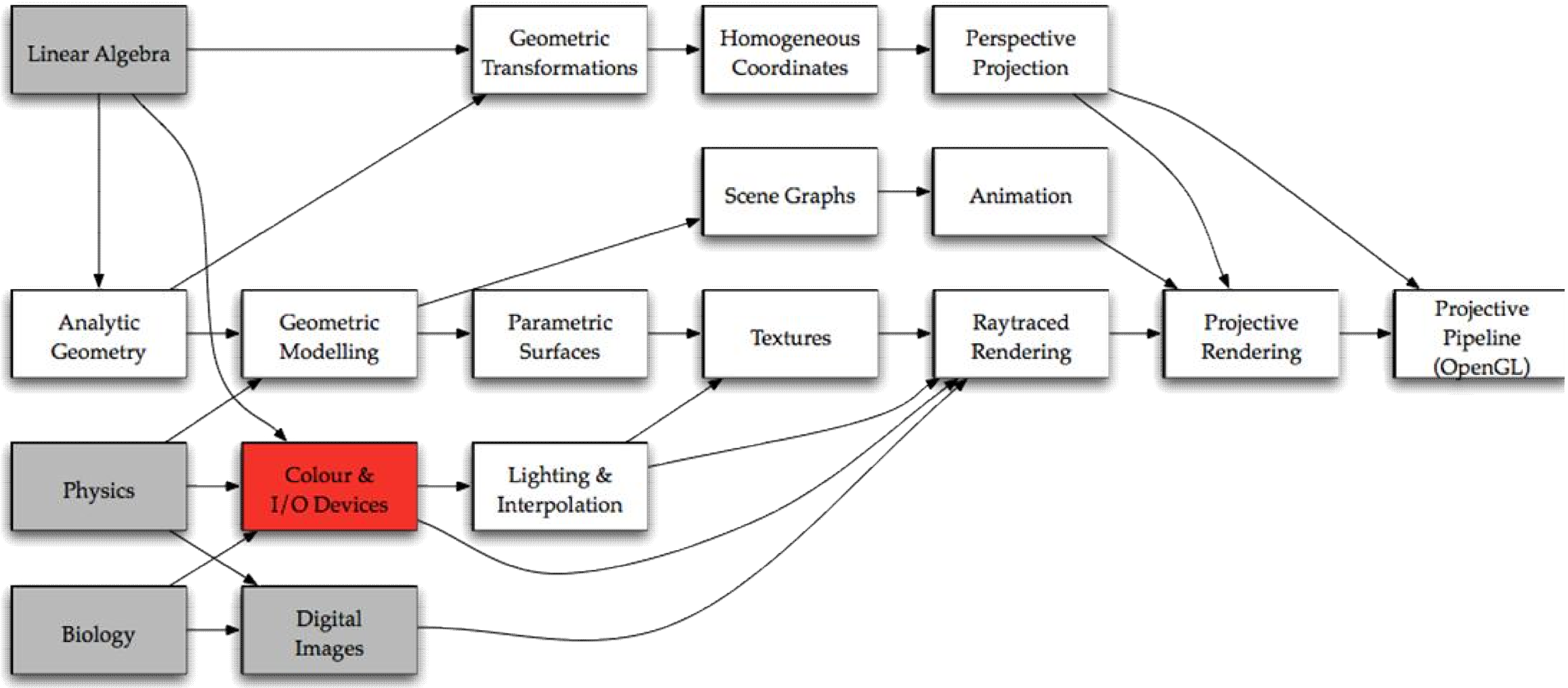
Colour & I/O Devices

Where we Are



Linear Algebra
Geometric Transformations
Homogeneous Coordinates
Perspective Projection
Scene Graphs
Animation
Analytic Geometry
Geometric Modelling
Parametric Surfaces
Textures
Raytraced Rendering
Projective Rendering
Projective Pipeline (OpenGL)
Physics
Colour & I/O Devices
Lighting & Interpolation
Biology
Digital Images

Today's Topics

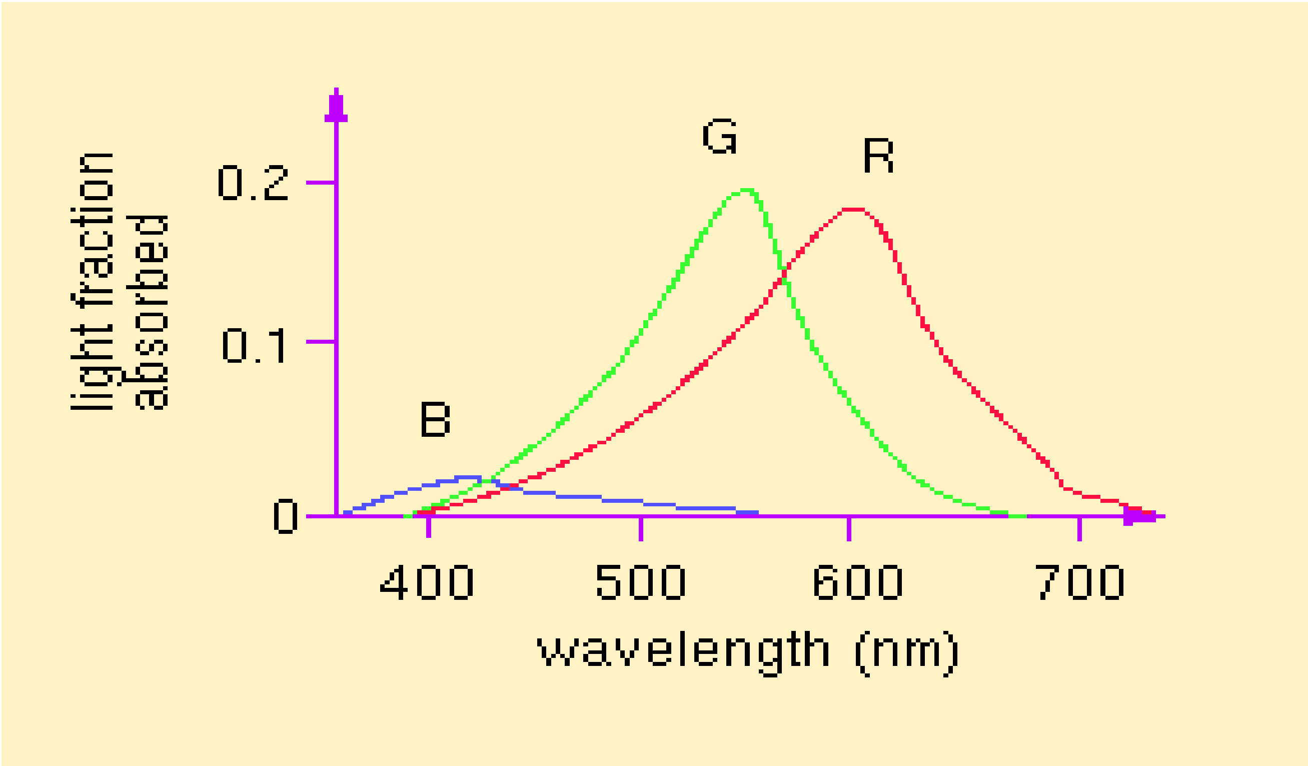
- How our Eyes see
- Colour Spaces
- Colour Models
- Sensors & Input Devices
- Output Devices

How are eyes see

- We have two types of cells in our eyes
  - Rods to see intensity of light
  - Cone to see different wavelengths (colour)

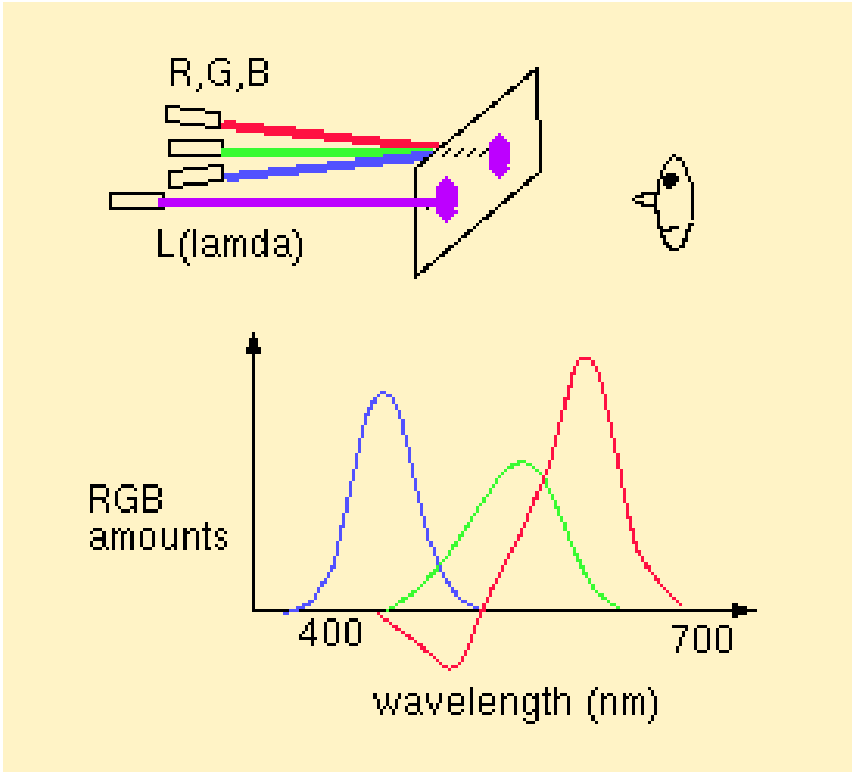
Cones & Colour

- Three types of cones
- Respond to different wavelengths:



Tri-stimulus Theory

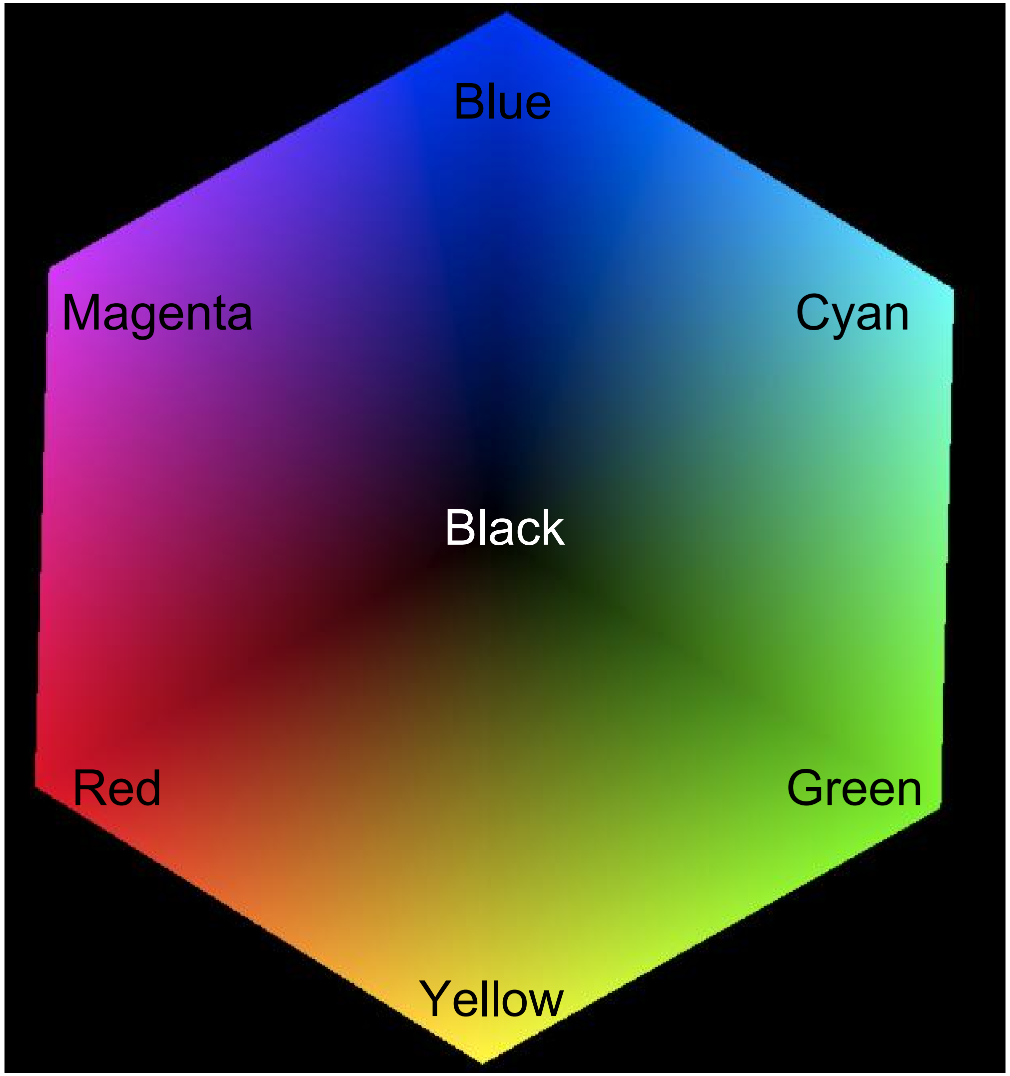
- Mix R, G & B to get any colour desired
- Human can't tell the difference



RGB Coordinates

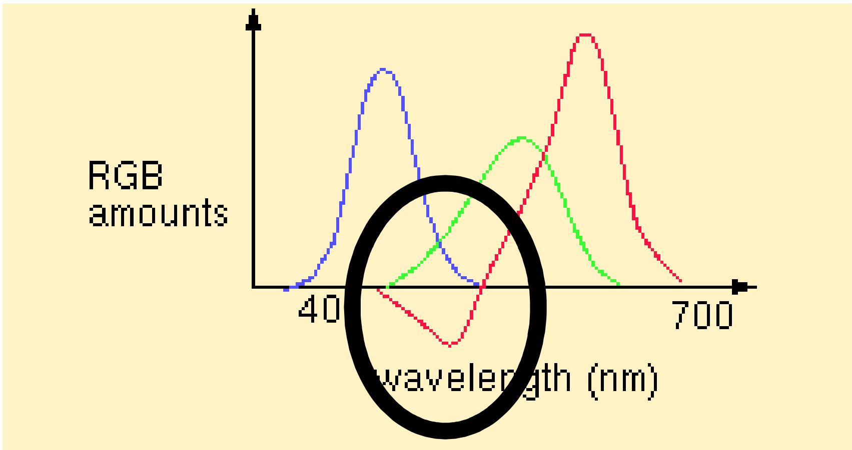
- Specify colours as a triple (R, G, B)
  - a *vector* representation of a colour
- We can define a *colour space*
  - the set of all possible RGB colours
- And we can change coordinate systems!

RGB Colour Cube



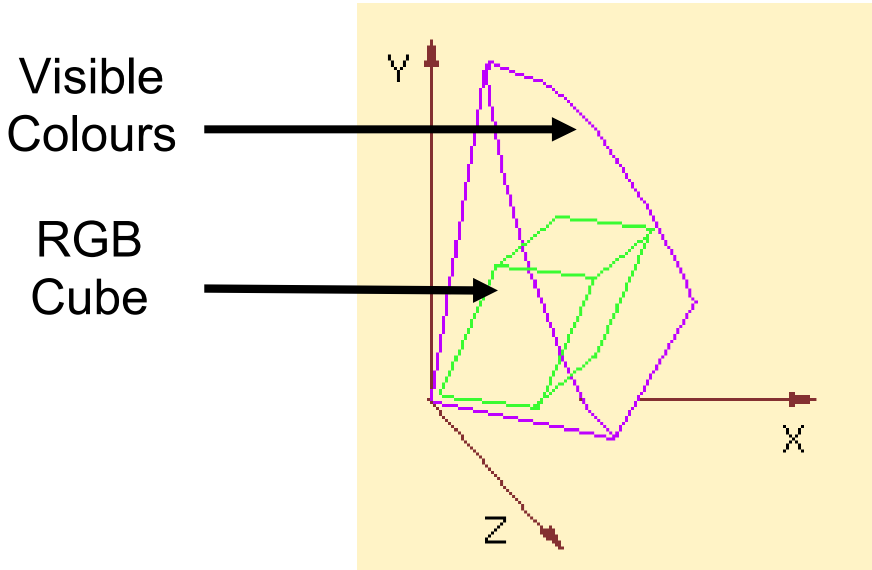
RGB Constraints

- We can only use positive R, G, B values
- Some colours can't be matched properly
  - red & green cones overlap in response
  - blue cones are weaker than red & green



XYZ Colour Space

- By the CIE (Commission Internationale d'Eclairage)
- Every visible colour uses positive coords



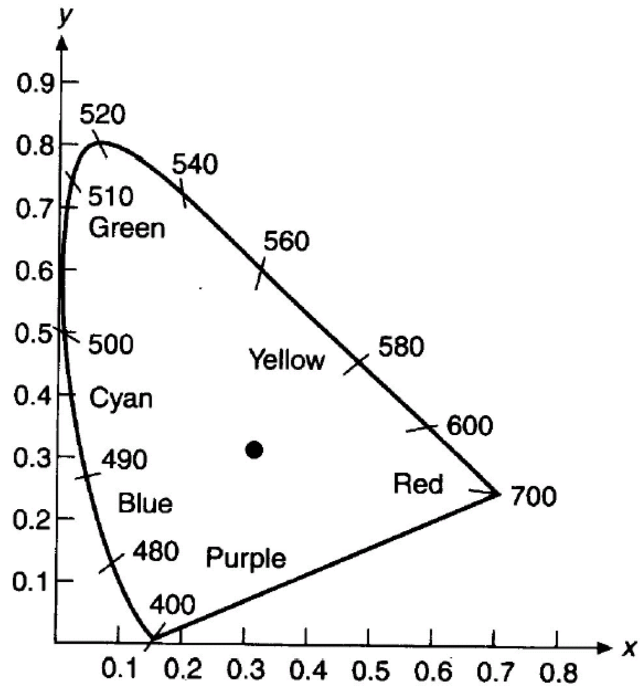
RGB to XYZ

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 2.36460 & -0.51515 & 0.00520 \\ -0.89653 & 1.42640 & -0.01441 \\ -0.46807 & 0.08875 & 1.00921 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- This is just a matrix transformation
  - we'll worry about that later

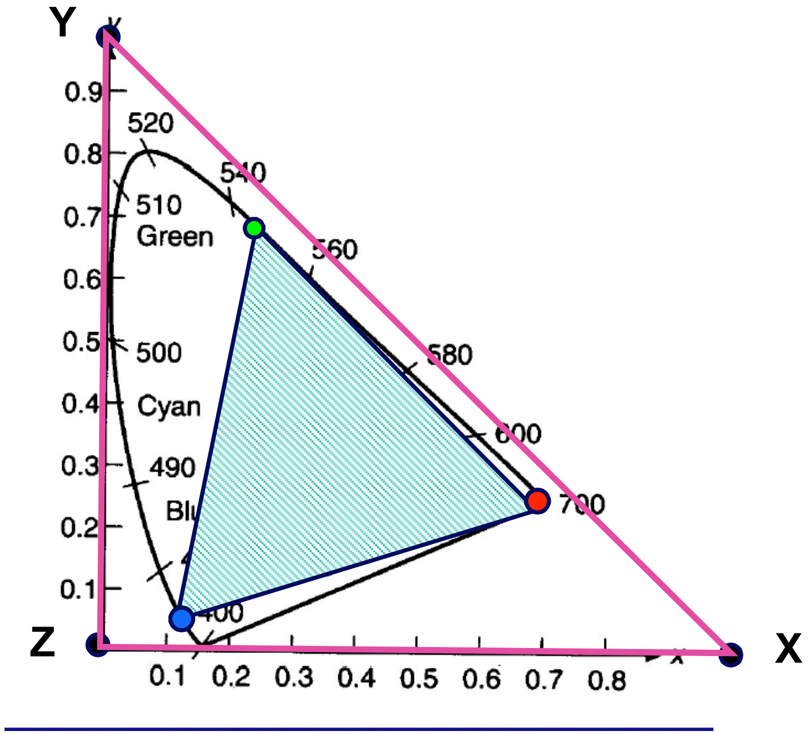
CIE Chromaticity Diagram

- Project colour space to plane X + Y + Z = 1
- Pure colours appear along the edge



RGB vs. XYZ

- RGB colour combines positive RGB coords
- Only colours in triangle can be given in RGB

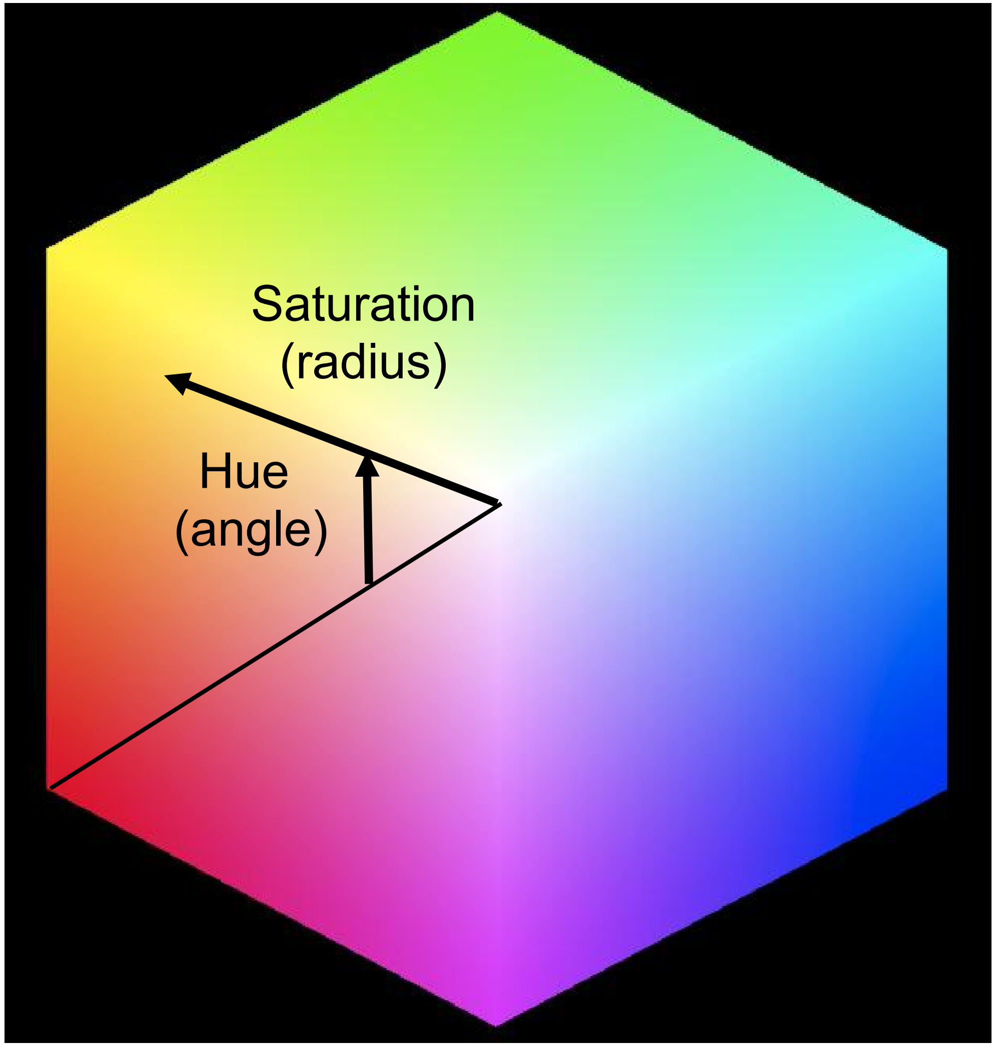


YUV Colour Space

- Early TV was a monochrome signal
  - Measured total intensity Y of light
  - Axis from black to white
- Colour TV is backward compatible
  - Y component is still transmitted
  - Components U,V were added

HSV Colour Space

- The *colour wheel*
  - H - *hue*
  - S - *saturation*
  - V - *value*
    - (or B - *brightness*)



Choosing Colours

- How do we get “yellow”?
  - start with the rainbow: R O Y G B I V
  - mix R & G to get Y
- Or look at the colour wheel
- Or just play with RGB until we get it right

Additive Colour

- These models assume light is *added*
  - Colour is the *sum* of components
  - Suitable for combining light sources
- But this isn’t the only way of doing it
  - Go back to the physics again

Colour Absorption

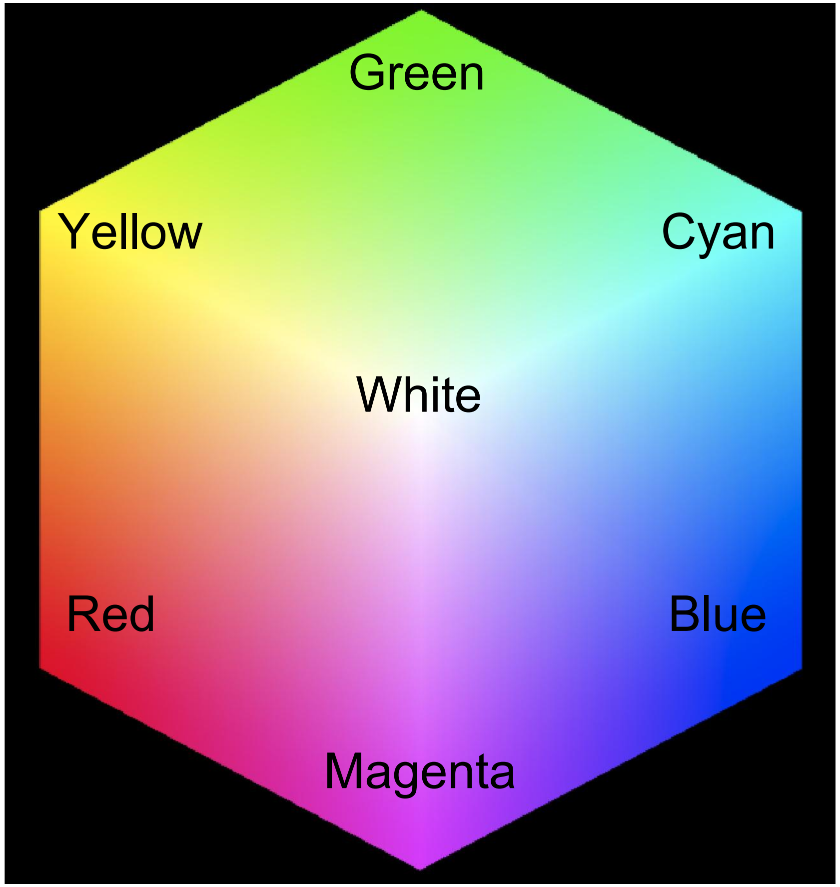
- Objects are coloured by *pigments*
  - that absorb certain colours of light
- E.g. *chlorophyll* in leaves
  - absorbs almost all red / blue light
  - but reflects green light
  - so output light is green

Subtractive Colour

- For pigments, we *subtract* colour
  - Blue + Yellow = Green
    - *blue* reflects some green as well
    - so does *yellow*
    - *green* is only colour reflected by both
- We learned this colour model in school

CMYK model

- Printers use *CMYK*
  - *Cyan* removes red
  - *Magenta* removes green
  - *Yellow* removes blue
  - *Black* removes everything



Colour Lighting

- A coloured light shines on a coloured surface
- The surface subtracts colour from the light
- Only reflects wavelengths common to *both*
- This is called *colour modulation*
- We assume only 3 wavelengths possible: RGB

Colour Modulation

- Light source is given as (R, G, B)
- Surface colour is given as (r, g, b)
- Output colour is (R * r, G * g, B * b)

Input Devices

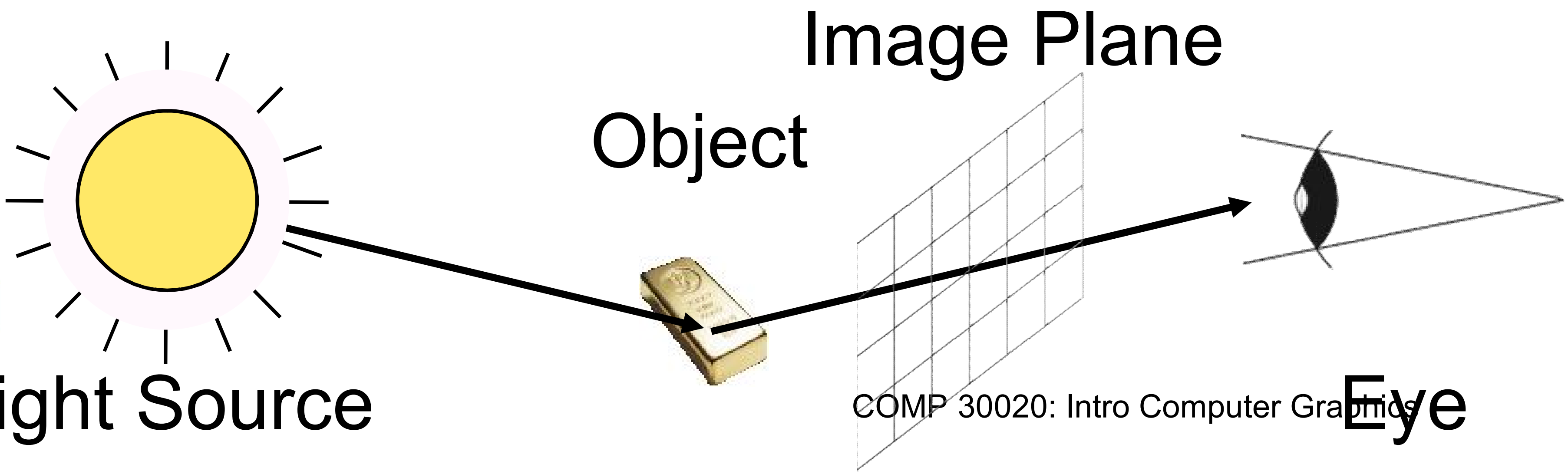
- Generically called *sensors*
  - Human Eye
  - Film Cameras
  - Digital Cameras / Scanners (CCDs)
  - Sensors for non-visible light

Sensors

- Infrared imaging
- Radar
- Lidar
- X-ray imaging
- Satellite imaging

Theory of Images

- Back to Alberti's Window:
- Measure light passing through image plane
  - At a single point or for entire square?



Ideal Image

- We want to measure light *everywhere*
  - for each point on retina
  - parameterize retina with x, y
- So light *intensity* (brightness) is a function
  - $I(x,y)$
- Intensity is a *continuous* function

Detecting Light

- Photons are *energetic*
  - they carry packets (*quanta*) of energy
  - transferred to something else on impact
- Some chemicals are *light-sensitive*
  - good at absorbing light
  - basis of *all* sensors

Sensor Construction

- Sensor cells have light-sensitive molecules
  - collect energy from photons
  - *many* molecules / cell
  - measure *total* intensity over cell area
  - the *integral* of the intensity over the cell

Film Photography

- Light-sensitive *silver iodide* crystals
  - Uniformly small in size (i.e. cell size)
  - Turn dark when hit by photons
    - a *negative* image
  - Treated (*developed*) with chemicals
    - to *fix* the image (*prevent* more changes)
  - Second picture reverses negative image

Digital Photography

- Most digital cameras use CCDs:
  - *charge-coupled devices*
  - one capacitor per pixel stores energy
  - releases it all at once when triggered
  - transferred to standard memory

Infrared Photography

- *Infrared* is just light we *can’t* see
    - our eyes have the wrong chemicals
    - can build sensors with the right ones
- Same is true for *microwave*, *ultraviolet*, X-rays, &c.

Radar / Lidar

- Still the same idea:
  - radar uses microwaves
  - lidar uses visible light
- But they send the light out first
  - i.e. a big spotlight + a sensor

Multi-Spectral Sensors

- Measure different wavelengths separately
  - the eye (R, G, B)
  - cameras (R, G, B tinted silver iodide)
  - TV cameras (R, G, B phosphors)
  - different microwave wavelengths (radar)

Output Devices

- Fall into three basic categories:
  - *Reflective*, *subtractive* colour (printing)
  - *Emissive*, *additive* colour (CRTs, LEDs)
  - *Polarizing*, *additive* colour (LCDs)

Colour Printing

- The *subtractive* colour model
  - add pigments to white paper
  - subtract light from reflection
  - capable of *very* high resolution
  - may require *many* pigments

Colour TV

- A TV is a CRT (*cathode-ray tube*)
- Electron gun spits out electrons
- Electrons hit inside of front glass
- Electron energy absorbed by coloured *phosphors*
- Phosphors *re-emit* light slowly
  - hence the way TVs fade out when turned off

Raster Scan

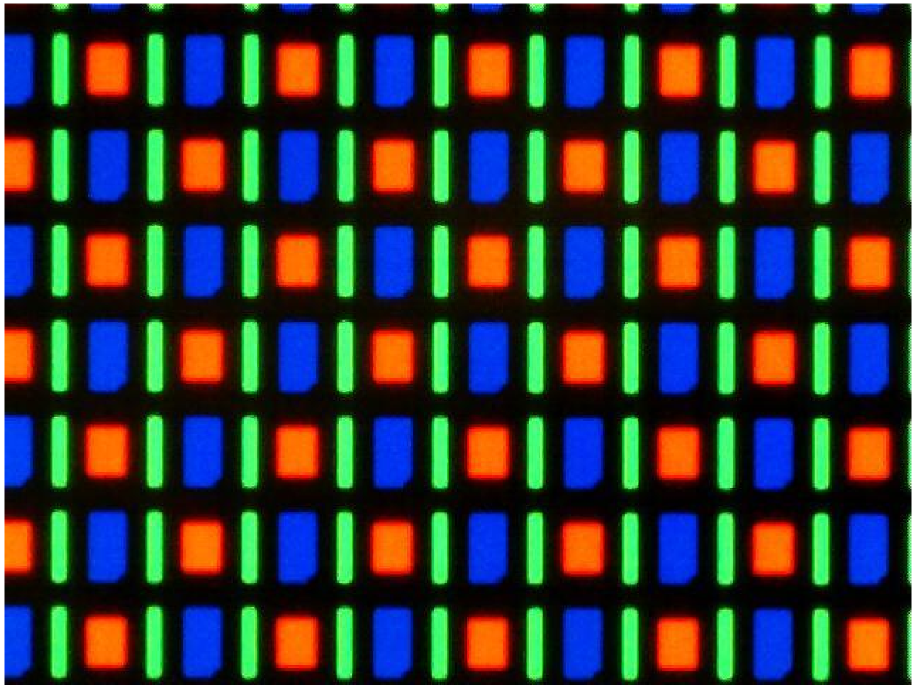
- Electron beam is *deflected* in x, y
  - beam *scans* from left to right
  - then returns to left, but further down
  - returns to top when done
  - *phosphors* glow *unevenly*
  - which is why 60 Hz+ is necessary
  - (*raster* is from Latin word for *rake*)

LCD Panels

- *Liquid Crystal Diode* panels
  - Backlight is *polarized* light
  - Crystals in front *polarize* with electricity
    - block the light from passing through
    - we control *how much* light electronically
  - No raster scan needed

OLED Displays

- *Most Common in new phones , Organic Light Emitted Diodes*
- *Only possible with advanced in LED technology ,*
- *Blue diode: 2014 Nobel Prize*
- OLED are cheaper to manufacture than typical LED’s.
- Directly produce light as can be seen in this image



Nexus One smartphone using the RGBG system of the PenTile matrix family
(Image from Wikipedia)

Efficiency per Watt (why LED are used)

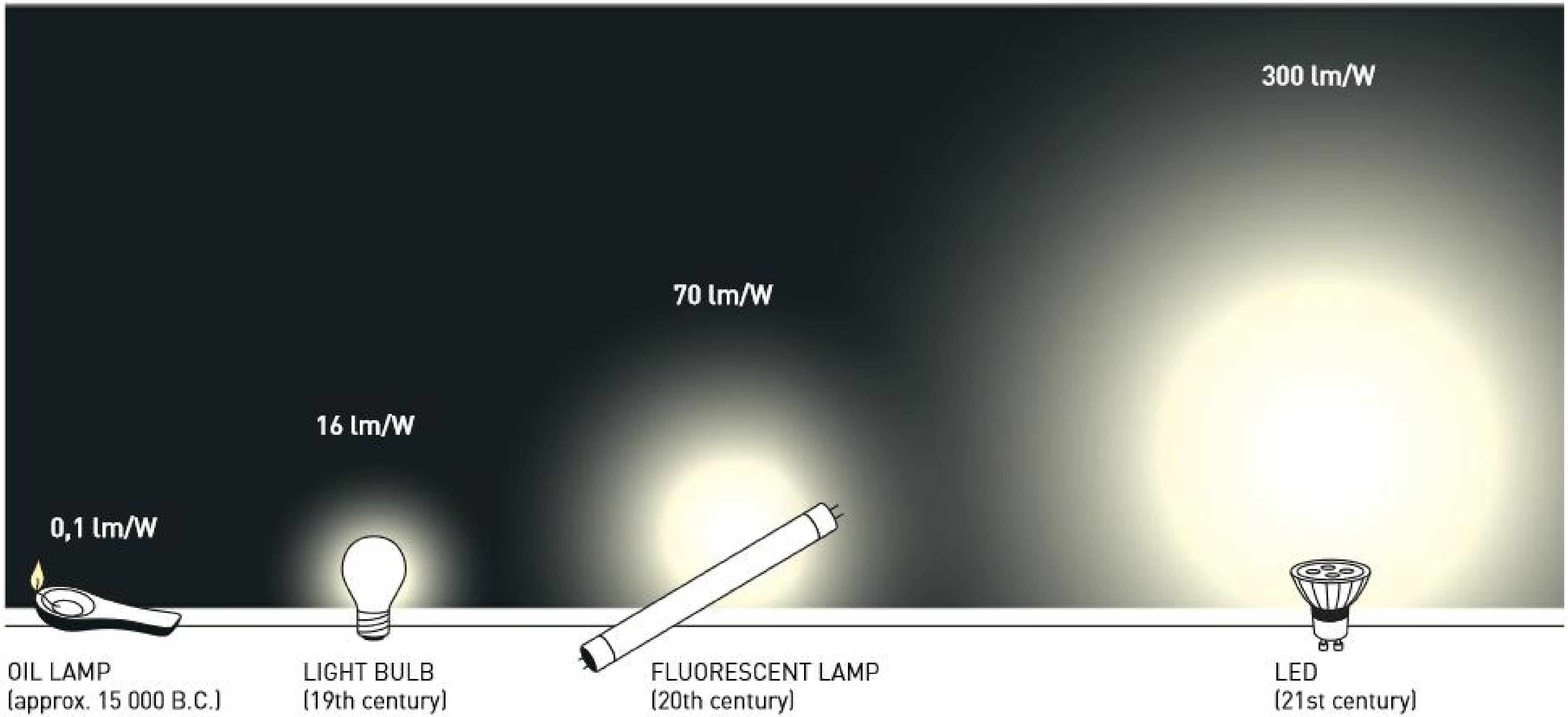


Image taken from Nobel Prize 2014 booklet

Colour Calibration

- The *gamut* of a device is the set of colours it can display
- Different devices have different gamuts
- Similarly, different sensors are sensitive to different frequencies
- Must *convert* colours between devices
- Requires *calibrating* colour of a device