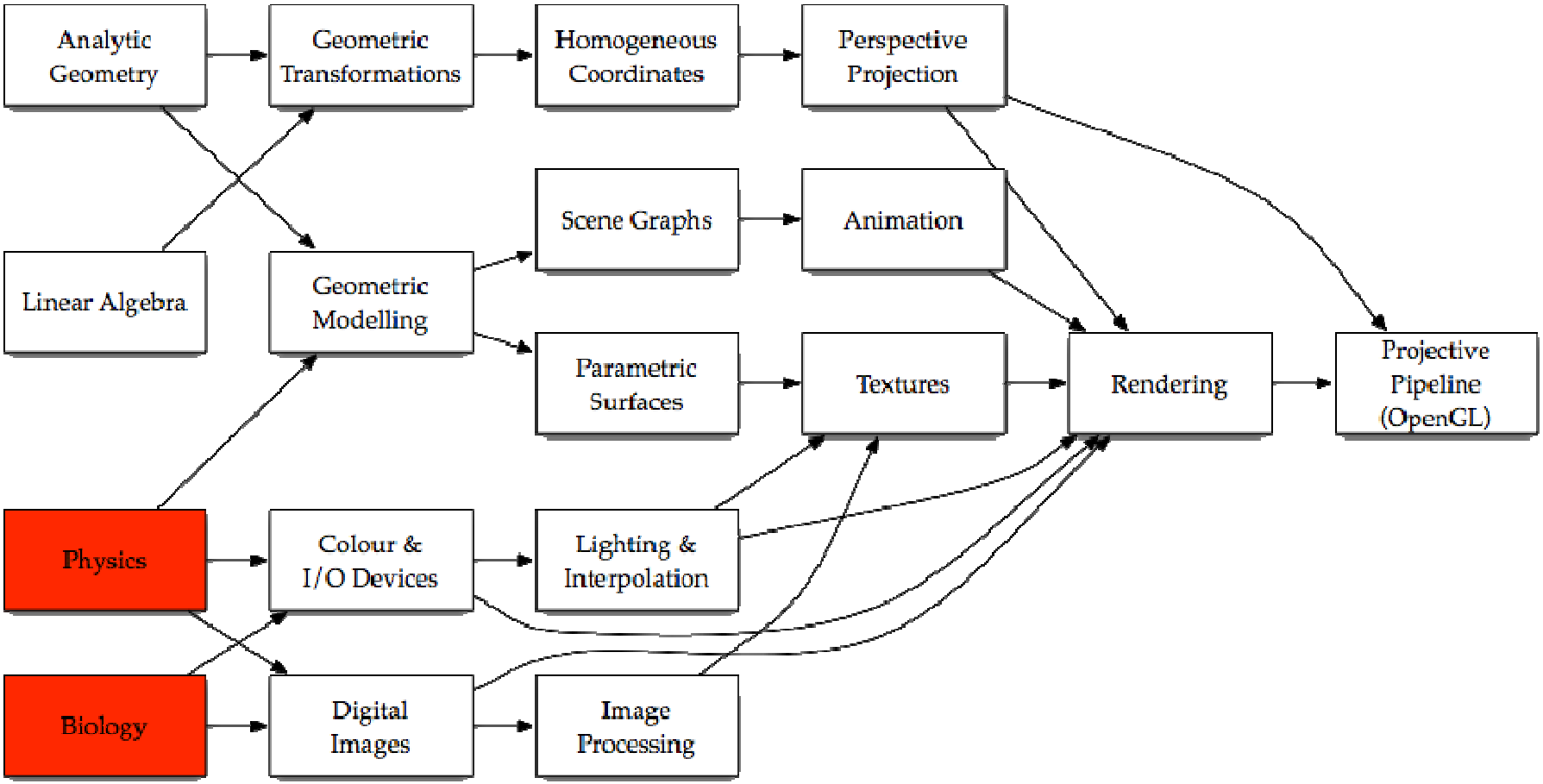
Physics & Biology of Vision

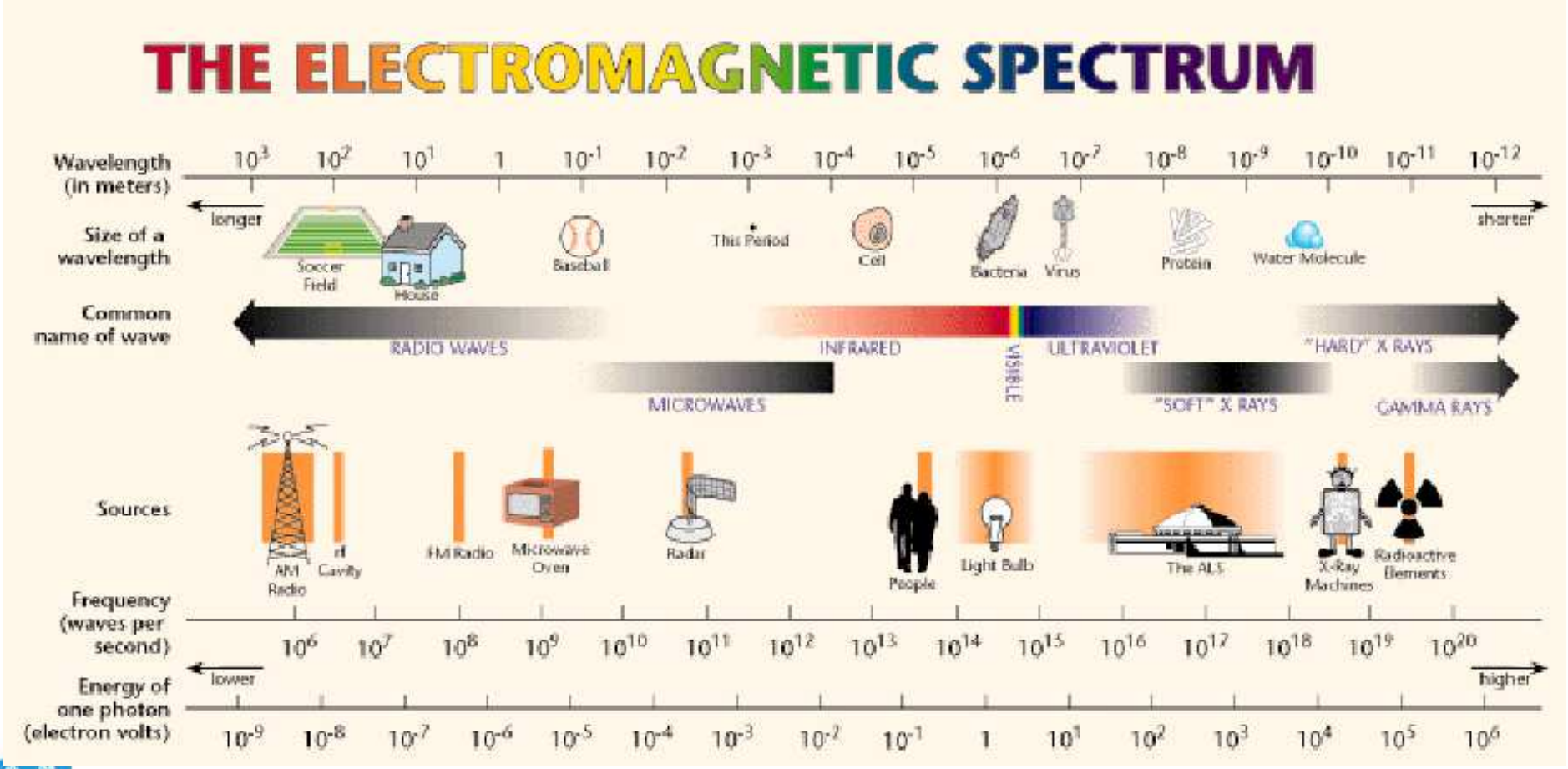
Block Diagram



Physics of Light

- What is Light?
- What is Colour?
- What is White Light?
- How does Light behave?

What is Light?

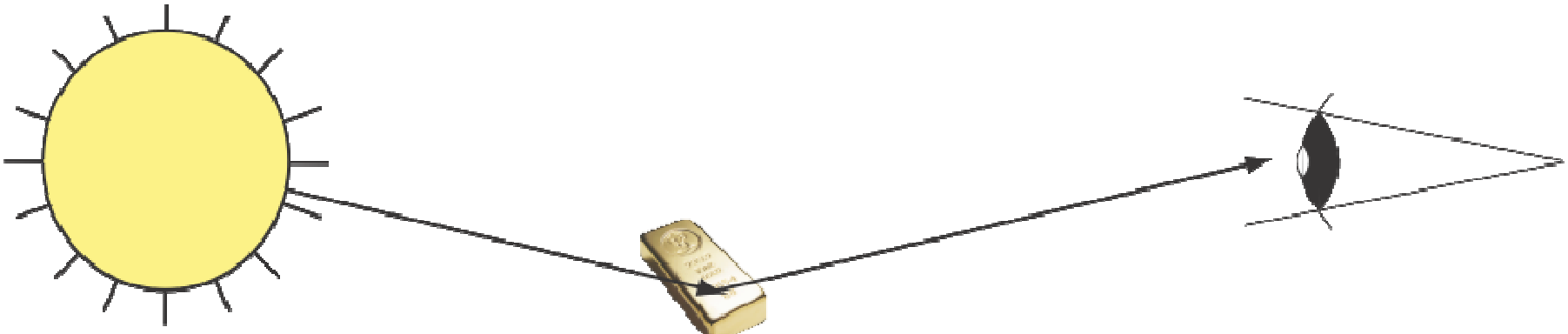


Waves or Particles?

- Major argument in science:
  - is light particles or waves?
- Actually, it's both
  - but we will mostly treat it as particles
  - sometimes we will treat it as waves

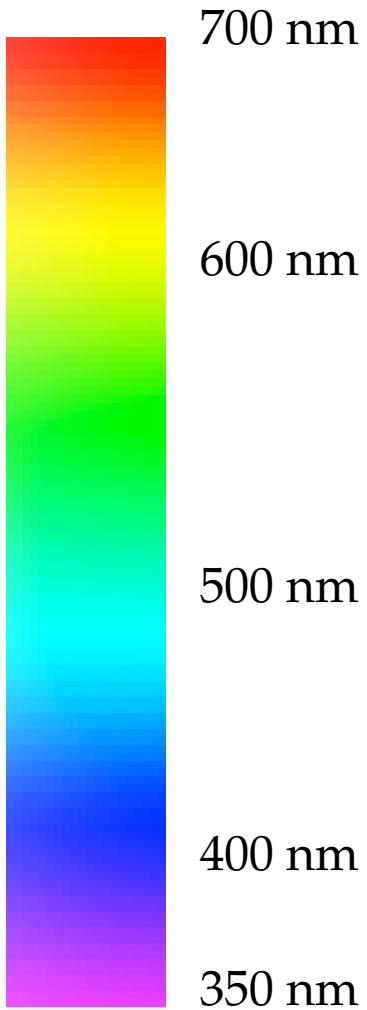
Particles & Rays

- Photons are emitted by a source
- Travel at 2.99 x 1011 m/s
- Apply Newtonian mechanics
- We can model them with rays



Wavelength & Colour

- Photons carry energy with them
  - Proportional to “wavelength”
  - “Wavelength” is “colour”
- Our eyes can see:
  - wavelengths 350 - 700 nm
  - all the colours of the rainbow



Spectral Distribution

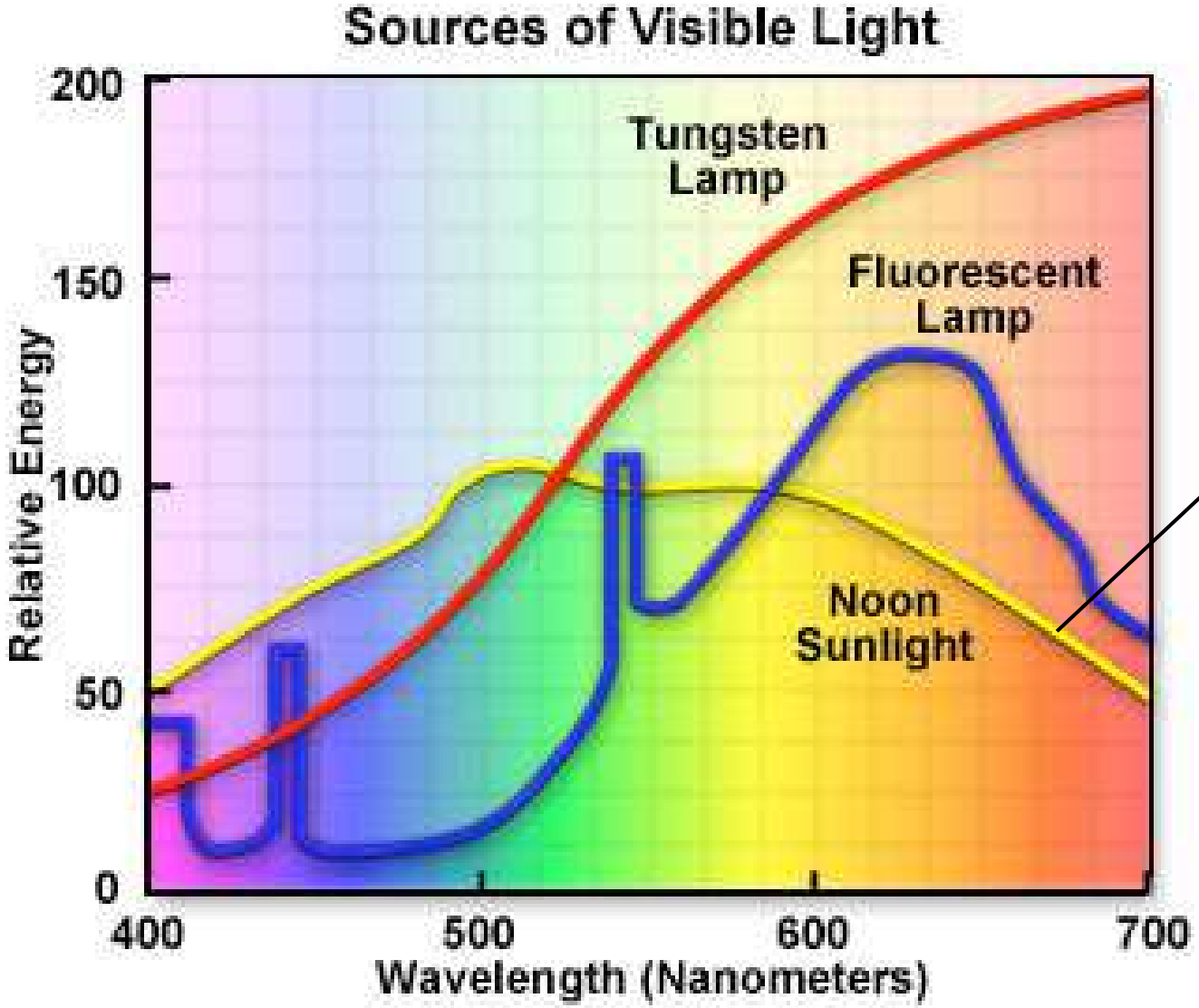


Figure 2

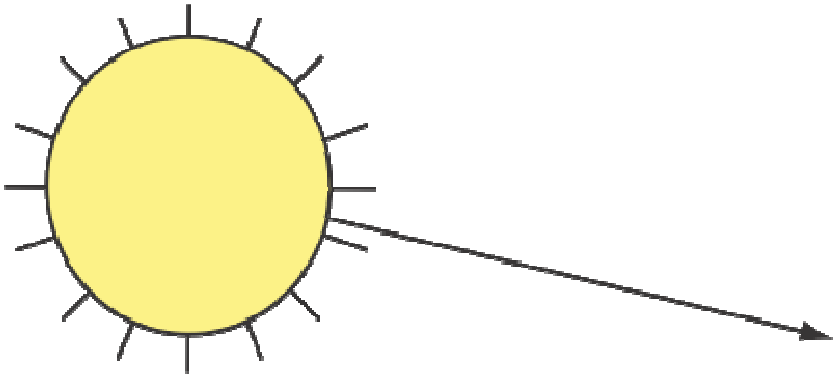
"White" light

Physics of Light

- Light is:
  - emitted
  - reflected
  - absorbed
  - Also but not covered in this course
    - refracted
    - diffracted

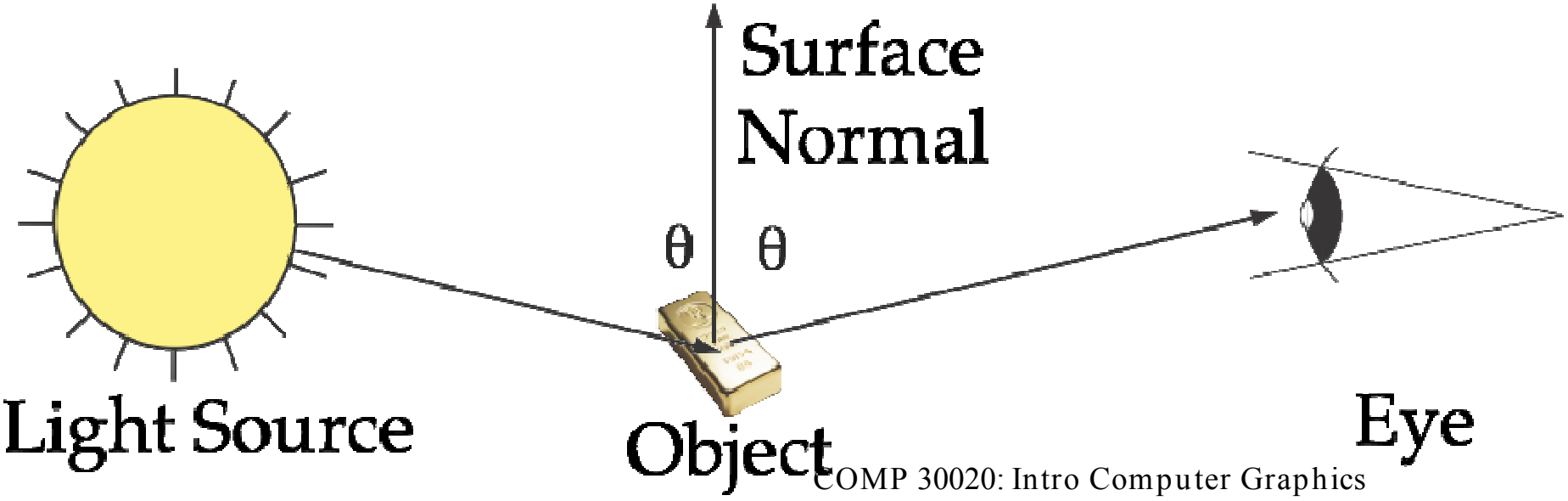
Emission

- Atoms emit photons to lose energy
- Wavelength depends on which atom



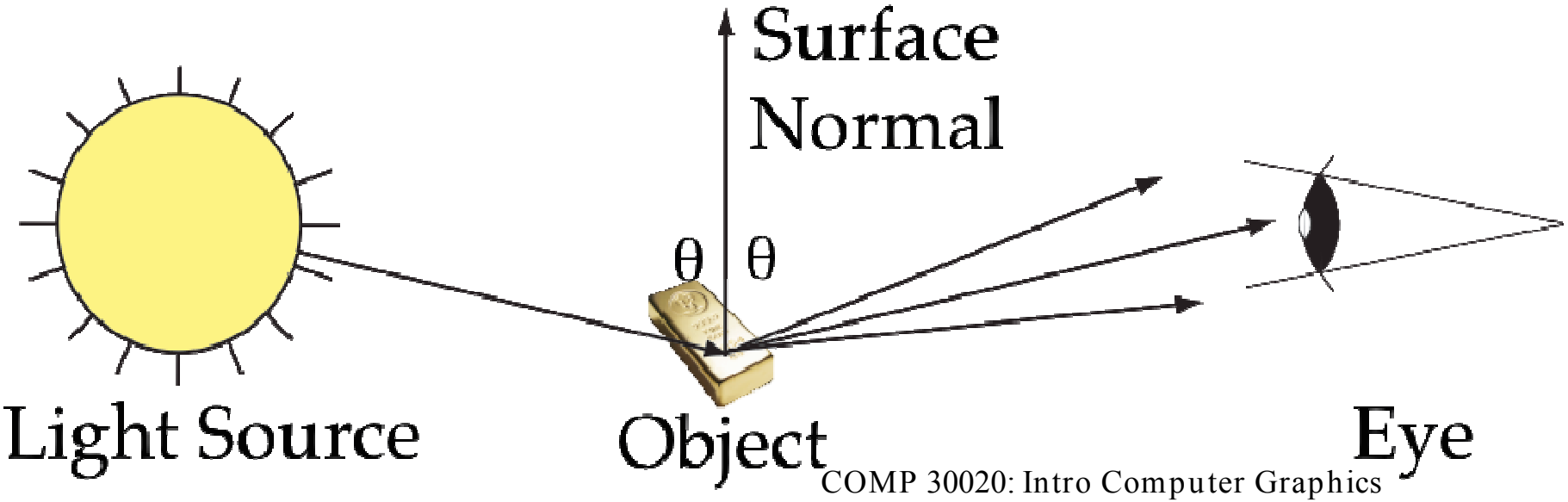
Reflection

- A photon strikes a surface
- By Newtonian mechanics, it bounces
- Angle of incidence = angle of reflection



More Reflection

- Few surfaces are entirely smooth
- Reflection angle is somewhat random
- We'll come back to this



Absorption

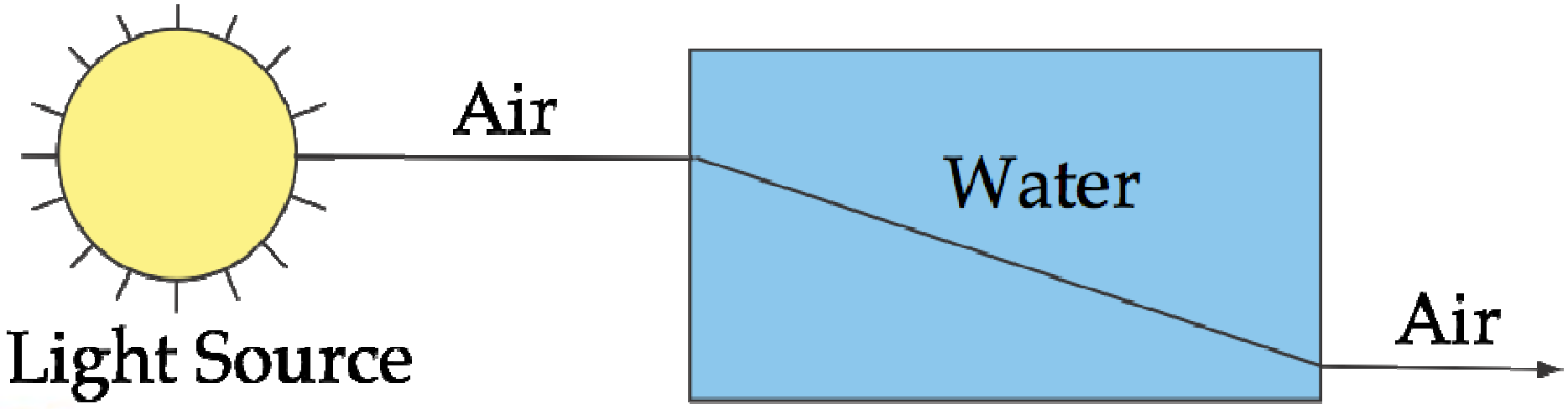
- Photons can be absorbed by atoms
- Energy is transferred to atom
- Basis of vision, photosynthesis, warmth

Absorption & Colour

- Why is this buttercup yellow?
- It reflects mostly yellow photons

Refraction

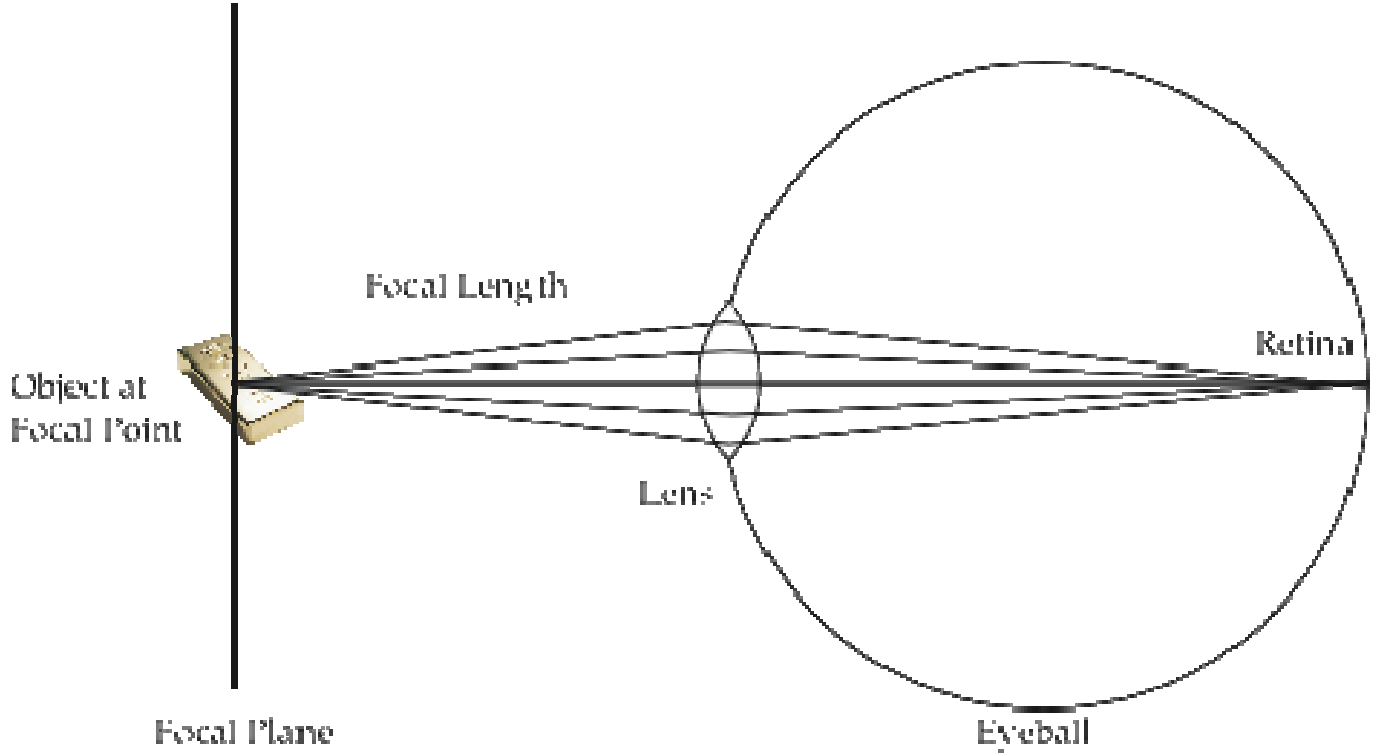
- Light bends when it changes media
- How much depends on the material
- And on the wavelength of the light



An Example

- Note the reflections & refractions

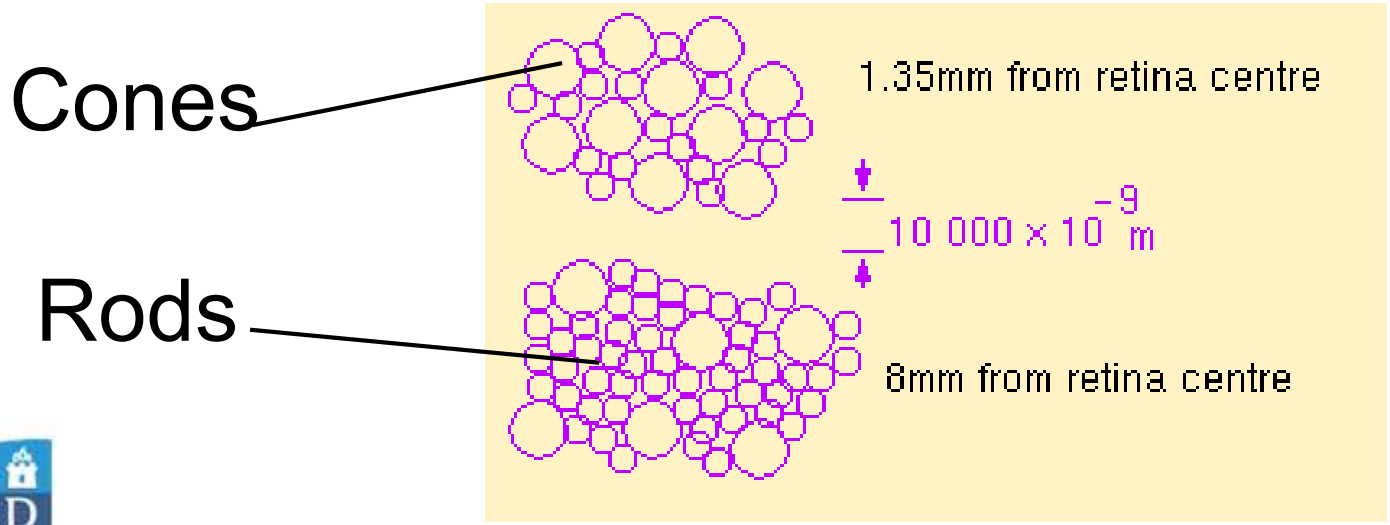
Human Vision



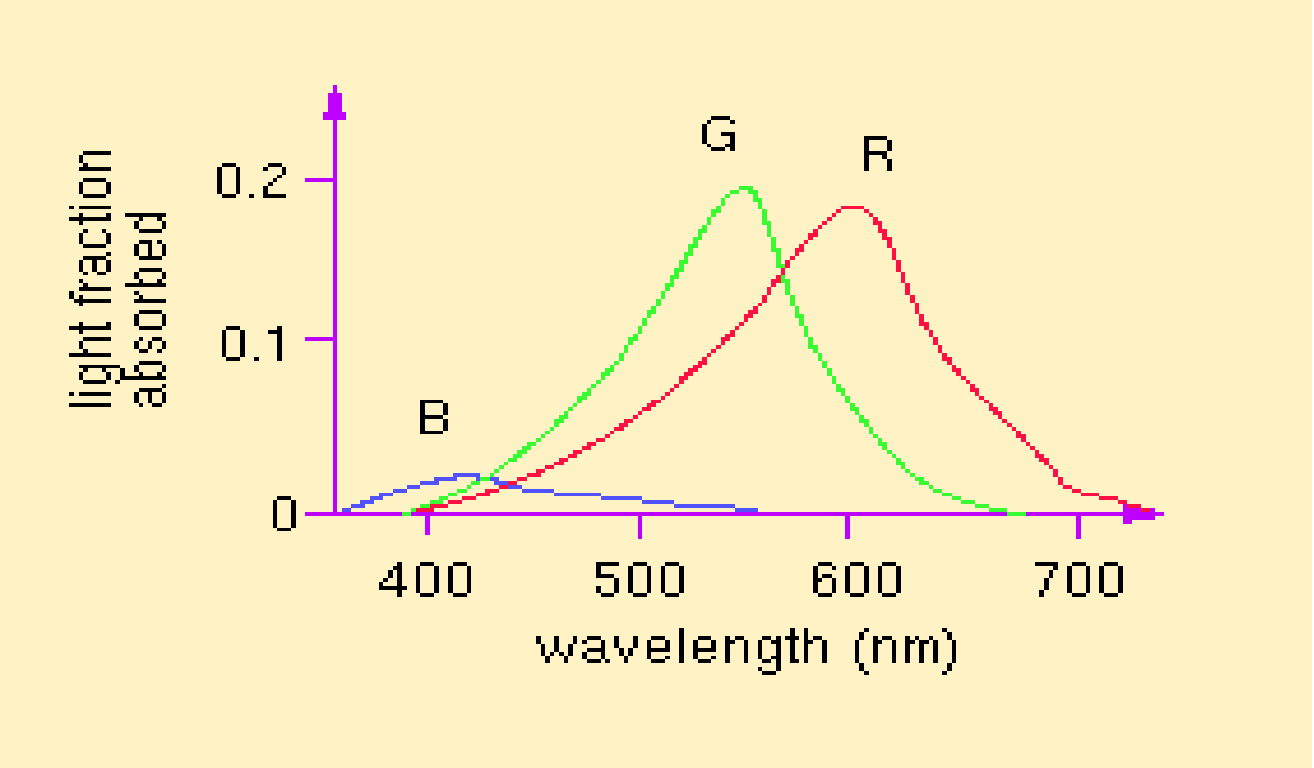
- Lens focusses light on retina
- Objects in focal plane are seen clearly

The Retina

- A patchwork of light-sensitive cells
  - Rods: low light conditions (B/W)
  - Cones: ordinary conditions (colour)

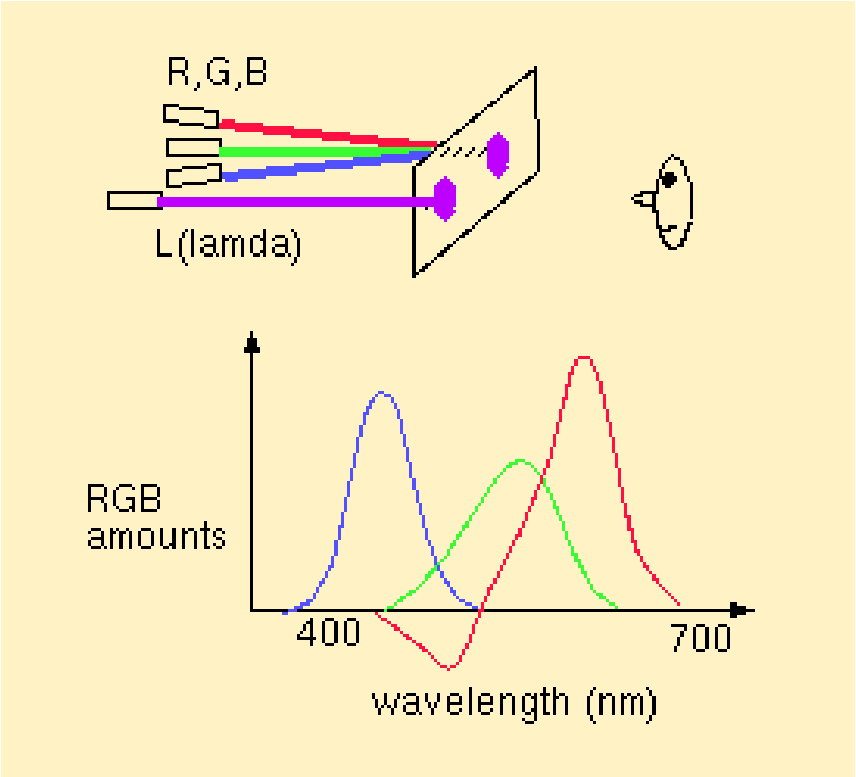


Cones & Colour



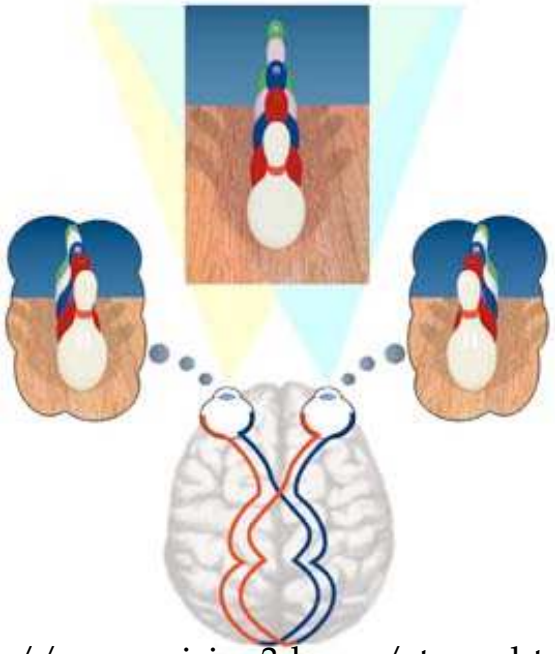
- Three types of cones
- Respond to different wavelengths:

Tri-stimulus Theory



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

Stereoscopic Vision



http://www.vision3d.com/stereo.html

- Two images at slightly different places
- Allow the brain to perceive depth
- The Brian also uses other tricks such as Focus and motion parallax

Limitations of the Eye

- The eye sees images at 24 Hz (+/-)
- Therefore, we render at 30 fps or better
  - On CRTs, double that to at least 60
  - We'll see why later
- This is why < 30 fps looks jerky

Rendering Images

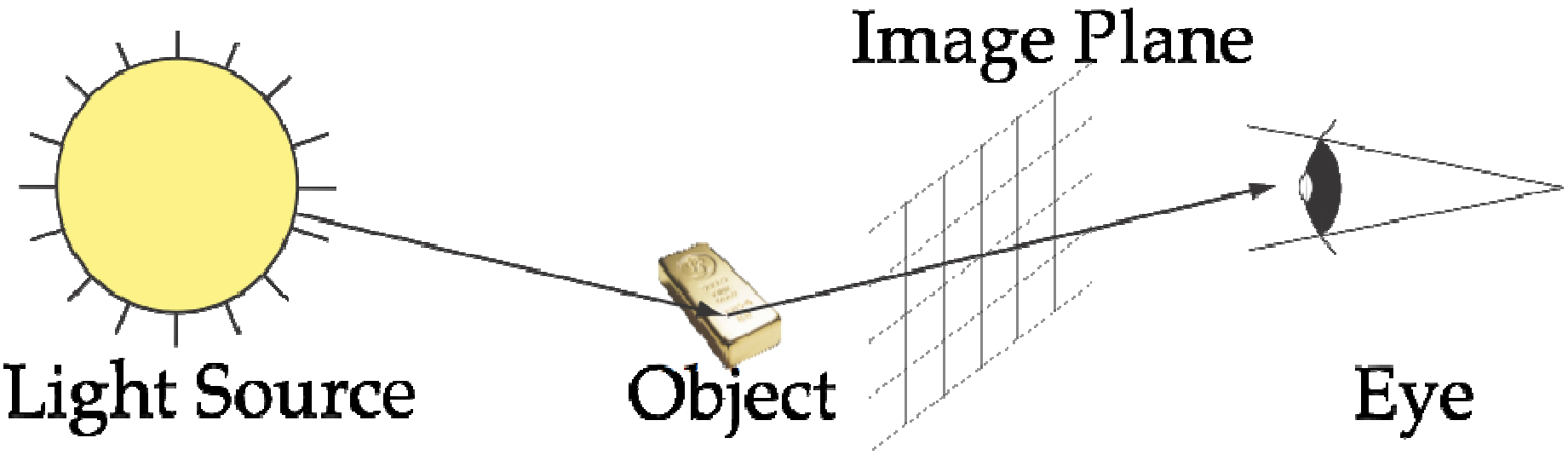
- How can we fake reality?
  - make the eye think something's there
- Goes back to the Renaissance
  - Brunelleschi, Alberti, da Vinci, &c.
- Apply mathematics to the world

Basic Rendering

- Draw coloured image
  - Renaissance: copy what you see
  - Now: invent what you see
- Put in front of the eyes
- Look at it

Alberti's Window

- Place glass sheet in front of the eye
- Draw what you see on the glass sheet
- Then take the sheet with you



Ideal Image

- We want to measure light everywhere
  - at each point (x,y) on retina
- So light intensity (brightness) is a function
  - I(x,y): intensity at retina (or A.'s window)
- Intensity is a continuous function
- Sadly, computers are discrete machines

Pixel Image

- Instead of a function, use an array

Digital Images

- A digital image is an array of intensities
- Assume image is 8-bit greyscale
  - each pixel is 0 ... 255 (Y in colour space)
- Each value is a sample point
  - $p_{ij} = I\left(x_i, y_j\right)$
  - actually an integral

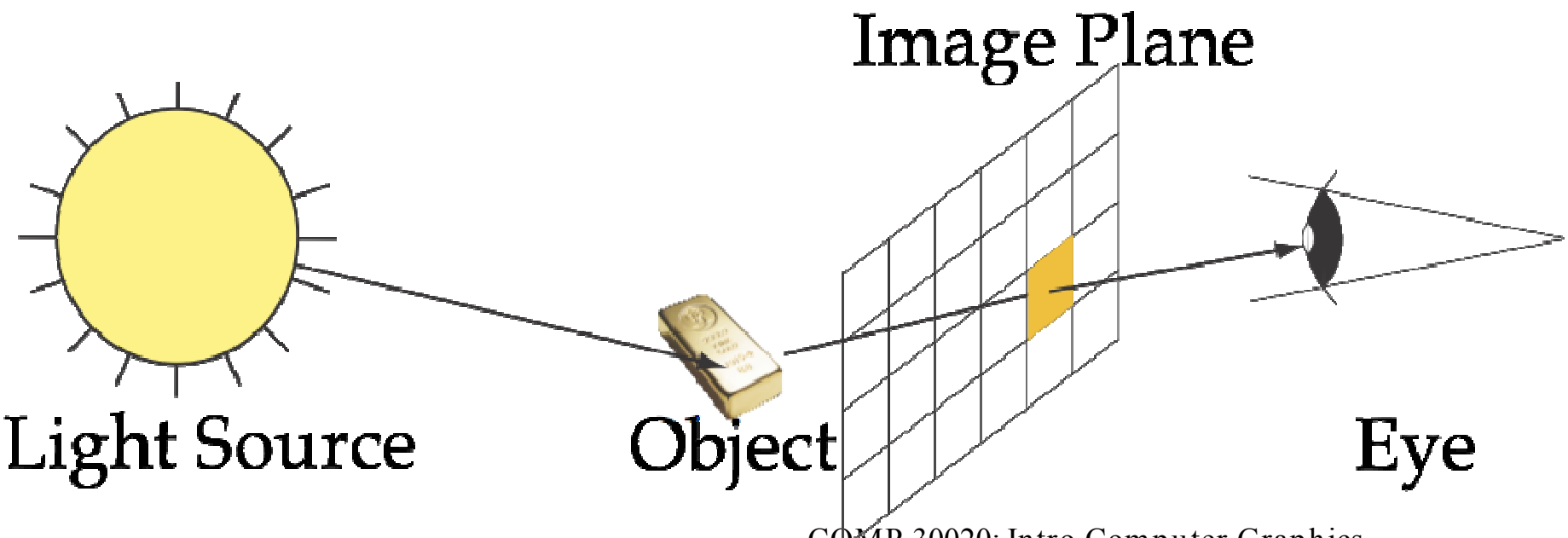
$$p_{ij} = \int_{x_i - \frac{1}{2}\Delta x}^{x_i + \frac{1}{2}\Delta x} \int_{y_j - \frac{1}{2}\Delta y}^{y_j + \frac{1}{2}\Delta y} I(x,y)\, dy\, dx$$

Rendering Images

- Three basic ways of doing this:
  - raytracing (Renderman /movies)
  - projective rendering (OpenGL)
  - radiosity (architecture)
- There are others such as Image based rendering

Raytracing

- For each pixel
  - Trace a ray from the eye
  - Compute colour of object it hits



What We Need

- Geometric descriptions of lines & planes
  - and other things
- Geometric descriptions of locations
- Geometric definitions of directions
- i.e. linear algebra