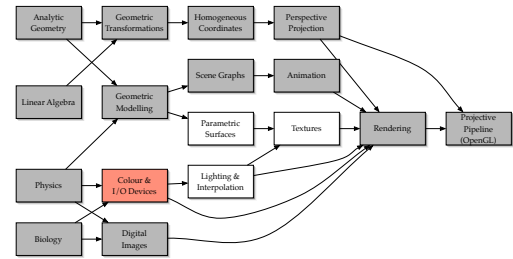


Colour & I/O Devices

COMP 3003 Autumn 2005

Where we Are

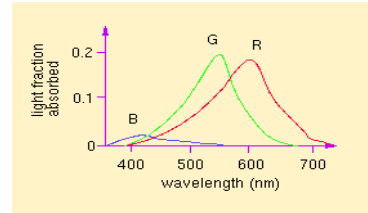


Today's Topics

- Colour Spaces
- Colour Models
- Sensors & Input Devices
- Output Devices

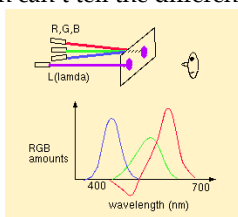
Cones & Colour

- Three types of cones
- Respond to different wavelengths:



Tri-stimulus Theory

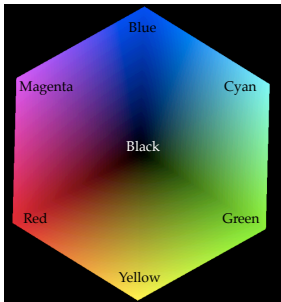
- Mix R, G & B to get any colour desired
- Human can't tell the difference



RGB Coordinates

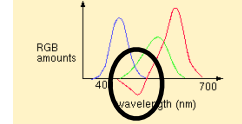
- Specify colours as a triple (R, G, B)
 - a *vector* representation of a colour
- We can define a *colour space*
 - the set of all possible RGB colours
- And we can change coordinate systems!

RGB Colour Cube



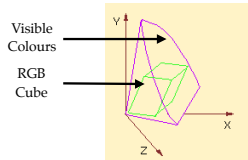
RGB Constraints

- 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



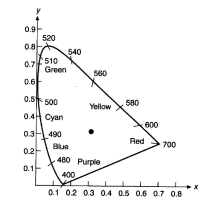
RGB to XYZ

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

- This is just a matrix transformation

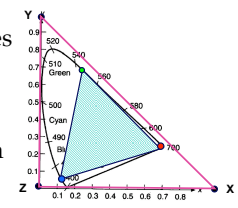
CIE Chromaticity Diagram

- 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

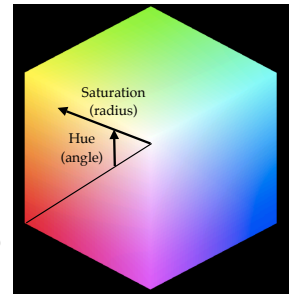


YUV Colour Space

- 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

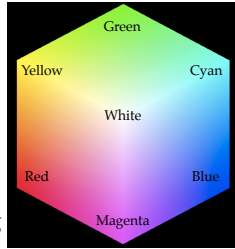
- Objects are coloured by *pigments*
 - that absorb certain colours of light
- E.g. *chlorophyll* in leaves
 - absorbs almost all red / blue light
 - but reflects green light
 - so output light is green

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 in OpenGL

- If lighting is turned off:
 - `glColor()` specifies colour directly
 - applied to each vertex separately
 - OpenGL state carries colour over
- If lighting is on, it's more complex

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 $(R * r, G * g, B * b)$
- Specify colours with `glMaterialv()`

`glMaterialv()`

- Defines *material properties* of surface
- `glMaterialfv(face, pname, param)`
- *face* specifies which *side* of surface
- *pname* specifies the property
- *param* is a colour in RGB space

face parameter

- Front side is defined by normal vector
- Only front side is normally lit (cheaper)
- Use `glLightModel()` to change this
- `GL_FRONT` applies property to front
- `GL_BACK` applies property to back
- `GL_FRONT_AND_BACK`: both sides

pname parameter

- Specifies which property is affected
 - GL_AMBIENT, GL_DIFFUSE, GL_AMBIENT_AND_DIFFUSE, GL_SPECULAR, GL_EMISSION
- To turn a property off, set to black (0,0,0)

Input Devices

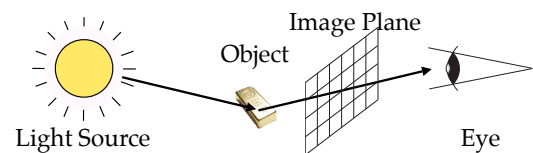
- Generically called *sensors*
 - Human Eye
 - Film Cameras
 - Digital Cameras / Scanners (CCDs)
 - Sensors for non-visible light

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
- Hence our anti-aliasing problems

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

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

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