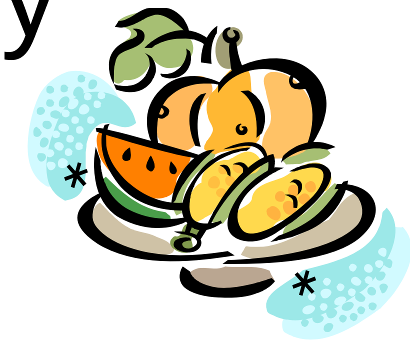
Computer Graphics: Recap

Part 2 – Lecture 15

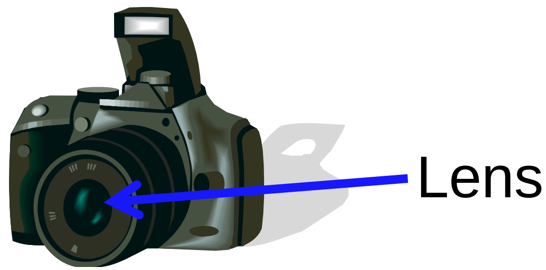
The Camera Analogy

1. **Model Transformations**
   Arranging objects in a scene



2. **View Transformation**
   Positioning the camera

3. **Projection**
   Choosing a lens & taking a photo



4. **Viewport Transformation**
   Printing a photo

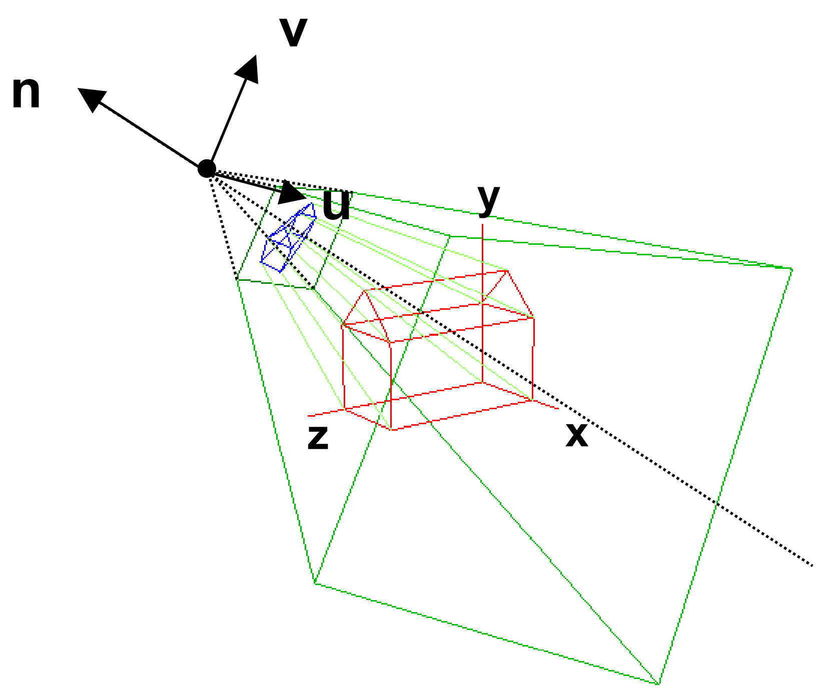
The View Coordinate System

```
gluLookAt(
    eyeX, eyeY, eyeZ,
    lookAtX, lookAtY, lookAtZ,
    upX, upY, upZ
)
```

n = Normalised(Eye – LookAt)

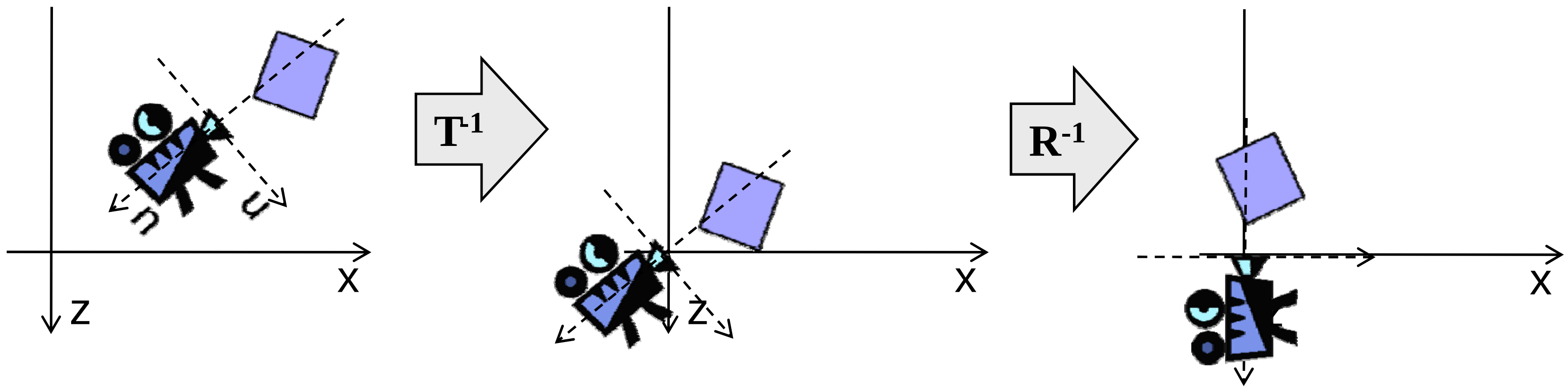
u = Normalised(Cross(**Up, n**))

v = Cross(**n, u**)



View Transformation

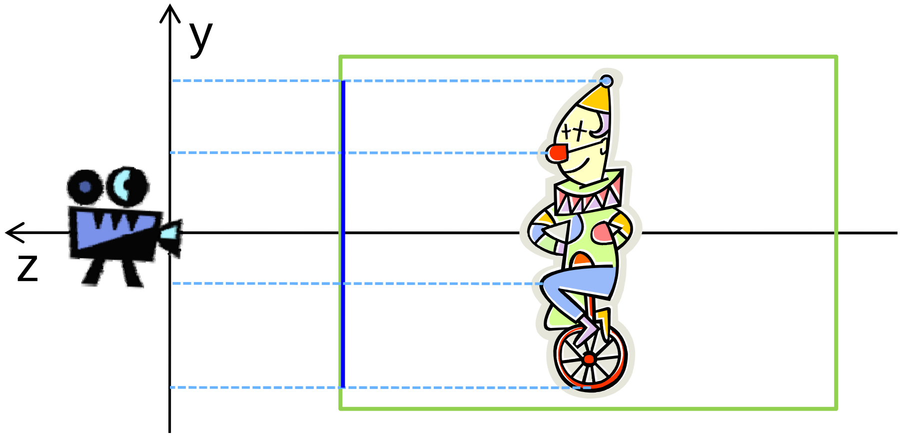
- Camera is at the origin looking down negative Z axis
- Could change camera position with translation **T** and rotation **R**
- But instead of rotating and moving camera, transform our scene inversely so that the camera sees what we want it to see:



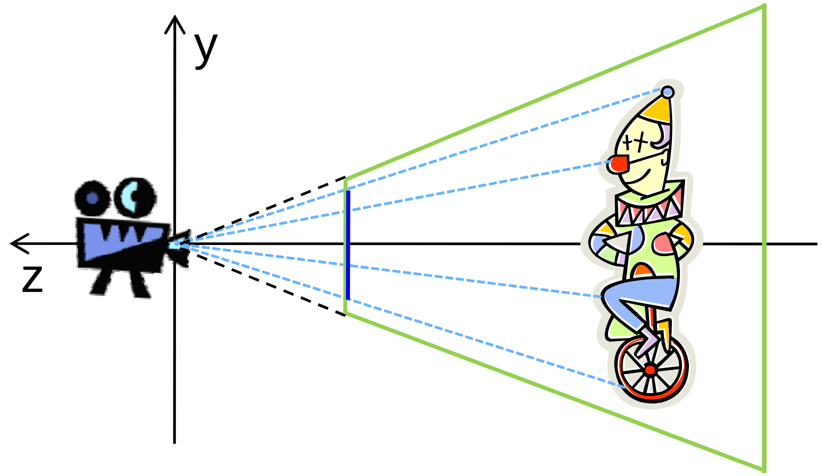
- In other words: we translate and rotate **view coordinate system** so that it is aligned with world coordinate system
- Viewing transform can be done as the last transform in $\mathbf{M}_{\mathbf{ModelView}}$ (i.e. must be set first in program)

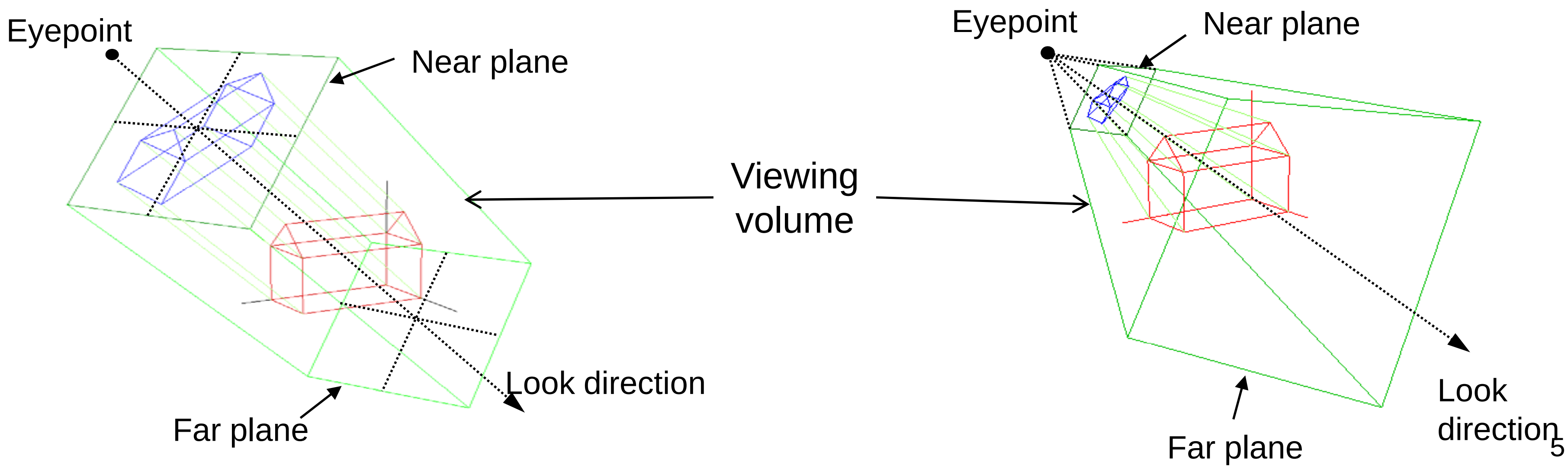
Orthographic vs. Perspective Projection

Orthographic Projection

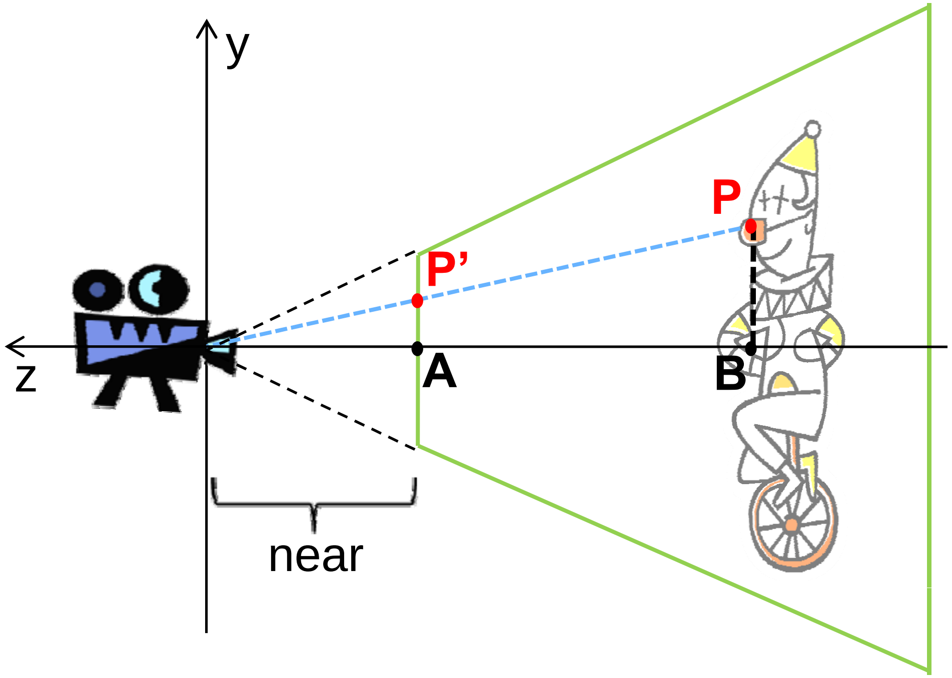


Perspective Projection





Perspective Projection of a Vertex



- What are the coordinates of **P'** ?
- Camera-**A**-**P'** and Camera-**B**-**P** are similar triangles
- Ratios of similar sides are equal:

$$\frac{P_y'}{near} = \frac{P_y}{-P_z} \Leftrightarrow P_y' = \frac{near}{-P_z} P_y$$

- When looking from the bottom, we get analogous calculations for the x-coordinate of **P'**:

$$\frac{P_x'}{near} = \frac{P_x}{-P_z} \Leftrightarrow P_x' = \frac{near}{-P_z} P_x$$

- Perspective scaling factor $s_{persp} = \frac{near}{-P_z}$

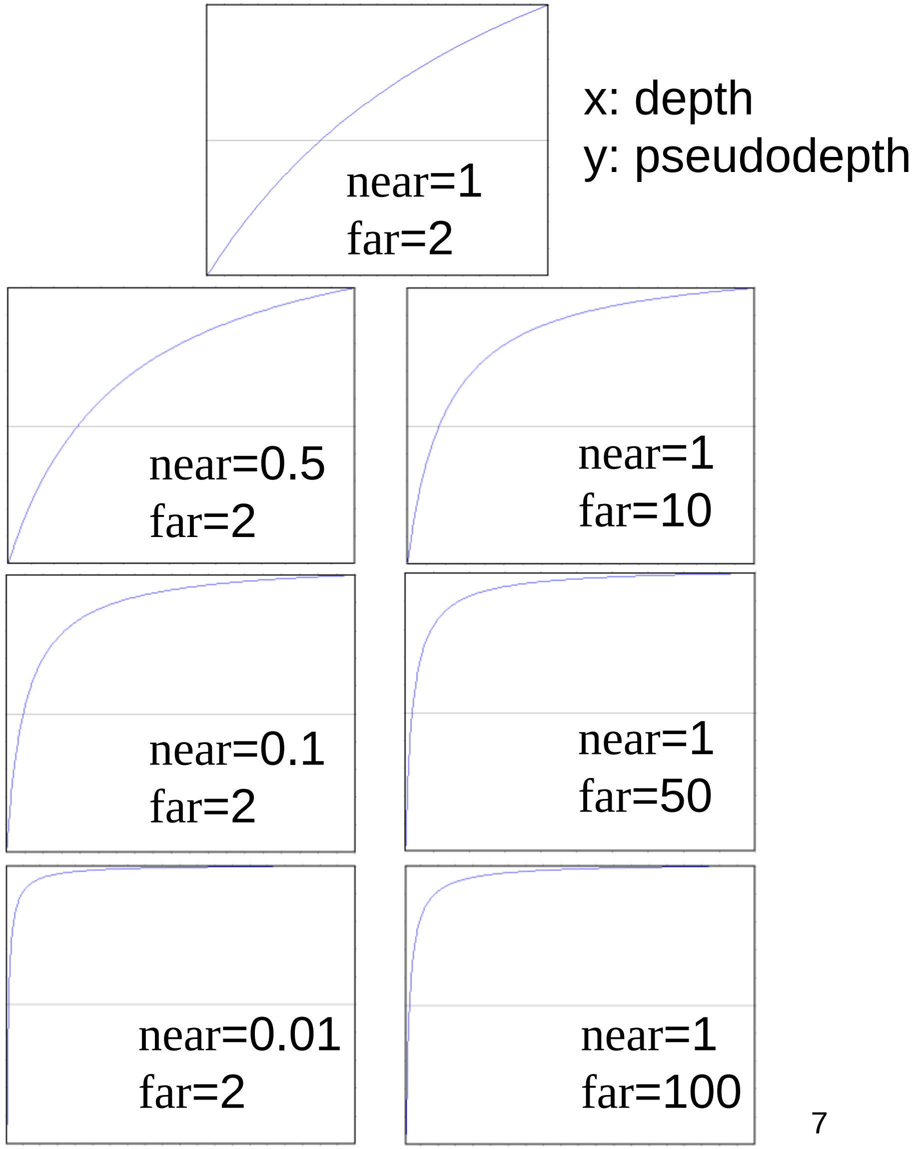
Pseudodepth

- Transformed z* not linear function of z

$$z^* = \frac{(far + near)z + 2\,far * near}{(far - near)z}$$

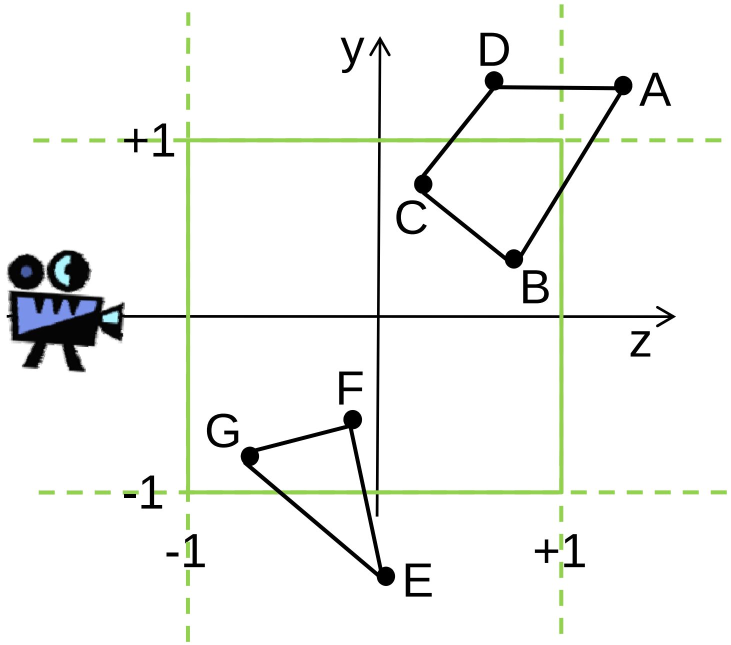
- This is ok because
  1. z* monotonic increasing, and
  2. z* = -1 for z = -near
     z* = +1 for z = -far

- Avoid very small near and very large far
  → resolution too low for points that are further away



Clipping

- Determine which lines are in the canonical view volume (using NDC)
- Outside of the view volume is given by:
  $p_x < -1$, $p_x > +1$, $p_y < -1$, $p_y > +1$,
  $p_z < -1$, $p_z > +1$
  ($\rightarrow$ **clip planes**)
- Each line is either…
  1. completely inside
     $\rightarrow$ **trivial accept**
  2. completely outside
     $\rightarrow$ **trivial reject**
  3. Partially in the view volume
     $\rightarrow$ need to find out which part is inside



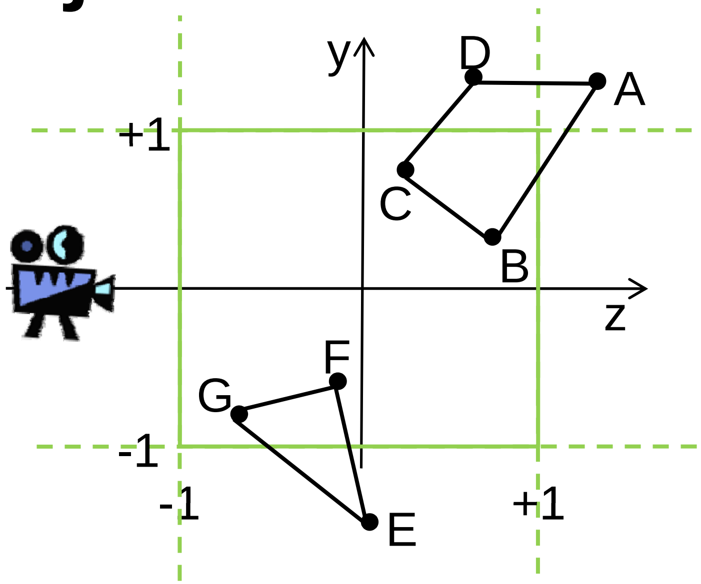
Trivial accept for:
CB and GF

Trivial reject for:
DA

Partially visible:
AB, CD, EF and EG

Trivial Accept and Reject Tests

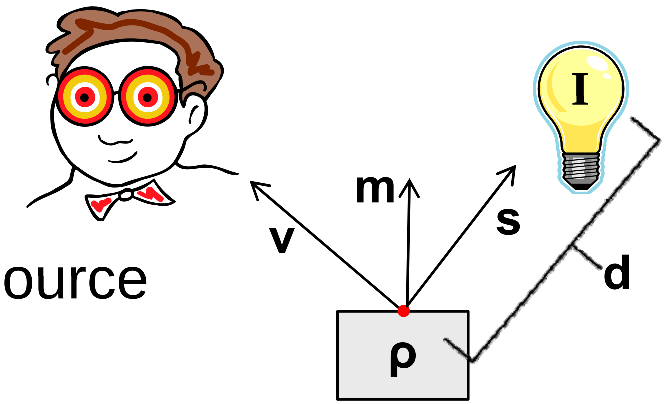
- For each point, check if it is outside of left (L), right (R), bottom (B), top (T), near (N) and far (F) clip plane
- Create table with **outcodes**:
  1 if point is outside, 0 if inside
  - **Trivial reject** of a line PQ:
    = P and Q outside of the same clip plane
    = outcodes for same plane both 1
    = `(outcode P & outcode Q)!=0`
  - **Trivial accept** of a line PQ:
    = both endpoints inside of all clip planes
    = all outcodes 0
    = `(outcode C | outcode D)==0`

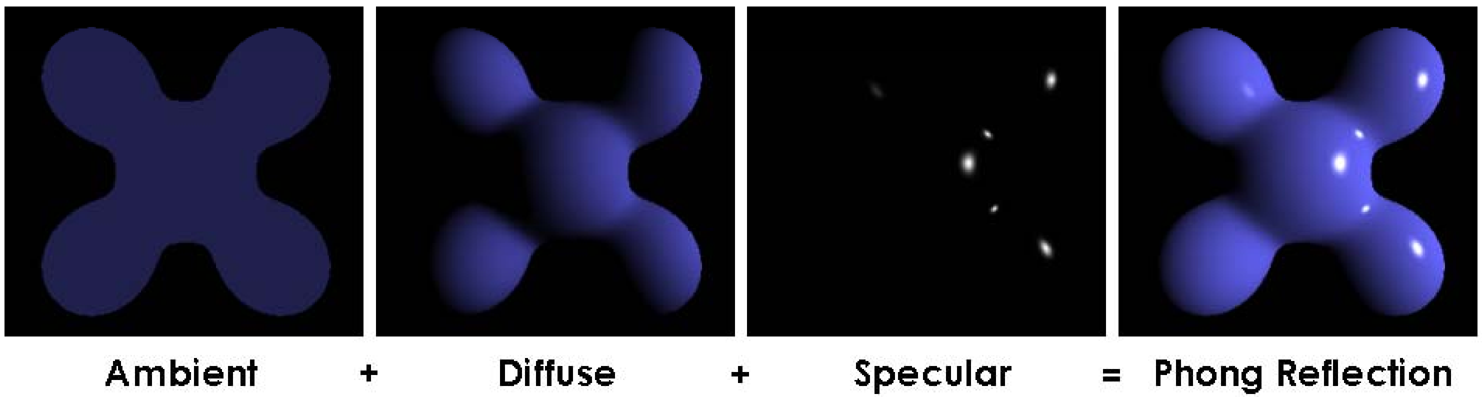


	L	R	B	T	N	F
A	0	0	0	**1**	0	**1**
B	0	0	0	0	0	0
C	0	0	0	0	0	0
D	0	0	0	**1**	0	0
E	0	0	**1**	0	0	0
F	0	0	0	0	0	0
G	0	0	0	0	0	0

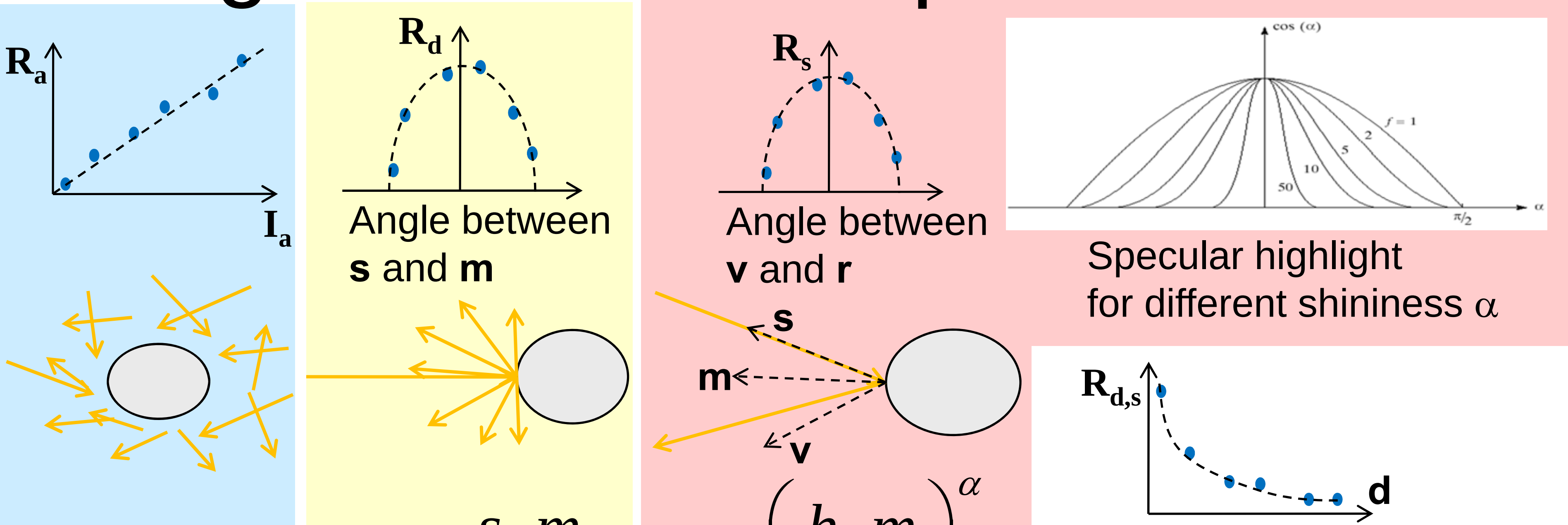
Phong Illumination Model

- **Idea**: calculate intensity **R** (and color) of visible light at a point as the sum of ambient, diffuse and specular reflection
- Variables taken into account:
  - Intensities $\mathbf{I_a}$, $\mathbf{I_d}$, $\mathbf{I_s}$ for incident light
  - Surface normal vector **m**
  - Vector **s** describing the direction to the light source
  - Distance **d** to light source
  - Vector **v** describing the direction to the viewer
  - Reflection coefficients of the surface material ρ_a, ρ_d, ρ_s

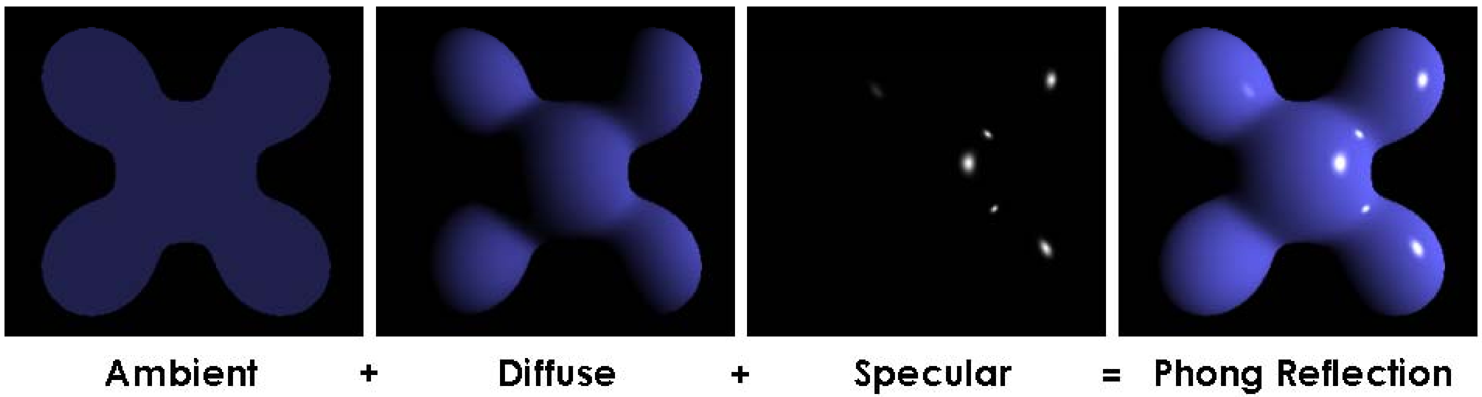




Phong Illumination Equation



$$\mathbf{R} = \mathbf{I_a}\,\rho_a + \left(\mathbf{I_d}\,\rho_d \frac{s \cdot m}{|s||m|} + \mathbf{I_s}\,\rho_s \left(\frac{h \cdot m}{|h||m|}\right)^{\alpha}\right) / \left(k_c + k_l d + k_q d^2\right)$$



Setting Up Lights

```
float lightPos0[] = {-1.0, 2.0, 3.0, 1.0}; // point source
glLightfv(GL_LIGHT0, GL_POSITION, lightPos0);

float lightPos1[] = {0.0, 1.0, 2.0, 0.0};  // directional
glLightfv(GL_LIGHT1, GL_POSITION, lightPos1);

glEnable(GL_LIGHTING);    // enable lighting in general
glEnable(GL_LIGHT0);      // enable light number 0
glEnable(GL_LIGHT1);      // enable light number 1
```

For setting the properties of lights, use one of

```
glLightfv(GLenum light, GLenum pname, float* params)
glLightf(GLenum light, GLenum pname, float param)
```

- `light` selects a light `GL_LIGHT`i with 0 < i < `GL_MAX_LIGHTS` (8)
- pname selects a property to set (e.g. `GL_POSITION`)

- For point sources: set position to (x, y, z, 1)
- For directional light sources: set position to (x, y, z, 0)
  (x,y,z) points towards the light source

Using Materials

```
float ambient[] = {0.1, 0.1, 0.1, 1.0};        // ρar, ρag, ρab, 1
float diffuse[] = {0.4, 0.4, 0.6, 1.0};        // ρdr, ρdg, ρdb, 1
float specular[] = {0.8, 0.8, 1.0, 1.0};       // ρsr, ρsg, ρsb, 1

glMaterialfv(GL_FRONT, GL_AMBIENT, ambient);
glMaterialfv(GL_FRONT, GL_DIFFUSE, diffuse);
glMaterialfv(GL_FRONT, GL_SPECULAR, specular);

glMaterialf(GL_FRONT, GL_SHININESS, 40.0);     // α=40
```

Set the current material, then draw primitives (they will use the material)

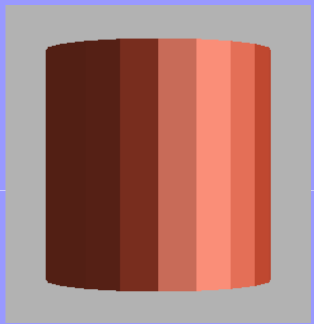
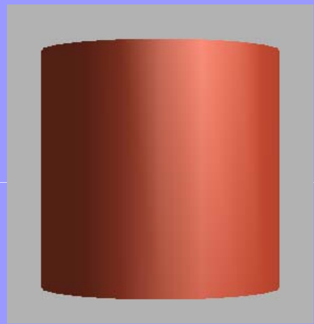
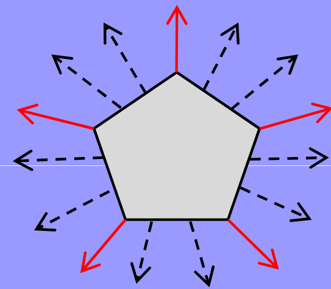
`glMaterialfv(GLenum face, GLenum pname, float* params)`

`glMaterialf(GLenum face, GLenum pname, float param)`

- `face` selects side to use material on (`GL_FRONT`, `GL_BACK` or `GL_FRONT_AND_BACK`)
- pname selects a property to set (e.g. `GL_AMBIENT`, `GL_EMISSION`, `GL_AMBIENT_AND_DIFFUSE`, `GL_SHININESS`, …)

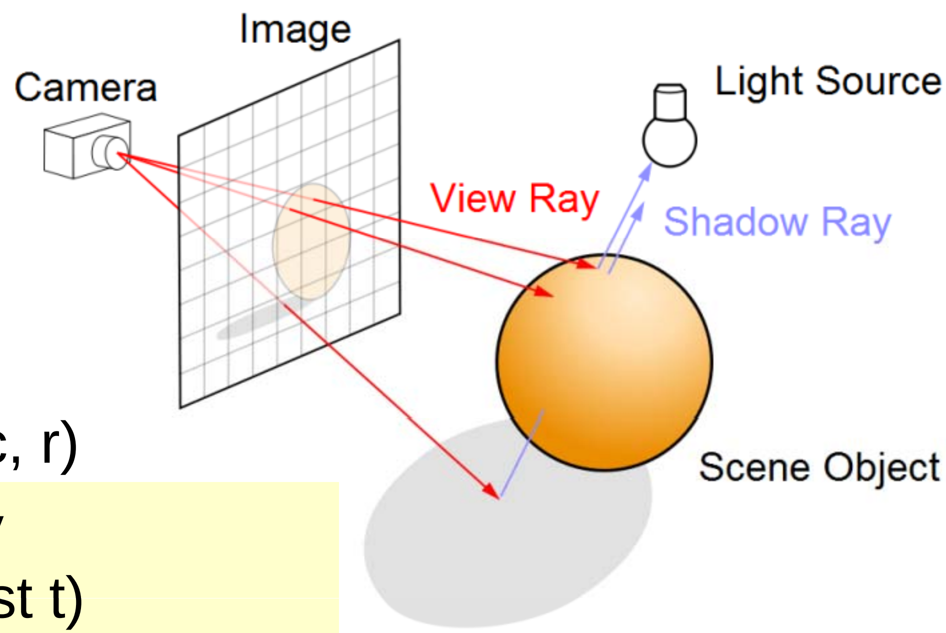
- Set coefficients as RGBA: A (alpha) for color blending, is usually 1

Shading Algorithms

Flat Shading	Gouraud Shading	Phong Shading
		
Simple and fast Phong equation only once per face	Still fast Phong equation at each vertex No 0th-order color discontinuities	Crisp highlights with few vertices
Mach Bands	Slight mach bands, Color invariance with quadrilaterals, Problems with highlights	Slow Phong calculation for every Pixel

Ray Casting Algorithm

```
define scene = ({ objects }, { lights })
define camera (eye, u, v, n)
for (int r = 0; r < nRows; r++) {
    for (int c = 0; c < nCols; c++) {
        construct ray going through (c, r)
        find closest intersection of ray
                with an object (smallest t)
        find intersection point P                 intersect
        get the surface normal at P
        get the color at the intersection         shade
        pixel(c, r) = color
} }
```

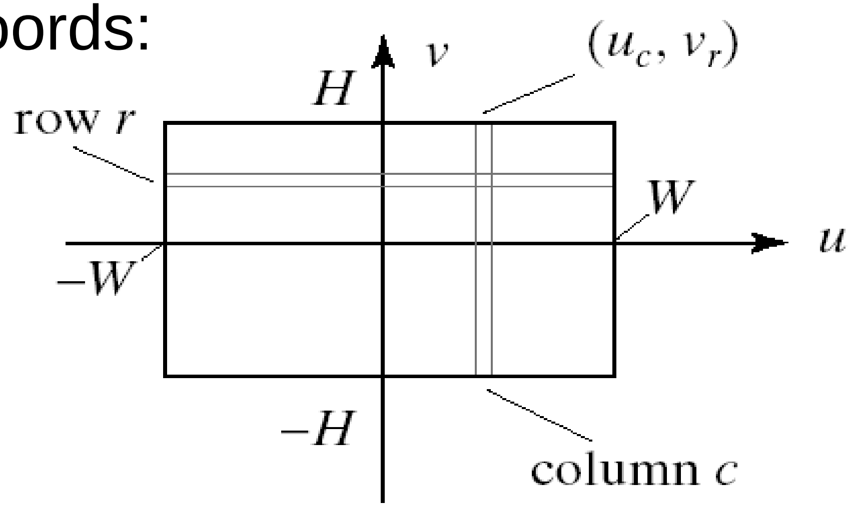


Constructing Rays

Wanted: ray (***startPoint***, ***direction***) from eye through every pixel

- Corners of the view plane in world coords:

  *bottomLeft = centre + (-W**u**, -H**v**)*
  *bottomRight = centre + (W**u**, -H**v**)*
  *topLeft = centre + (-W**u**, H**v**)*
  *topRight = centre + (W**u**, H**v**)*

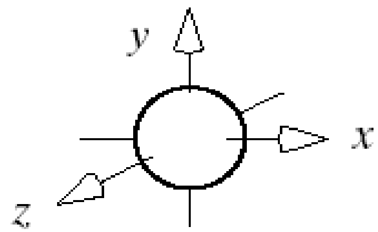


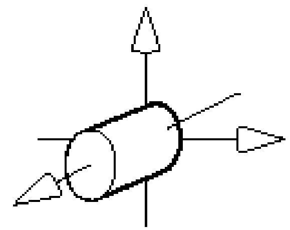
- Go through all pixels, with column 0 and row 0 at *bottomLeft*
- Ray direction ***d*** = ***pixelPos*** - ***eye***

$$\mathbf{d} = -N\mathbf{n} + W\left(\frac{2c}{nCols} - 1\right)\mathbf{u} + H\left(\frac{2r}{nRows} - 1\right)\mathbf{v}$$

Ray-Object Intersection

- Define each object as an implicit function f:
  f(**p**) = 0 for every point **p** on the surface of the object
  (if **p** is not on surface, then f(**p**) ≠ 0)
- Examples for simple objects ("primitives"):
  - Sphere (center at origin, radius 1)
    $f(\mathbf{p}) = x^2 + y^2 + z^2 - 1 = |\mathbf{p}|^2 - 1$
  - Cylinder (around z-axis, radius 1)
    $f(\mathbf{p}) = x^2 + y^2 - 1$

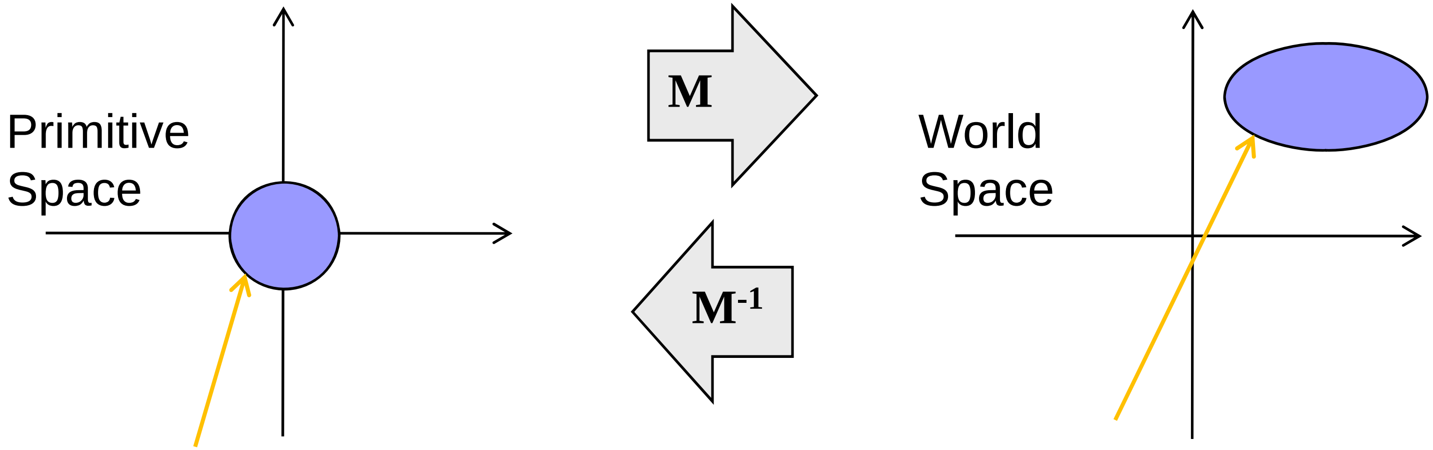




- Where a ray (**eye** + **d** *t*) meets the object:
  f(**eye** + **d** *t*) = 0
  → solve for *t* and get intersection point **eye** + **d** *t*

Transformed Primitives

Problem: How to intersect with transformed primitives?
(e.g. scaled and translated unit sphere)



Solution: intersection of ray with transformed primitive is the same as intersection with inversely transformed ray and primitive

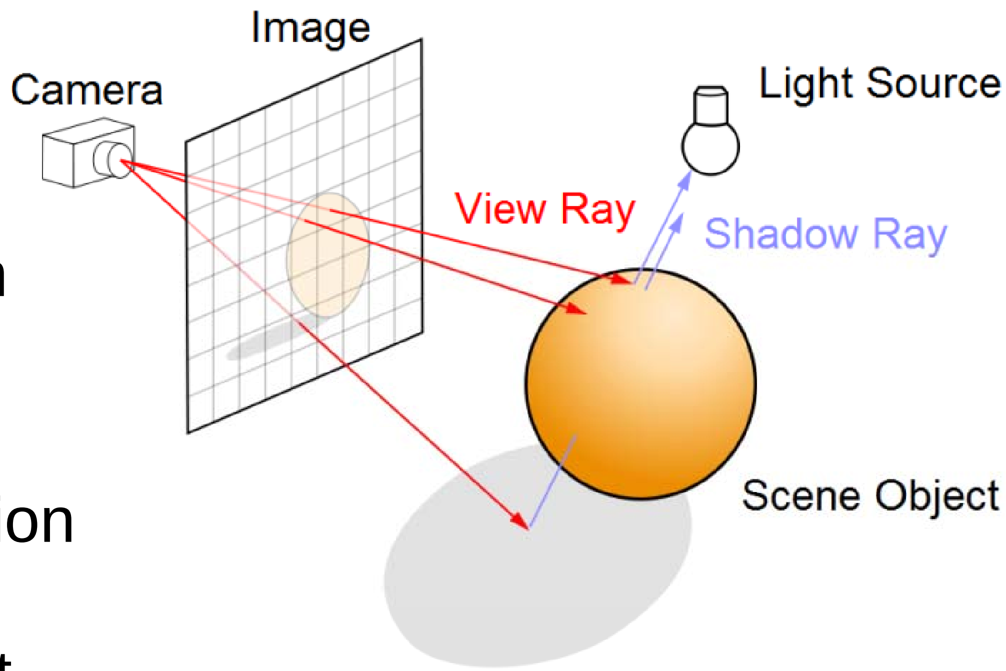
- Intersect with transformed ray ($\mathbf{eye_t} + \mathbf{d_t}\, t$)
  i.e. $\mathbf{eye_t} = \mathbf{M}^{-1}\,\mathbf{eye}$ and $\mathbf{d_t} = \mathbf{M}^{-1}\,\mathbf{d}$
- *t* for the intersection is the same in world and primitive space

Shadow Feelers

Problem: How do we know if a point **p** is in shadow of a light **l** ?

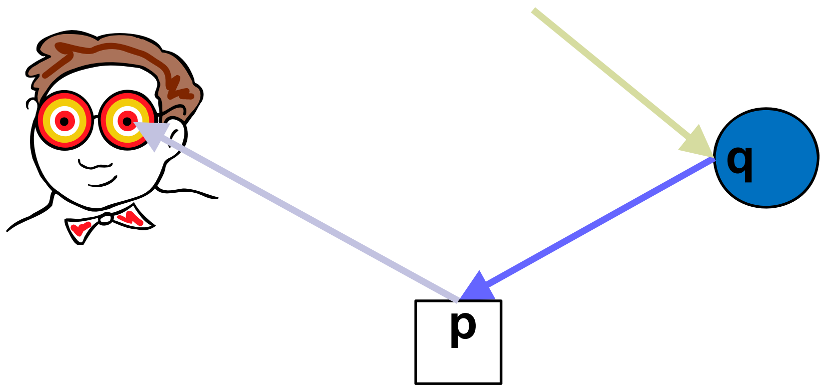
Solution: Check if there is something between **p** and **l**

1. Calculate (**source**, **d**) for a ray that starts at **p** and goes to **l** (a "shadow feeler")
2. Check if there is an intersection with any scene object (→ use `intersect`)
3. If there is a ray-object intersection between **p** and **l** then:
   do not illuminate **p** with the light
   i.e. do not add R_d and R_s
   Otherwise: normal illumination



Ray Tracing Reflections

Idea: the color of a point is influenced by the color that the ray carries over from the previous reflection



Ray is reflected at **q** (blue sphere) before being reflected at **p** (white box)
→ ray has bluish color when it hits the box

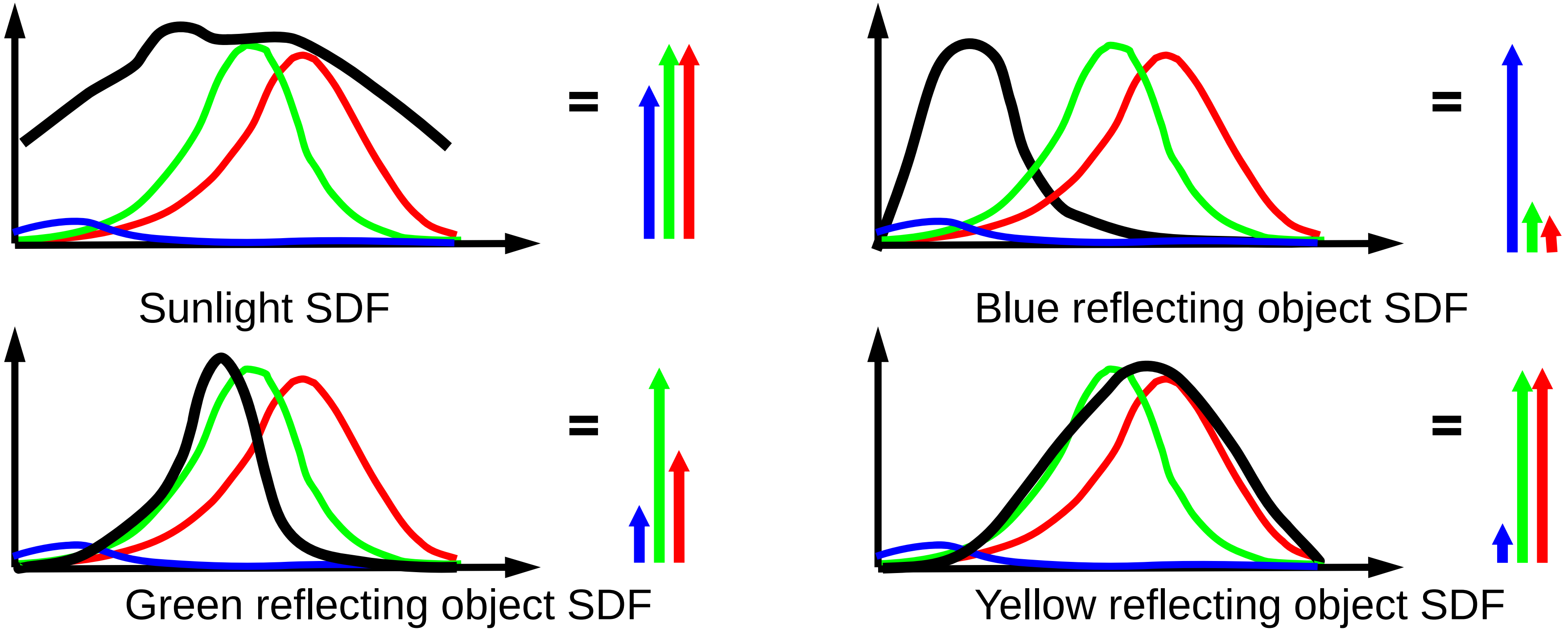
Reflectivity: fraction of incident radiation reflected by a surface (between 0 and 1)

Add the fraction of light reflected from q to the reflection at p:

$$R_p = R_{ambient,p} + R_{diffuse,p} + R_{specular,p} + reflectivity_p \; R_q$$

Seeing Red, Green, Blue (cont'd)

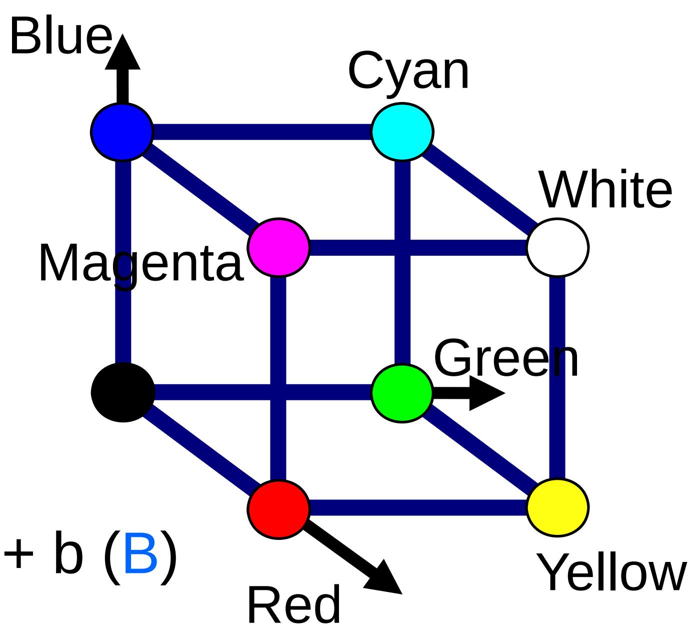
- Example L, M, S responses for various SDF's

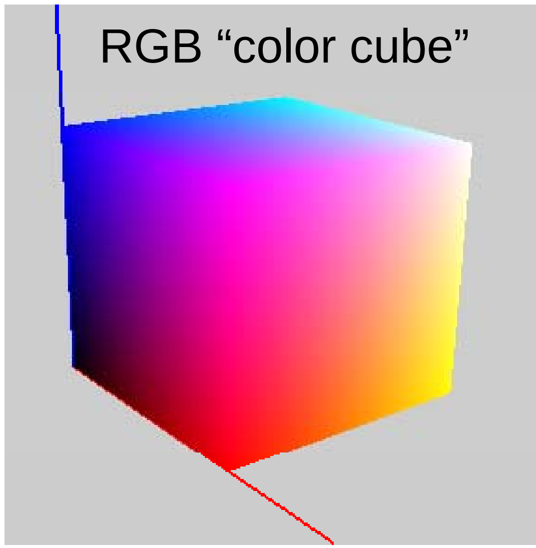


- Resulting L, M, and S SRF responses are independent values
- The 3 SRF response values are interpreted as hues by our brain, e.g. red + green = yellow, red + green + blue = white

Color Coordinate Space

- Defines 3 SRFs (**color matching functions**) for some sensing system
- One dimension for each SRF (→ **tristimulus color space**)
  - Each dimension represents a **primary color P**
  - Coordinate value = resulting SDF integral normalized to (0, 1)
- Color triple is 3D point defined by **chromaticity values** (c_0, c_1, c_2)
- Example: RGB color space
  - Primaries:
    Red, Green, Blue
    with basis vectors
    R = (0,0,1)
    G = (1,0,0)
    B = (0,1,0)
  - Chromaticity values:
    (r,g,b) = r (R) + g (G) + b (B)

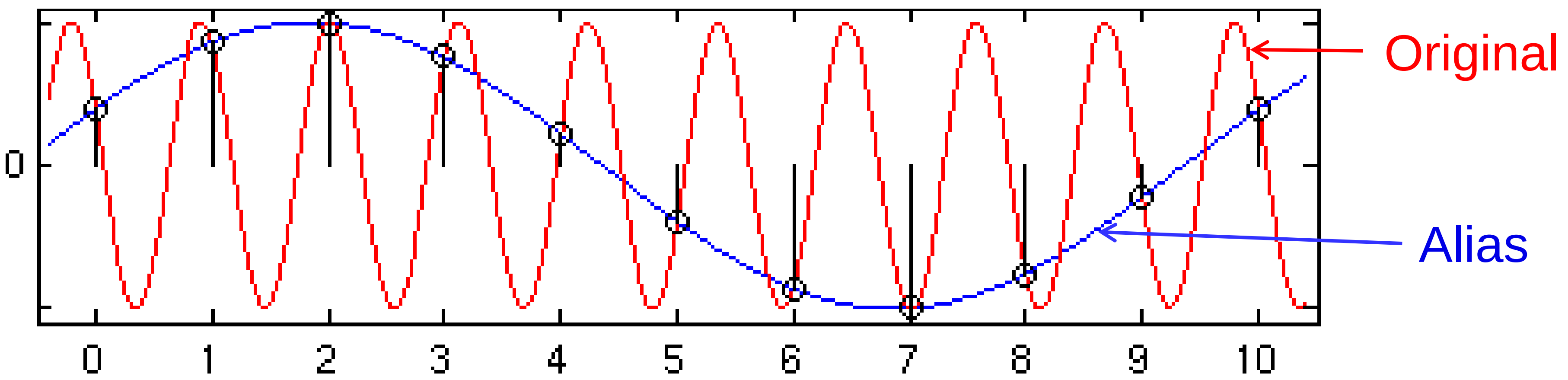




Aliasing

A signal looks like another signal (the “alias”) after sampling

- Not a problem if the signals are still very similar
- But is a problem if the alias looks really different ($\rightarrow$ aliasing artifacts)
- Happens particularly when sampling a high-frequency signal with a low sample frequency



Exam

- Multiple-choice only
- Closed book
- Question types in my part:
  - A few calculations (involving matrices)
  - Which formula is correct?
  - Which of the statements is false?
  - Given some code:
    - "What needs to be changed to achieve X?"
    - "What happens if you change X?"