University of British Columbia
CPSC 314 Computer Graphics
Jan-Apr 2010

Tamara Munzner

Viewing/Projection V, Vision/Color

Week 5, Mon Feb 1

http://www.ugrad.cs.ubc.ca/~cs314/Vjan2010

Events this week

Resume Editing Drop-In Session
Date: Mon., Feb 1
Time: 11 am – 2 pm
Location: Rm 255, ICICS/CS

EADS Info Session
Date: Mon., Feb 1
Time: 3:30 – 5:30 pm
Location: CEME 1202

Job Interview Practice Session (for non-coop students)
Date: Tues., Feb 2
Time: 11 am – 1 pm
Location: Rm 206, ICICS/CS

RIM Info Session
Date: Thurs., Feb 4
Time: 5:30 – 7 pm
Location: DMP 110

Events next week

Finding a Summer Job or Internship Info Session
Date: Wed., Feb 10
Time: 12 pm
Location: X836

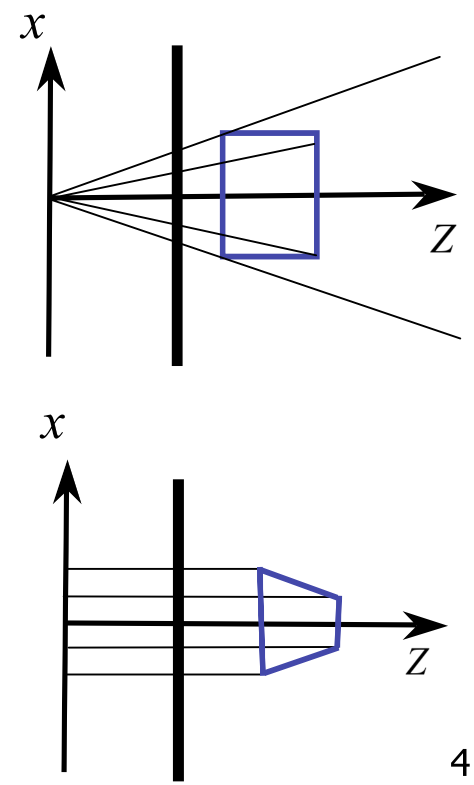
Masters of Digital Media Program Info Session
Date: Thurs., Feb 11
Time: 12:30 – 1:30 pm
Location: DMP 201

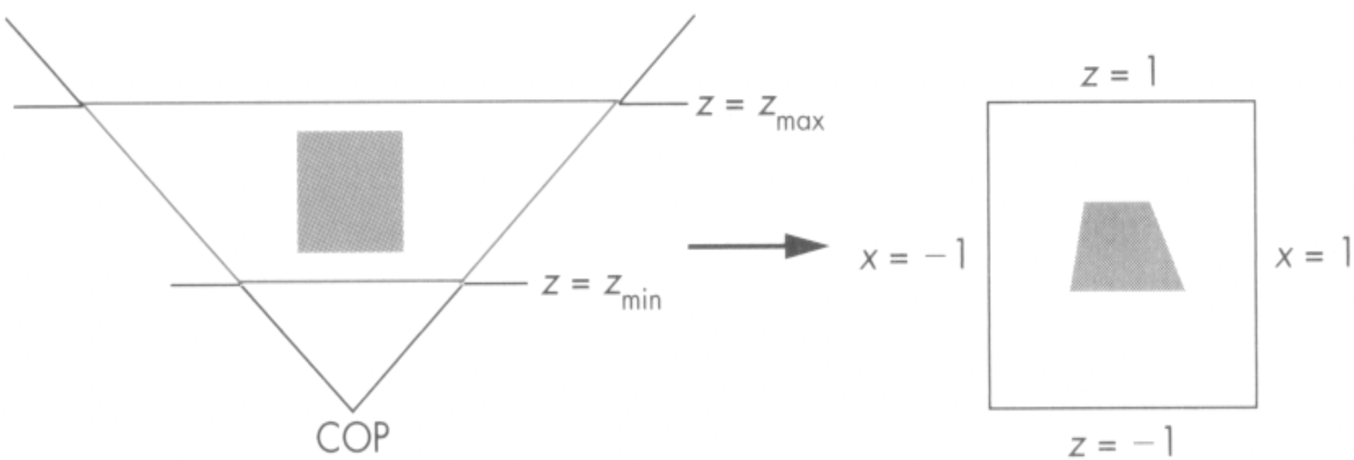
Project 1 Grading News

- don’t forget to show up 5 min before your slot
  - see news item on top of course page for signup sheet scan
- if you have not signed up or need to change your time, contact shailen AT cs.ubc.ca
  - you will lose marks if we have to hunt you down!

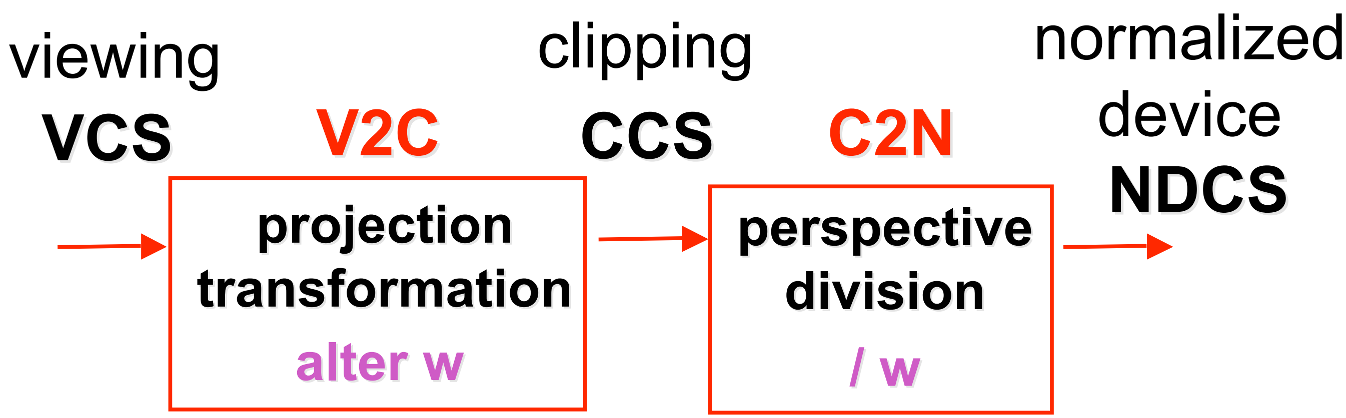
Review: Perspective Warp/Predistortion

- perspective viewing frustum predistorted to cube
- orthographic rendering of warped objects in cube produces same image as perspective rendering of original frustum





Review: Separate Warp and Homogenize

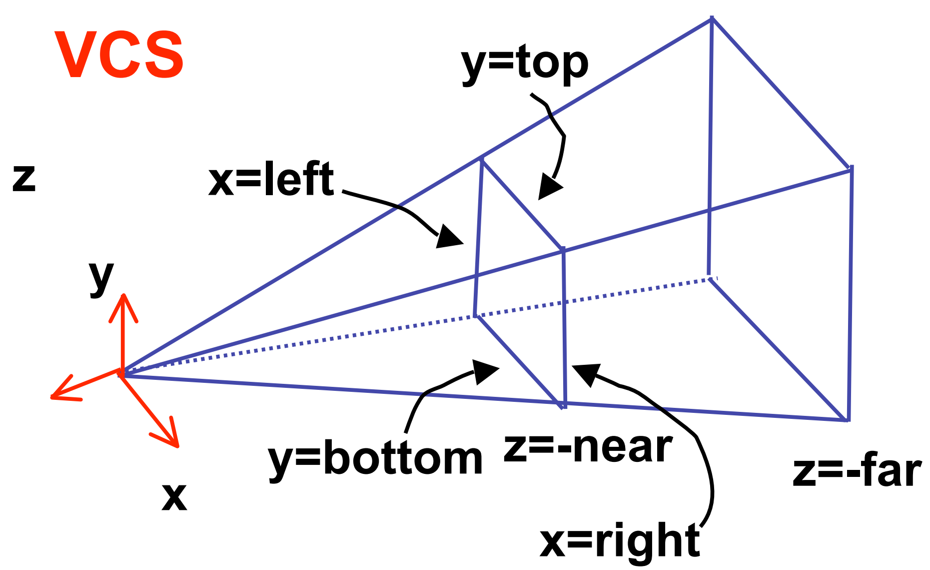


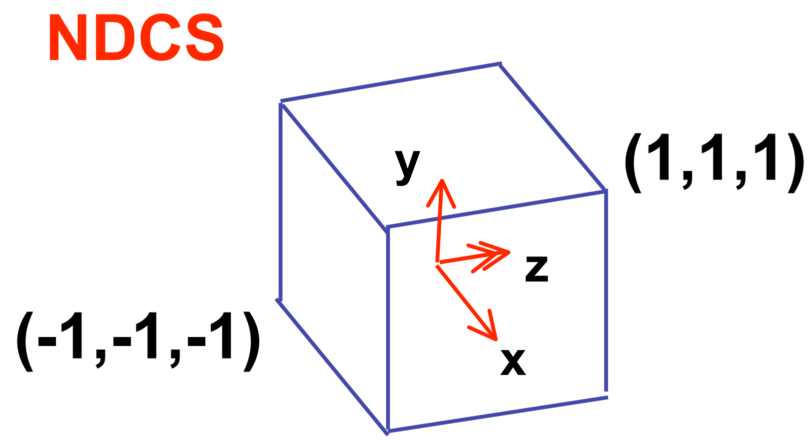
- warp requires only standard matrix multiply
  - distort such that orthographic projection of distorted objects shows desired perspective projection
    - w is changed
  - clip after warp, before divide
  - division by w: homogenization

Review: Perspective to NDCS Derivation

- shear
- scale
- projection-normalization

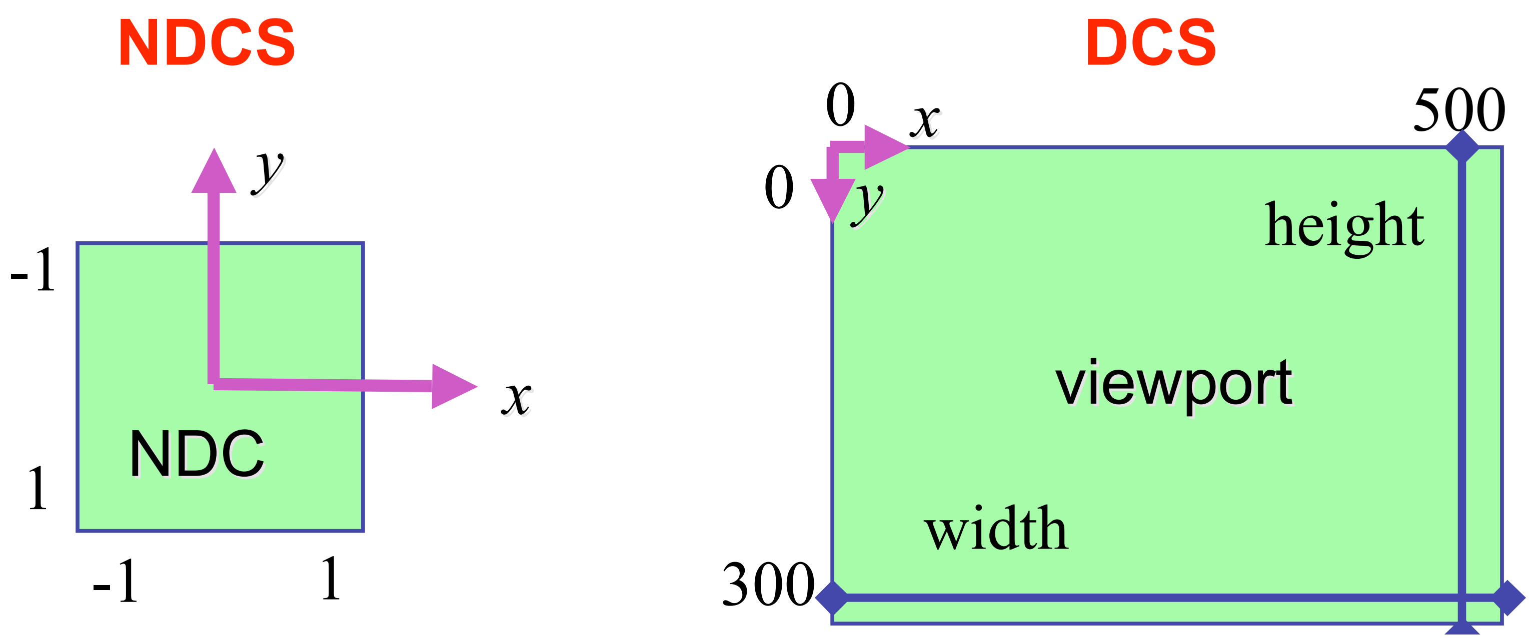
$$\begin{bmatrix} \frac{2n}{r-l} & 0 & \frac{r+l}{r-l} & 0 \\ 0 & \frac{2n}{t-b} & \frac{t+b}{t-b} & 0 \\ 0 & 0 & \frac{-(f+n)}{f-n} & \frac{-2fn}{f-n} \\ 0 & 0 & -1 & 0 \end{bmatrix}$$





Review: N2D Transformation

$$\begin{bmatrix} x_D \\ y_D \\ z_D \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & \frac{width}{2} - \frac{1}{2} \\ 0 & 1 & 0 & \frac{height}{2} - \frac{1}{2} \\ 0 & 0 & 1 & \frac{depth}{2} \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \frac{width}{2} & 0 & 0 & 0 \\ 0 & \frac{height}{2} & 0 & 0 \\ 0 & 0 & \frac{depth}{2} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_N \\ y_N \\ z_N \\ 1 \end{bmatrix} = \begin{bmatrix} \frac{width(x_N + 1) - 1}{2} \\ \frac{height(-y_N + 1) - 1}{2} \\ \frac{depth(z_N + 1)}{2} \\ 1 \end{bmatrix}$$



Review: Projective Rendering Pipeline

glVertex3f(x,y,z)

object **OCS** → **O2W** → **modeling transformation** (glTranslatef(x,y,z), glRotatef(a,x,y,z), ...)

world **WCS** → **W2V** → **viewing transformation** (gluLookAt(...))

viewing **VCS** → **V2C** alter w → **projection transformation** (glFrustum(...))

clipping **CCS** → **C2N** / w → **perspective division**

normalized device **NDCS** → **N2D** → **viewport transformation** (glutInitWindowSize(w,h), glViewport(x,y,a,b))

device **DCS**

OCS - object coordinate system

WCS - world coordinate system

VCS - viewing coordinate system

CCS - clipping coordinate system

NDCS - normalized device coordinate system

DCS - device coordinate system

Perspective Example

$$\begin{bmatrix} \frac{2n}{r-l} & 0 & \frac{r+l}{r-l} & 0 \\ 0 & \frac{2n}{t-b} & \frac{t+b}{t-b} & 0 \\ 0 & 0 & \frac{-(f+n)}{f-n} & \frac{-2fn}{f-n} \\ 0 & 0 & -1 & 0 \end{bmatrix}$$

view volume

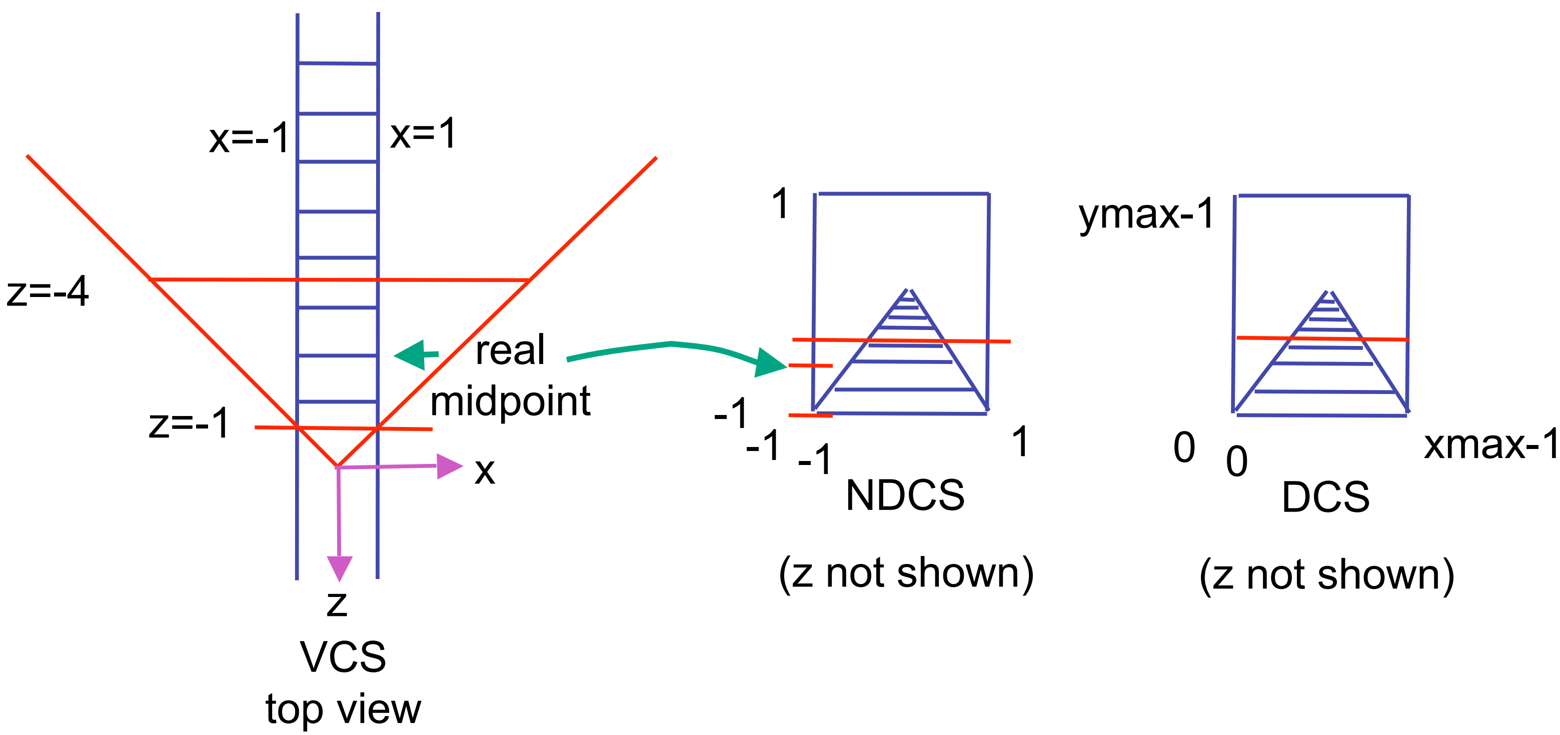
- left = -1, right = 1
- bot = -1, top = 1
- near = 1, far = 4

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -5/3 & -8/3 \\ 0 & 0 & -1 & 0 \end{bmatrix}$$

Perspective Example

tracks in VCS:
- left x=-1, y=-1
- right x=1, y=-1

view volume
- left = -1, right = 1
- bot = -1, top = 1
- near = 1, far = 4



Perspective Example

$$\begin{bmatrix} 1 \\ -1 \\ -5z_{VCS}/3-8/3 \\ -z_{VCS} \end{bmatrix} = \begin{bmatrix} 1 & & & \\ & 1 & & \\ & & -5/3 & -8/3 \\ & & -1 & \end{bmatrix} \begin{bmatrix} 1 \\ -1 \\ z_{VCS} \\ 1 \end{bmatrix}$$

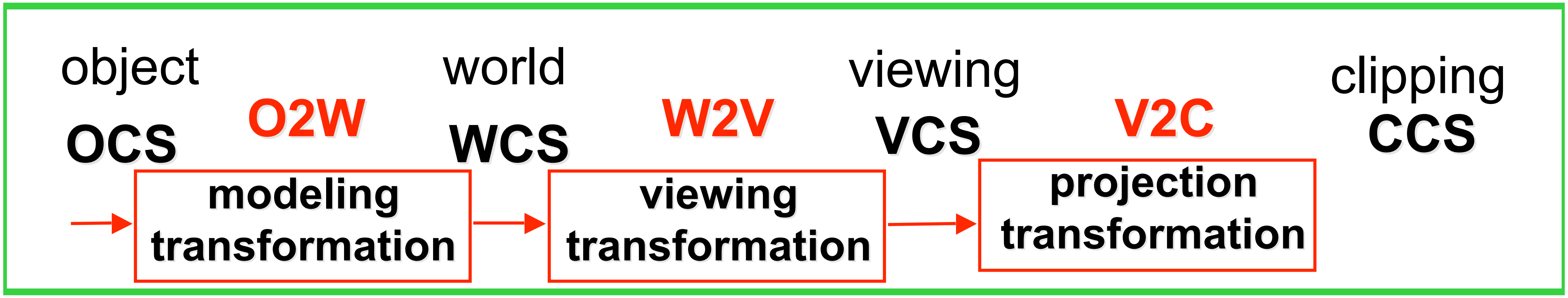
/ w

$$x_{NDCS} = -1/z_{VCS}$$

$$y_{NDCS} = 1/z_{VCS}$$

$$z_{NDCS} = \frac{5}{3} + \frac{8}{3z_{VCS}}$$

OpenGL Example

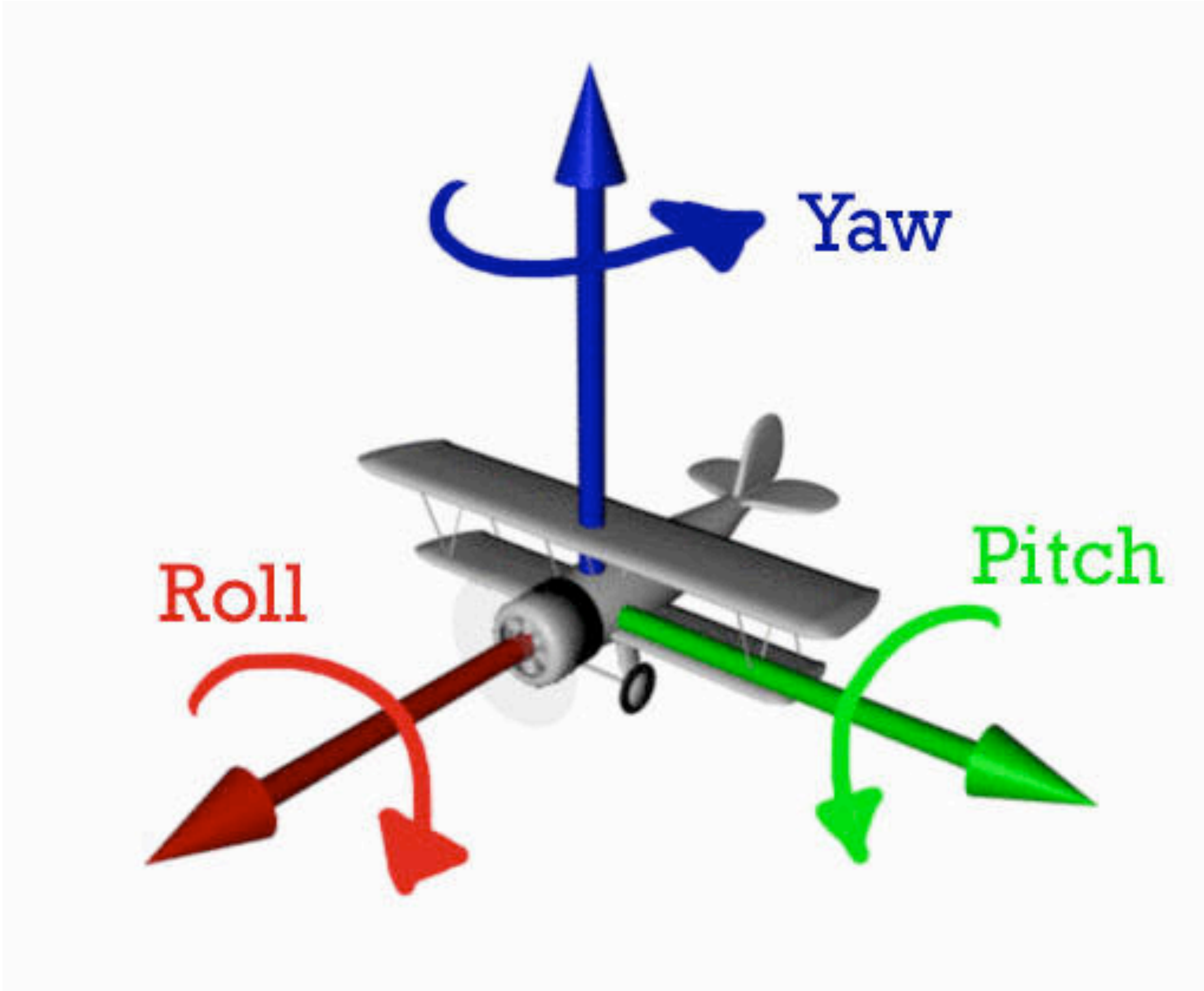



```
CCS    glMatrixMode( GL_PROJECTION );
       glLoadIdentity();
       gluPerspective( 45, 1.0, 0.1, 200.0 );
VCS    glMatrixMode( GL_MODELVIEW );
       glLoadIdentity();
       glTranslatef( 0.0, 0.0, -5.0 );
WCS    glPushMatrix()
       glTranslate( 4, 4, 0 );  W2O
OCS1   glutSolidTeapot(1);
       glPopMatrix();
       glTranslate( 2, 2, 0);   W2O
OCS2   glutSolidTeapot(1);
```

- transformations that are applied to object first are specified last

Viewing: More Camera Motion

Fly "Through The Lens": Roll/Pitch/Yaw



Viewing: Incremental Relative Motion

- how to move relative to current camera coordinate system?
  - what you see in the window
- computation in coordinate system used to draw previous frame is simple:
  - incremental change I to current C
  - at time k, want $p' = I_k I_{k-1} I_{k-2} I_{k-3} \ldots I_5 I_4 I_3 I_2 I_1 C p$
- each time we just want to premultiply by new matrix
    - p’=ICp
  - but we know that OpenGL only supports postmultiply by new matrix
    - p’=CIp

Viewing: Incremental Relative Motion

- sneaky trick: OpenGL modelview matrix has the info we want!
  - dump out modelview matrix with glGetDoublev()
    - C = current camera coordinate matrix
  - wipe the matrix stack with glIdentity()
  - apply incremental update matrix I
  - apply current camera coord matrix C
- must leave the modelview matrix unchanged by object transformations after your display call
  - use push/pop
- using OpenGL for storage and calculation
  - querying pipeline is expensive
    - but safe to do just once per frame

Caution: OpenGL Matrix Storage

- OpenGL internal matrix storage is columnwise, not rowwise

```
a   e   i   m
b   f   j   n
c   g   k   o
d   h   l   p
```

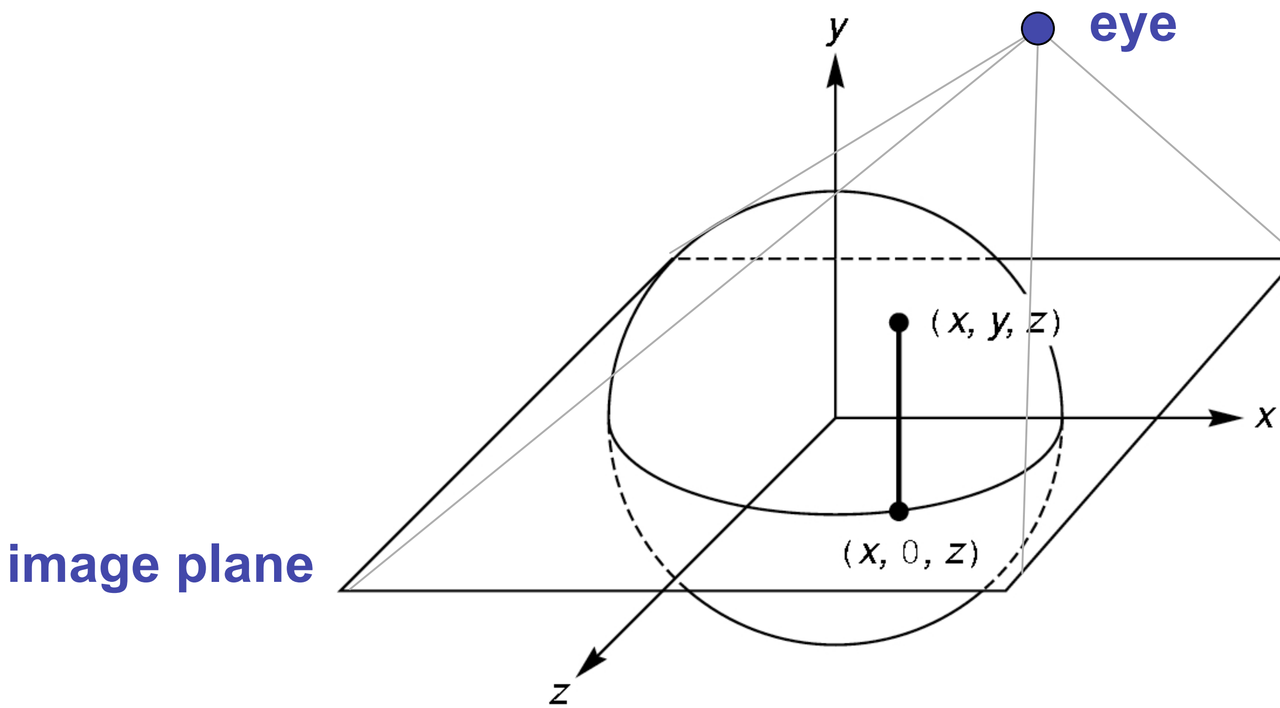
  - opposite of standard C/C++/Java convention
  - possibly confusing if you look at the matrix from glGetDoublev()!

Viewing: Virtual Trackball

- interface for spinning objects around
  - drag mouse to control rotation of view volume
    - orbit/spin metaphor
    - vs. flying/driving
- rolling glass trackball
  - center at screen origin, surrounds world
  - hemisphere “sticks up” in z, out of screen
  - rotate ball = spin world

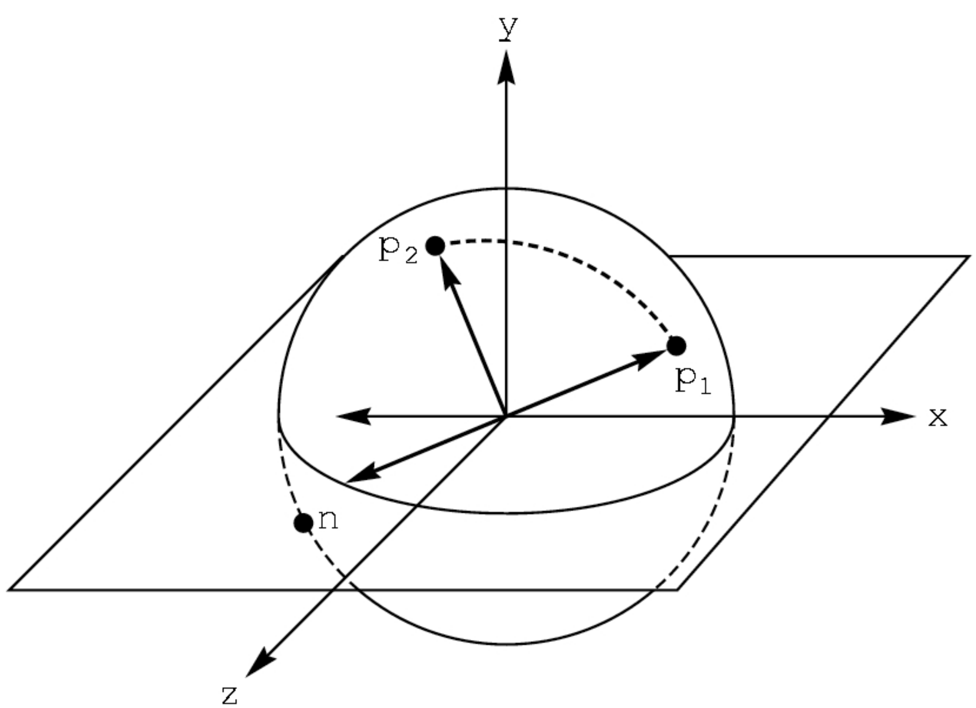
Virtual Trackball

- know screen click: (x, 0, z)
- want to infer point on trackball: (x,y,z)
  - ball is unit sphere, so ||x, y, z|| = 1.0
  - solve for y



Trackball Rotation

- correspondence:
  - moving point on plane from (x, 0, z) to (a, 0, c)
  - moving point on ball from $\mathbf{p_1}$ =(x, y, z) to $\mathbf{p_2}$ =(a, b, c)
- correspondence:
  - translating mouse from $\mathbf{p_1}$ (mouse down) to $\mathbf{p_2}$ (mouse up)
  - rotating about the axis $\mathbf{n} = \mathbf{p_1} \times \mathbf{p_2}$



Trackball Computation

- user defines two points
  - place where first clicked $\mathbf{p_1} = (x, y, z)$
  - place where released $\mathbf{p_2} = (a, b, c)$
- create plane from vectors between points, origin
  - axis of rotation is plane normal: cross product
    - $(\mathbf{p_1} - \mathbf{o}) \times (\mathbf{p_2} - \mathbf{o})$: $\mathbf{p_1} \times \mathbf{p_2}$ if origin = (0,0,0)
  - amount of rotation depends on angle between lines
    - $\mathbf{p_1} \bullet \mathbf{p_2} = |\mathbf{p_1}|\,|\mathbf{p_2}| \cos \theta$
    - $|\mathbf{p_1} \times \mathbf{p_2}| = |\mathbf{p_1}|\,|\mathbf{p_2}| \sin \theta$
- compute rotation matrix, use to rotate world

Picking

Reading

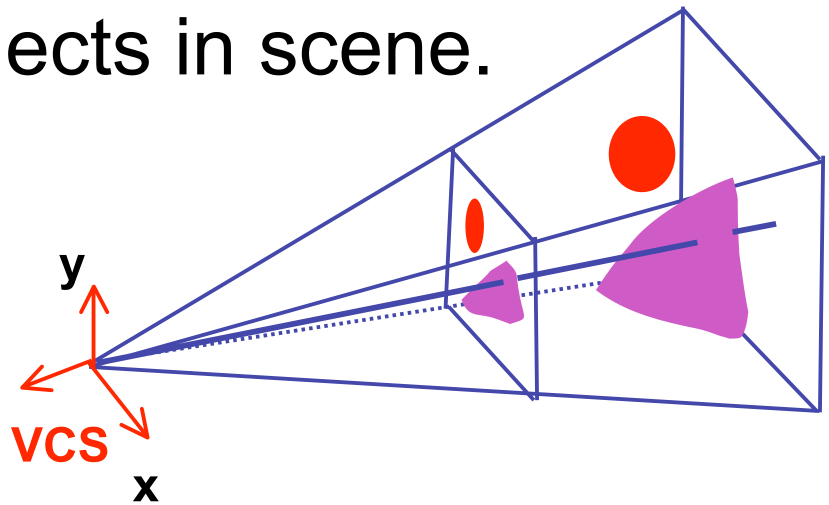
- Red Book
  - Selection and Feedback Chapter
    - all
  - Now That You Know Chapter
    - only Object Selection Using the Back Buffer

Interactive Object Selection

- move cursor over object, click
  - how to decide what is below?
  - inverse of rendering pipeline flow
    - from pixel back up to object
- ambiguity
  - many 3D world objects map to same 2D point
- four common approaches
  - manual ray intersection
  - bounding extents
  - backbuffer color coding
  - selection region with hit list

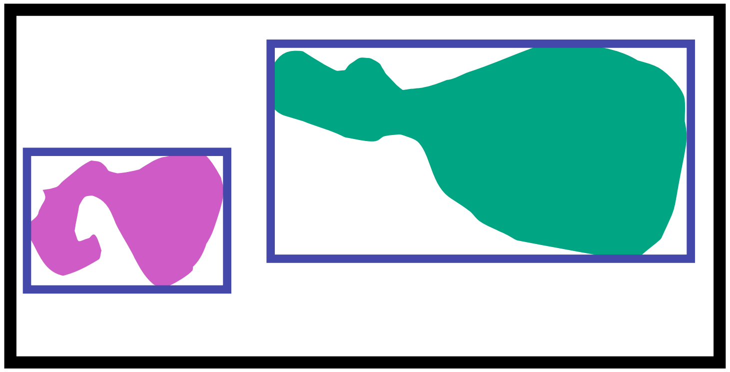
Manual Ray Intersection

- do all computation at application level
  - map selection point to a ray
  - intersect ray with all objects in scene.
- advantages
  - no library dependence
- disadvantages
  - difficult to program
  - slow: work to do depends on total number and complexity of objects in scene



Bounding Extents

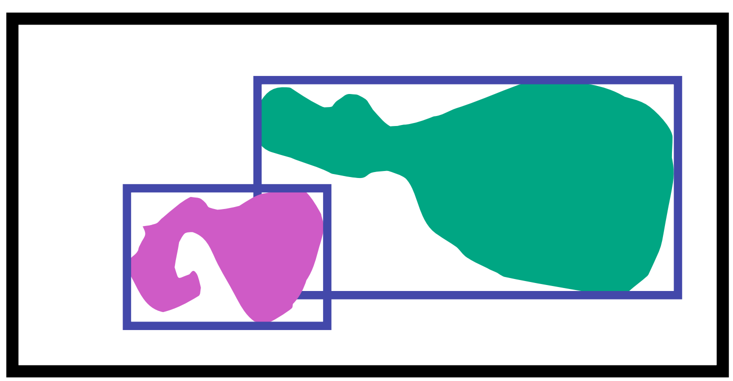
- keep track of axis-aligned bounding rectangles



- advantages
  - conceptually simple
  - easy to keep track of boxes in world space

Bounding Extents

- disadvantages
  - low precision
  - must keep track of object-rectangle relationship
- extensions
  - do more sophisticated bound bookkeeping
    - first level: box check.
    - second level: object check

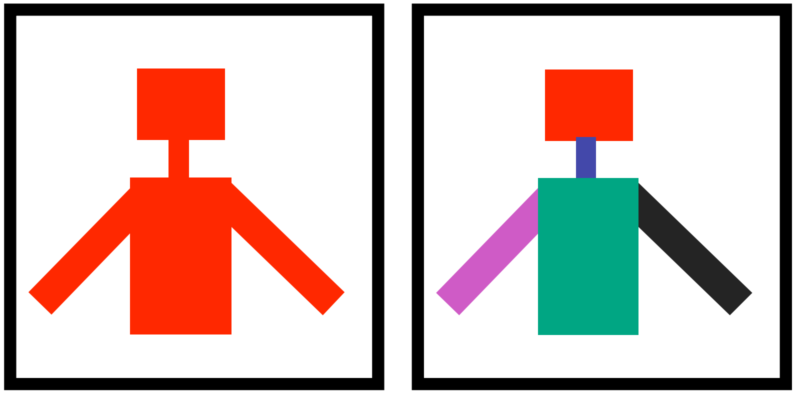


Backbuffer Color Coding

- use backbuffer for picking
  - create image as computational entity
  - never displayed to user
- redraw all objects in backbuffer
  - turn off shading calculations
  - set unique color for each pickable object
    - store in table
  - read back pixel at cursor location
    - check against table

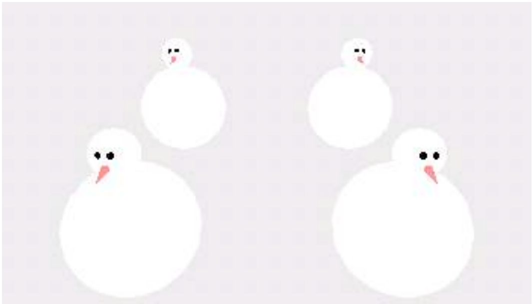
Backbuffer Color Coding

- advantages
  - conceptually simple
  - variable precision
- disadvantages
  - introduce 2x redraw delay
  - backbuffer readback very slow

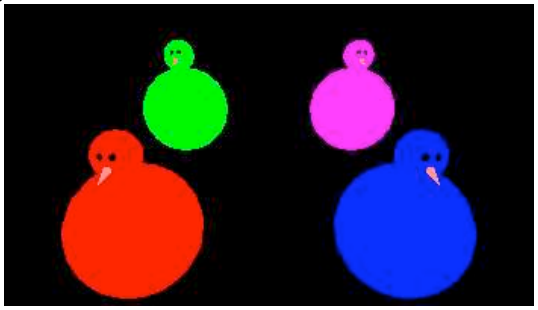


Backbuffer Example

```
glColor3f(1.0, 1.0, 1.0);
for(int i = 0; i < 2; i++)
    for(int j = 0; j < 2; j++) {
        glPushMatrix();
        glTranslatef(i*3.0,0,-j * 3.0);
        glColor3f(1.0, 1.0, 1.0);
        glCallList(snowman_display_list);
        glPopMatrix();
  }
```



```
for(int i = 0; i < 2; i++)
  for(int j = 0; j < 2; j++) {
    glPushMatrix();
    switch (i*2+j) {
      case 0: glColor3ub(255,0,0);break;
      case 1: glColor3ub(0,255,0);break;
      case 2: glColor3ub(0,0,255);break;
      case 3: glColor3ub(250,0,250);break;
    }
    glTranslatef(i*3.0,0,-j * 3.0)
    glCallList(snowman_display_list);
    glPopMatrix();
}
```



http://www.lighthouse3d.com/opengl/picking/

Select/Hit

- use small region around cursor for viewport
- assign per-object integer keys (names)
- redraw in special mode
- store hit list of objects in region
- examine hit list

- OpenGL support

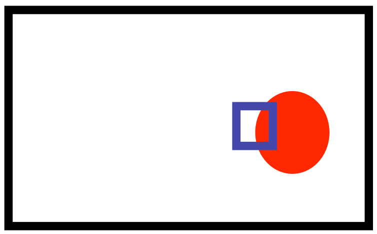
Viewport

- small rectangle around cursor
  - change coord sys so fills viewport

- why rectangle instead of point?
  - people aren't great at positioning mouse
    - Fitts' Law: time to acquire a target is function of the distance to and size of the target
  - allow several pixels of slop

Viewport

- nontrivial to compute
  - invert viewport matrix, set up new orthogonal projection
- simple utility command
  - gluPickMatrix(x,y,w,h,viewport)
    - x,y: cursor point
    - w,h: sensitivity/slop (in pixels)
  - push old setup first, so can pop it later



Render Modes

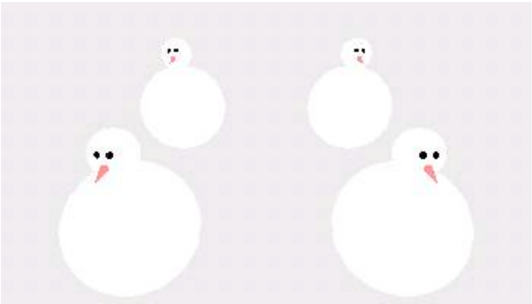
- glRenderMode(mode)
  - GL_RENDER: normal color buffer
    - default
  - GL_SELECT: selection mode for picking
  - (GL_FEEDBACK: report objects drawn)

Name Stack

- again, "names" are just integers
  glInitNames()
- flat list
  glLoadName(name)
- or hierarchy supported by stack
  glPushName(name), glPopName
  - can have multiple names per object

Hierarchical Names Example

```
for(int i = 0; i < 2; i++) {
  glPushName(i);
  for(int j = 0; j < 2; j++) {
    glPushMatrix();
    glPushName(j);
    glTranslatef(i*10.0,0,j * 10.0);
      glPushName(HEAD);
      glCallList(snowManHeadDL);
      glLoadName(BODY);
      glCallList(snowManBodyDL);
      glPopName();
    glPopName();
    glPopMatrix();
  }
  glPopName();
}
```



http://www.lighthouse3d.com/opengl/picking/

Hit List

- glSelectBuffer(buffersize, *buffer)
  - where to store hit list data
- on hit, copy entire contents of name stack to output buffer.
- hit record
  - number of names on stack
  - minimum and minimum depth of object vertices
    - depth lies in the NDC z range [0,1]
    - format: multiplied by 2^32 -1 then rounded to nearest int

Integrated vs. Separate Pick Function

- integrate: use same function to draw and pick
  - simpler to code
  - name stack commands ignored in render mode
- separate: customize functions for each
  - potentially more efficient
  - can avoid drawing unpickable objects

Select/Hit

- advantages
  - faster
    - OpenGL support means hardware acceleration
    - avoid shading overhead
  - flexible precision
    - size of region controllable
  - flexible architecture
    - custom code possible, e.g. guaranteed frame rate
- disadvantages
  - more complex

Hybrid Picking

- select/hit approach: fast, coarse
  - object-level granularity
- manual ray intersection: slow, precise
  - exact intersection point
- hybrid: both speed and precision
  - use select/hit to find object
  - then intersect ray with that object

OpenGL Precision Picking Hints

- gluUnproject
  - transform window coordinates to object coordinates given current projection and modelview matrices
  - use to create ray into scene from cursor location
  - call gluUnProject twice with same (x,y) mouse location
    - z = near: (x,y,0)
    - z = far: (x,y,1)
    - subtract near result from far result to get direction vector for ray
- use this ray for line/polygon intersection

Vision/Color

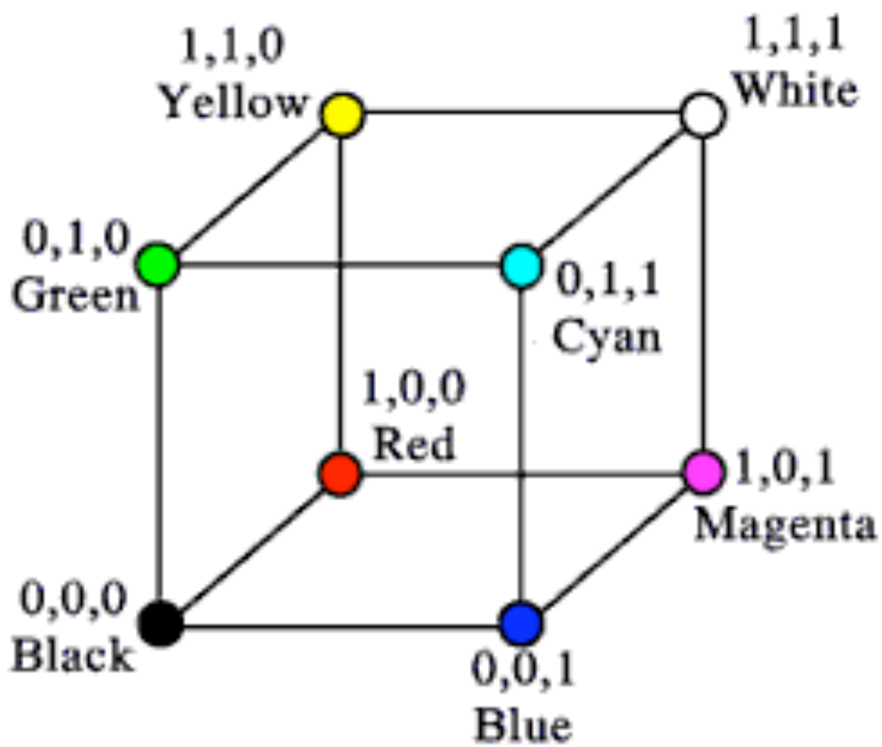
Reading for Color

- RB Chap Color

- FCG Sections 3.2-3.3
- FCG Chap 20 Color
- FCG Chap 21.2.2 Visual Perception (Color)

RGB Color

- triple (r, g, b) represents colors with amount of red, green, and blue
  - hardware-centric
  - used by OpenGL



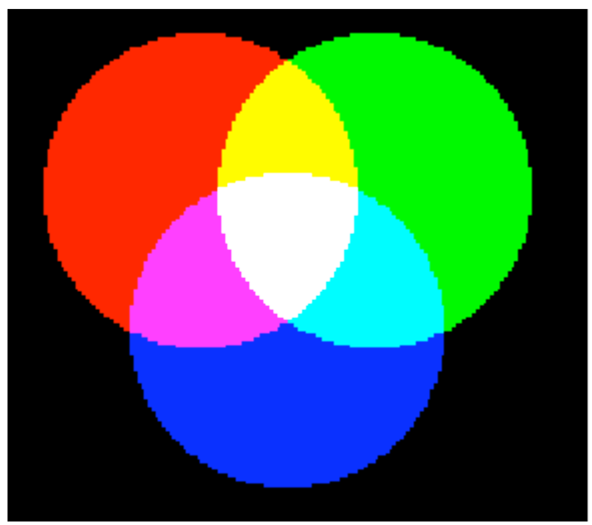
Alpha

- fourth component for transparency
  - (r,g,b,α)
- fraction we can see through
  - $c = \alpha c_f + (1-\alpha)c_b$
- more on compositing later

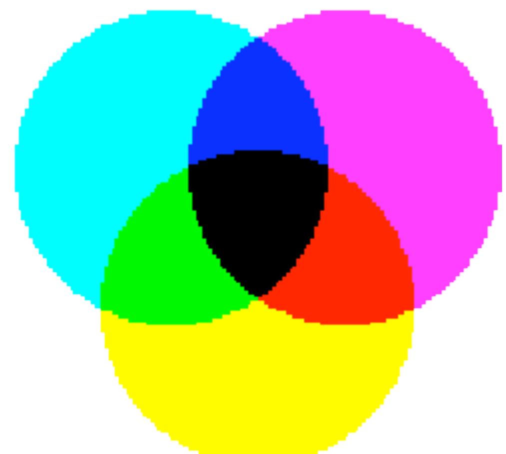
Additive vs. Subtractive Colors

- additive: light
  - monitors, LCDs
  - RGB model
- subtractive: pigment
  - printers
  - CMY model
  - dyes absorb light

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$



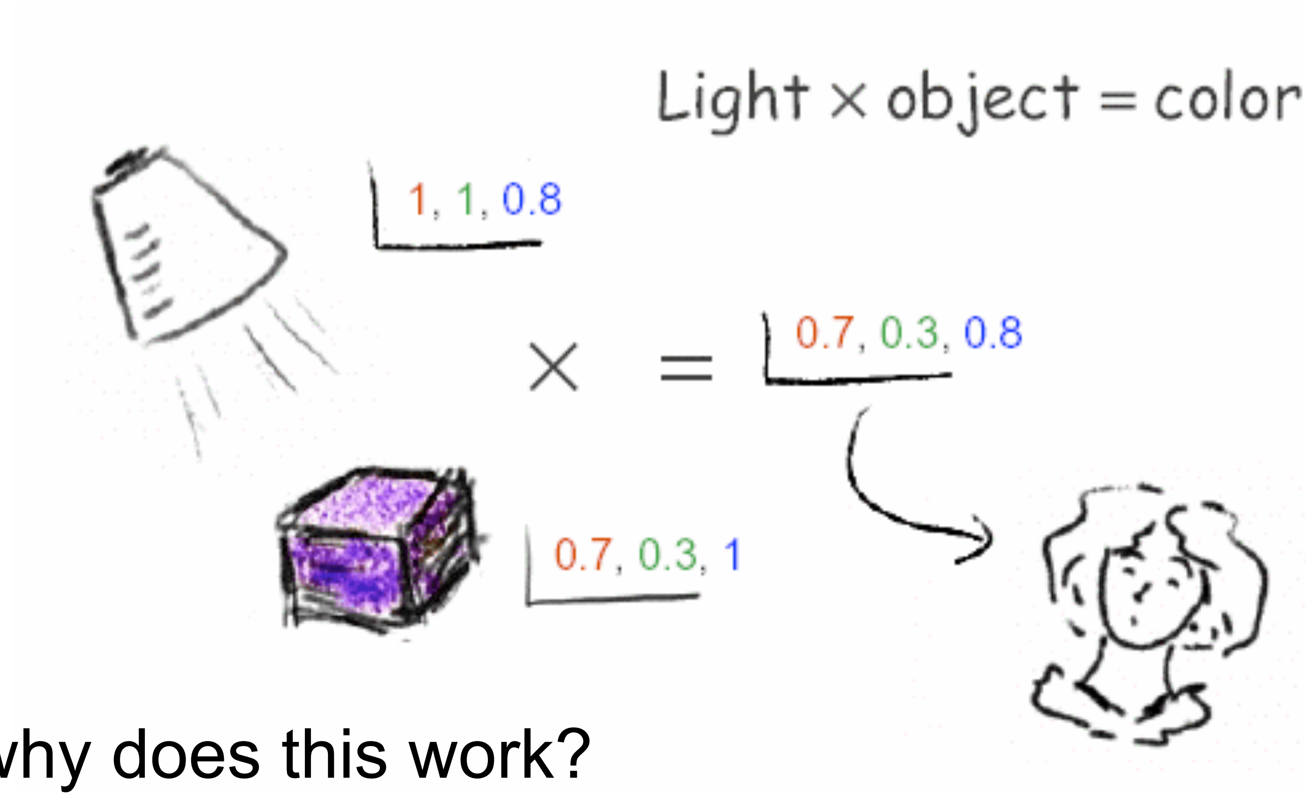
additive



subtractive

Component Color

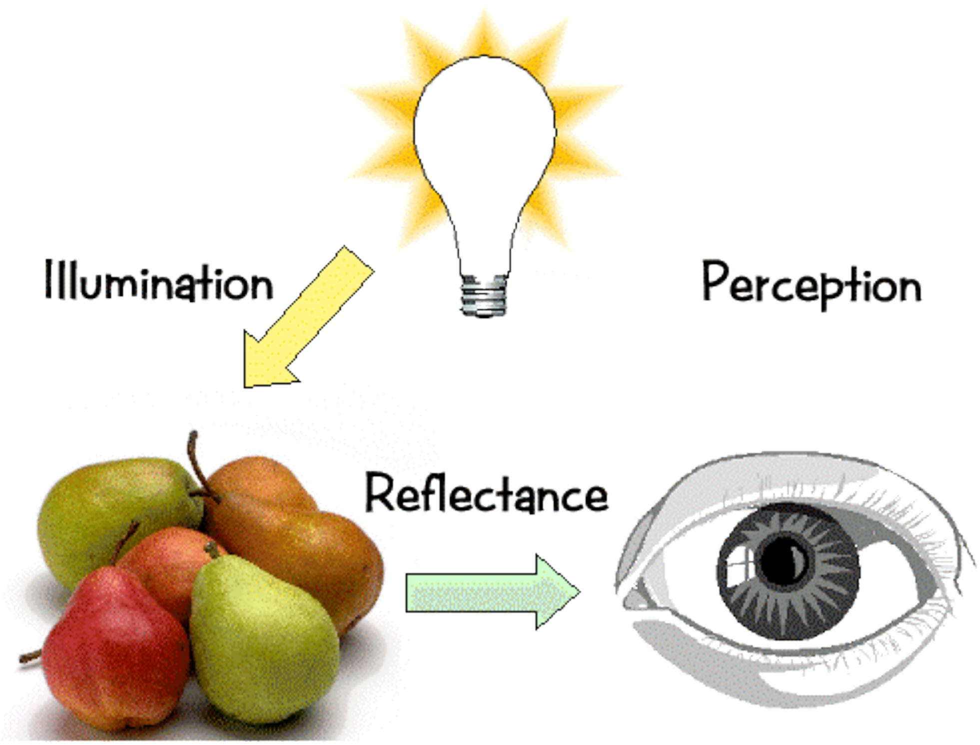
- component-wise multiplication of colors
  - (a0,a1,a2) * (b0,b1,b2) = (a0*b0, a1*b1, a2*b2)



  - why does this work?
    - must dive into light, human vision, color spaces

Basics Of Color

- elements of color:



Basics of Color

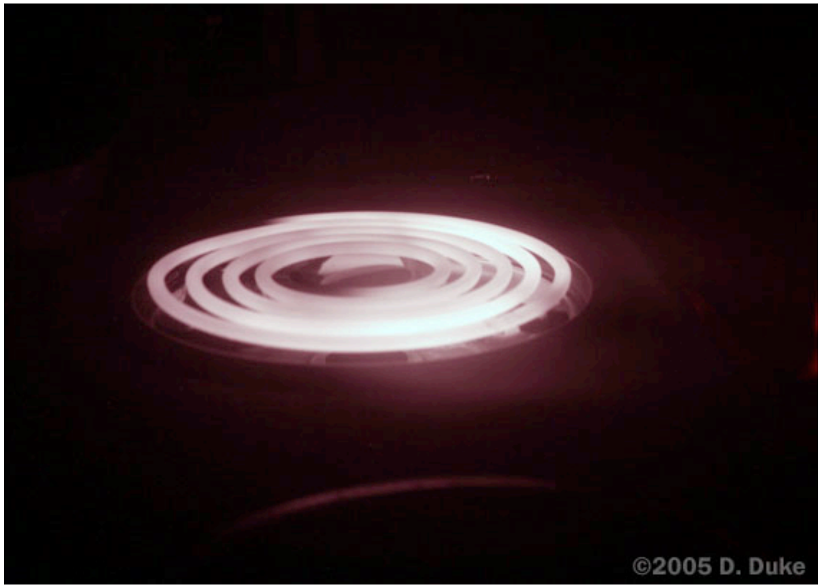
- physics
  - illumination
    - electromagnetic spectra
  - reflection
    - material properties
    - surface geometry and microgeometry
      - polished versus matte versus brushed
- perception
  - physiology and neurophysiology
  - perceptual psychology

Light Sources

- common light sources differ in kind of spectrum they emit:
  - continuous spectrum
    - energy is emitted at all wavelengths
      - blackbody radiation
      - tungsten light bulbs
      - certain fluorescent lights
      - sunlight
      - electrical arcs
  - line spectrum
    - energy is emitted at certain discrete frequencies

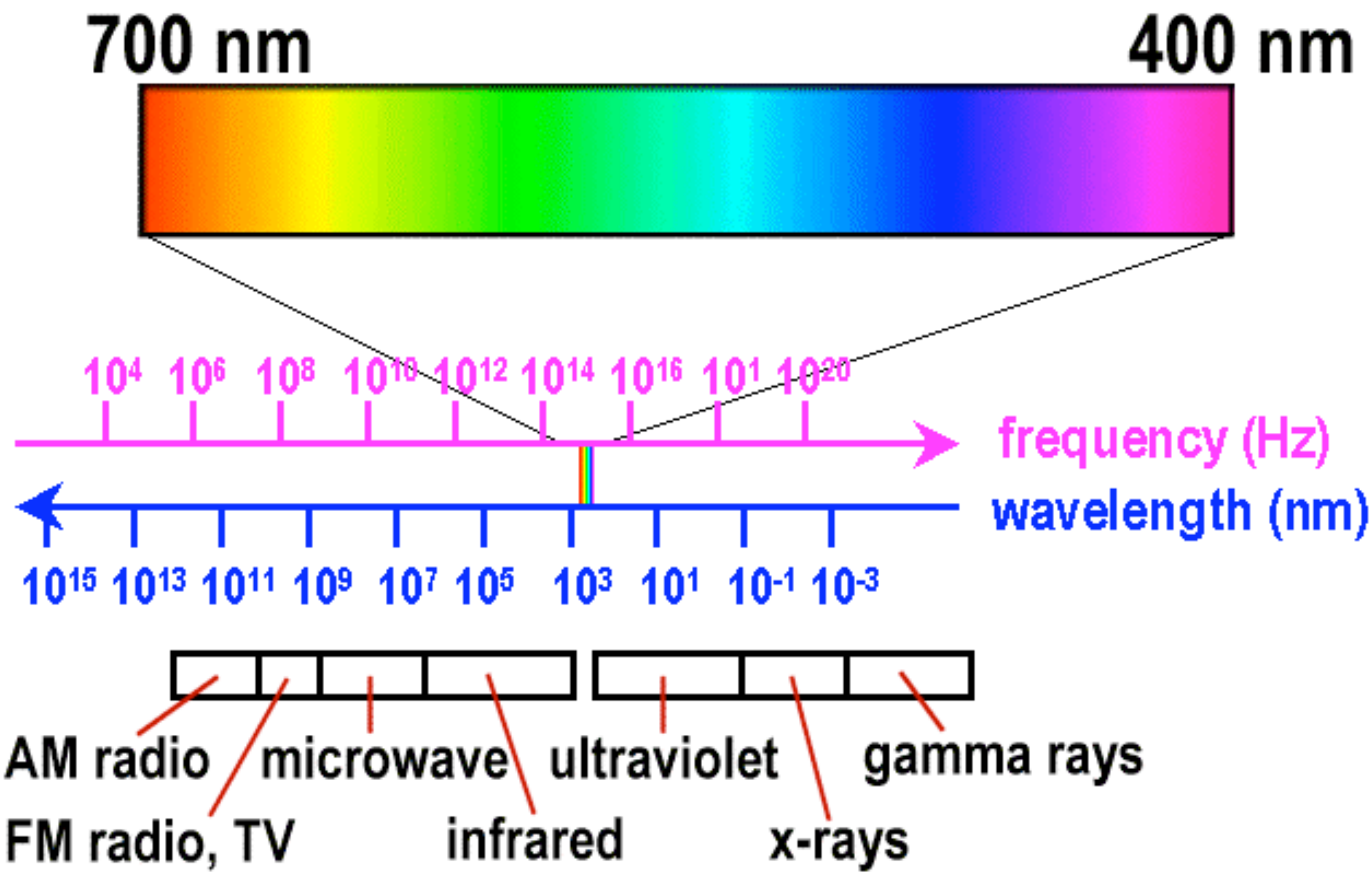
Blackbody Radiation

- black body
  - dark material, so that reflection can be neglected
  - spectrum of emitted light changes with temperature
    - this is the origin of the term “color temperature”
      - e.g. when setting a white point for your monitor
    - cold: mostly infrared
    - hot: reddish
    - very hot: bluish
  - demo:

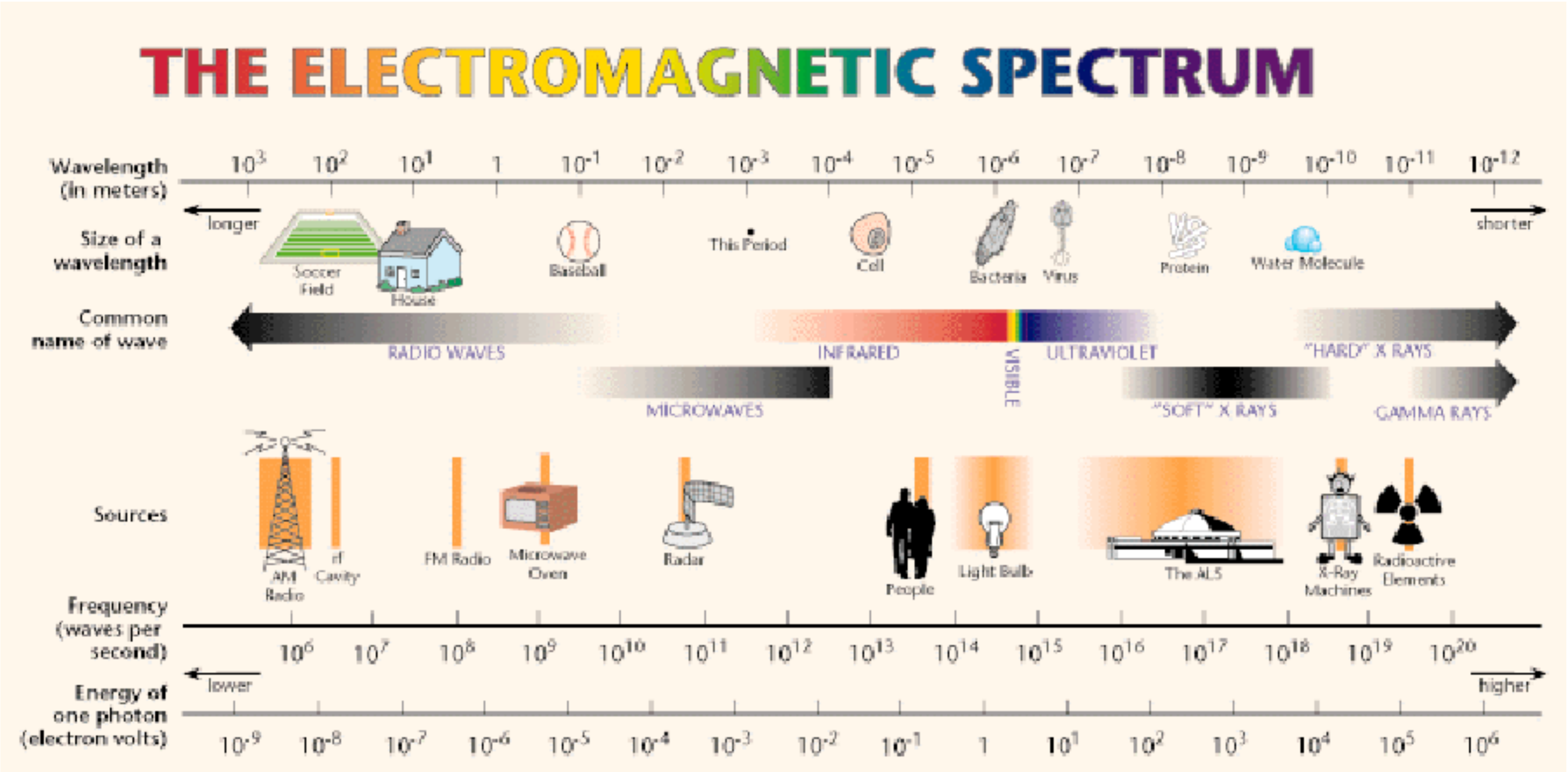


http://www.mhhe.com/physsci/astronomy/applets/Blackbody/frame.html

Electromagnetic Spectrum

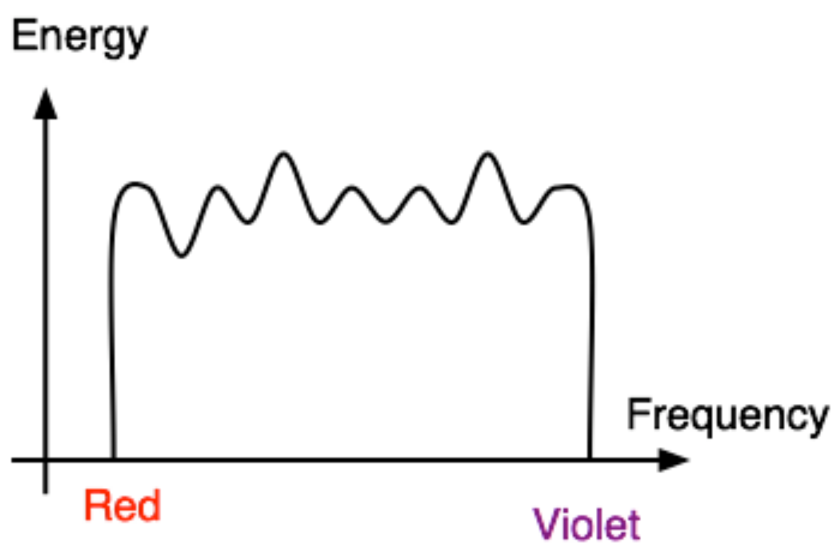


Electromagnetic Spectrum



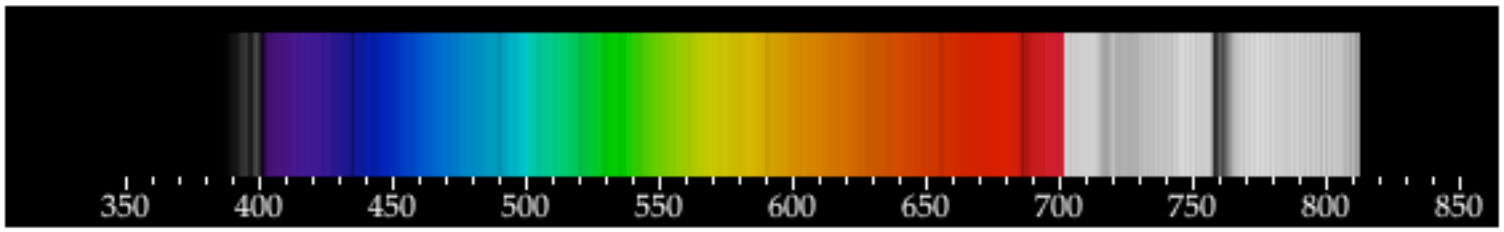
White Light

- sun or light bulbs emit all frequencies within visible range to produce what we perceive as "white light"

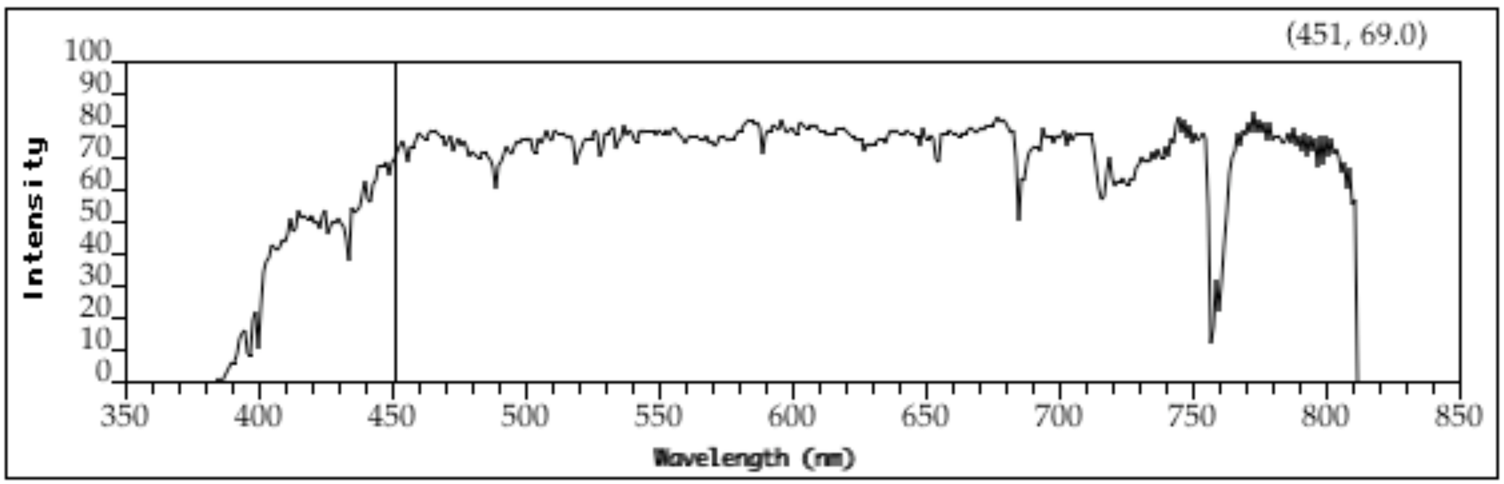


Sunlight Spectrum

- spectral distribution: power vs. wavelength



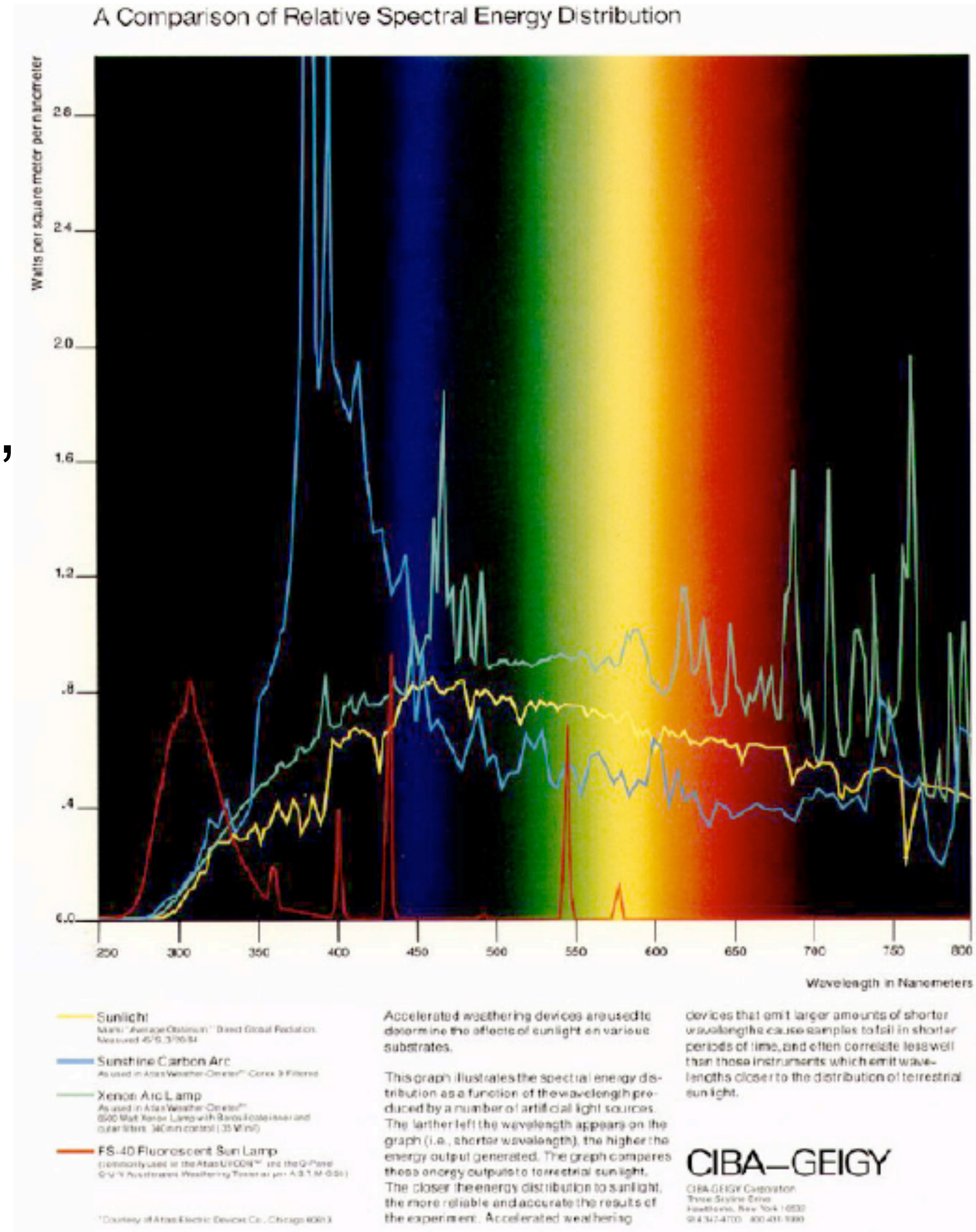
Emission Graph



Electromagnetic Spectrum

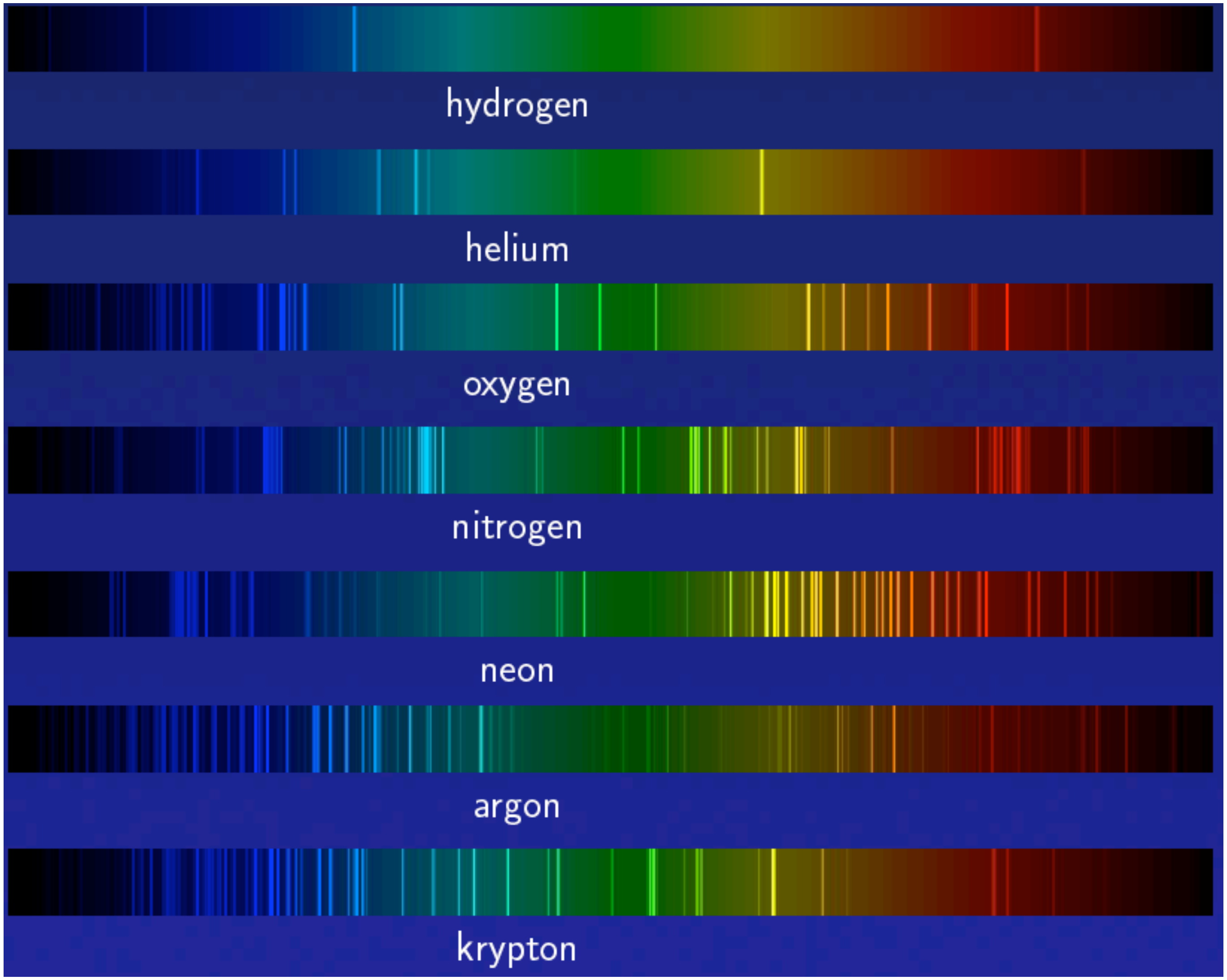
Continuous Spectrum

- sunlight
- various “daylight” lamps



Line Spectrum

- ionized gases
- lasers
- some fluorescent lamps

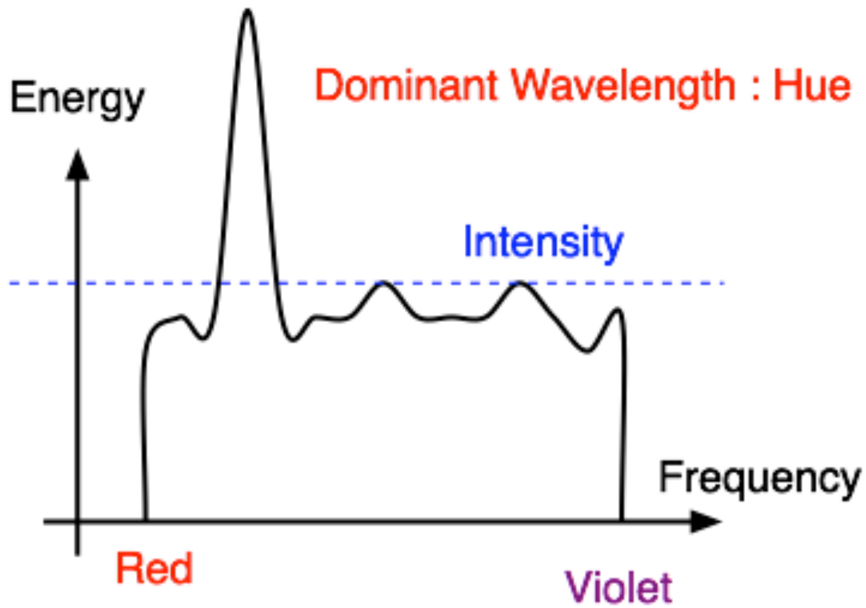


White Light and Color

- when white light is incident upon an object, some frequencies are reflected and some are absorbed by the object
- combination of frequencies present in the reflected light that determines what we perceive as the color of the object

Hue

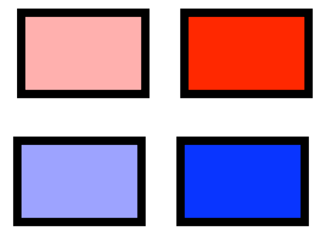
- hue (or simply, "color") is dominant wavelength/frequency

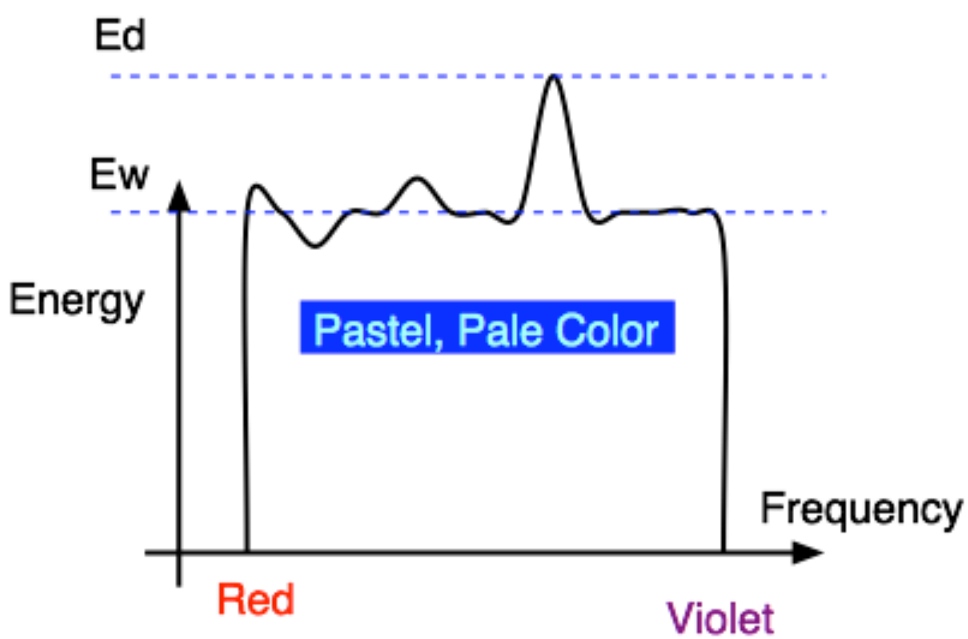


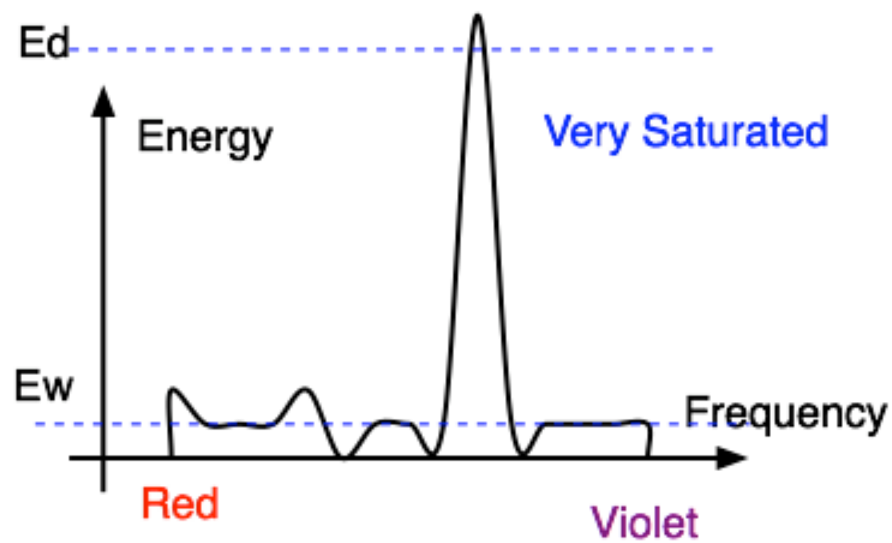
- integration of energy for all visible wavelengths is proportional to intensity of color

Saturation or Purity of Light

- how washed out or how pure the color of the light appears
  - contribution of dominant light vs. other frequencies producing white light
  - saturation: how far is color from grey
    - pink is less saturated than red
    - sky blue is less saturated than royal blue







Intensity vs. Brightness

- intensity : physical term
  - measured radiant energy emitted per unit of time, per unit solid angle, and per unit projected area of the source (related to the luminance of the source)
- lightness/brightness: perceived intensity of light
  - nonlinear

Perceptual vs. Colorimetric Terms

- Perceptual
  - Hue
  - Saturation
  - Lightness
    - *reflecting objects*
  - Brightness
    - *light sources*

- Colorimetric
  - Dominant wavelength
  - Excitation purity
  - Luminance
  - Luminance