Recall: Step 1: Create Texture Object

- OpenGL has **texture objects** (multiple objects possible)
  - 1 object stores 1 texture image + texture parameters
- First set up texture object

```
GLuint mytex[1];
glGenTextures(1, mytex);               // Get texture identifier
glBindTexture(GL_TEXTURE_2D, mytex[0]); // Form new texture object
```

- Subsequent texture functions use this object
- Another call to **`glBindTexture`** with new name starts new texture object

Recall: Step 2: Specifying a Texture Image

- Define input picture to paste onto geometry
- Define texture image as array of ***texels*** in CPU memory

```
Glubyte my_texels[512][512][3];
```

- Read in scanned images (jpeg, png, bmp, etc files)
  - If uncompressed (e.g bitmap): read into array from disk
  - If compressed (e.g. jpeg), use third party libraries (e.g. Qt, devil) to uncompress + load

bmp, jpeg, png, etc

Recall: Specify Image as a Texture

Tell OpenGL: this image is a texture!!

```
glTexImage2D( target, level, components,
    w, h, border, format, type, texels );
```

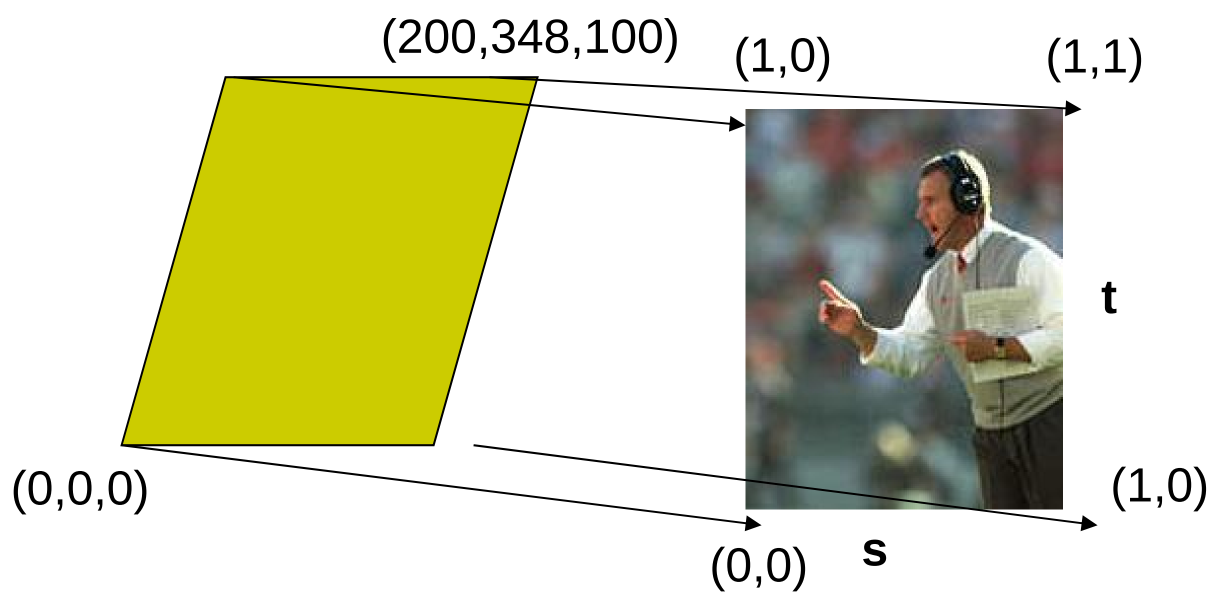
- `target:` type of texture, e.g. **`GL_TEXTURE_2D`**
- `level:` used for mipmapping (0: highest resolution. More later)
- `components:` elements per texel
- `w, h:` width and height of **`texels`** in pixels
- `border:` used for smoothing (discussed later)
- `format,type:` describe texels
- `texels:` pointer to texel array

Example:

```
glTexImage2D(GL_TEXTURE_2D, 0, 3, 512, 512, 0, GL_RGB,
  GL_UNSIGNED_BYTE, my_texels);
```

Recall: Step 3: Assign Object Corners to Texture Corners

- Each object corner (x,y,z) => image corner (s, t)
  - E.g. object (200,348,100) => (1,1) in image
- Programmer esablishes this mapping
- Target polygon can be any size/shape



Recall: Step 5: Passing Texture to Shader

- Pass vertex, texture coordinate data as vertex array
- Set texture unit

Variable names in shader

```
offset = 0;
GLuint vPosition = glGetAttribLocation( program, "vPosition" );
glEnableVertexAttribArray( vPosition );
glVertexAttribPointer( vPosition, 4, GL_FLOAT, GL_FALSE,
   0,BUFFER_OFFSET(offset) );

offset += sizeof(points);
GLuint vTexCoord = glGetAttribLocation( program, "vTexCoord" );
glEnableVertexAttribArray( vTexCoord );
glVertexAttribPointer( vTexCoord, 2,GL_FLOAT,
    GL_FALSE, 0, BUFFER_OFFSET(offset) );

// Set the value of the fragment shader texture sampler variable
//   ("texture") to the the appropriate texture unit.

glUniform1i( glGetUniformLocation(program, "texture"), 0 );
```

Recall: Step 6: Apply Texture in Shader (Fragment Shader)

- Textures applied in fragment shader
- Samplers return a texture color from a texture object

```
in vec4 color;  //color from rasterizer
in vec2 texCoord; //texure coordinate from rasterizer
uniform sampler2D texture; //texture object from application

void main()  {
    gl_FragColor = color * texture2D( texture, texCoord );
}
```

Output color Of fragment (gl_FragColor)

Original color of object (color)

Lookup color of texCoord (s,t) in texture (texture2D(texture, texCoord))

6 Main Steps to Apply Texture

1. Create texture object
2. Specify the texture
   - Read or generate image
   - assign to texture (hardware) unit
   - enable texturing (turn on)
3. Assign texture (corners) to Object corners
4. Specify texture parameters
   - wrapping, filtering
5. Pass textures to shaders
6. Apply textures in shaders

still haven't talked about setting texture parameters

Step 4: Specify Texture Parameters

- Texture parameters control how texture is applied
  - Wrapping parameters used if s,t outside (0,1) range

    Clamping: if s,t > 1 use 1, if s,t <0 use 0

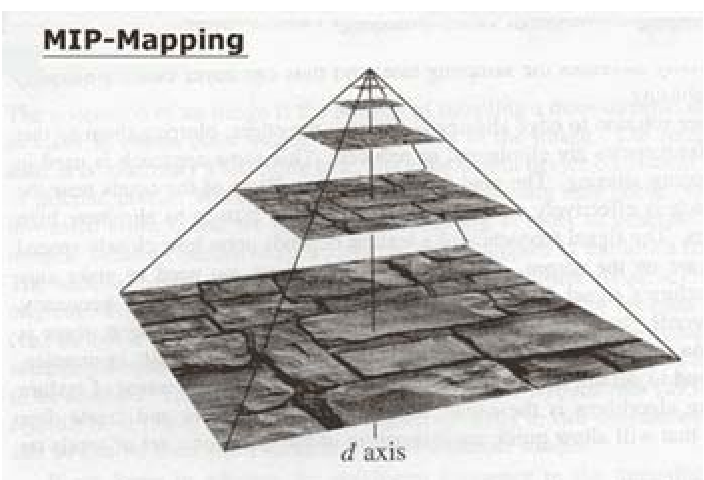
    Wrapping: use s,t modulo 1

```
glTexParameteri( GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_CLAMP )
glTexParameteri( GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_REPEAT )
```

Step 4: Specify Texture Parameters Mipmapped Textures

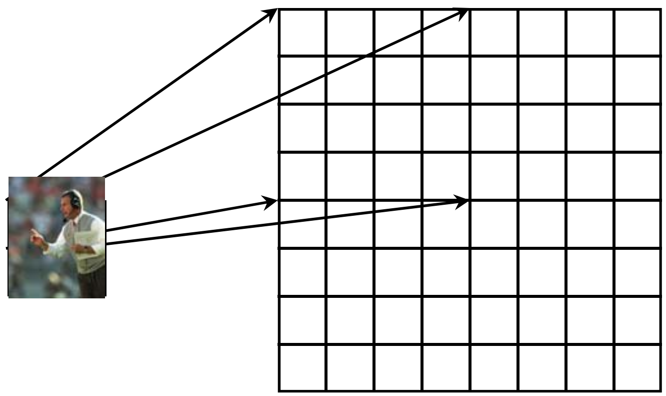
- Mipmapping pre-generates prefiltered (averaged) texture maps of decreasing resolutions
- Declare mipmap level during texture definition

```
glTexImage2D( GL_TEXTURE_*D, level, … )
```

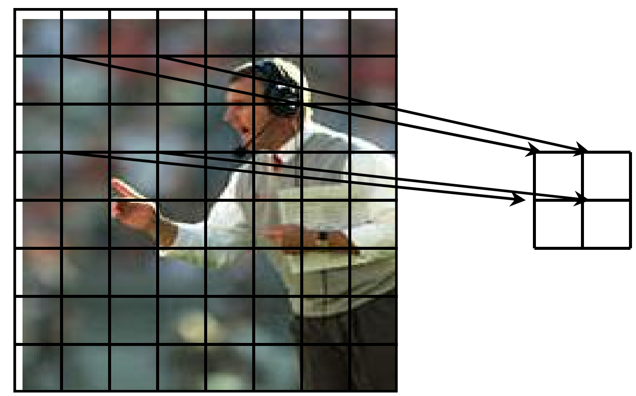


Magnification and Minification

Magnification: Stretch small texture to fill many pixels
Minification: Shrink large texture to fit few pixels

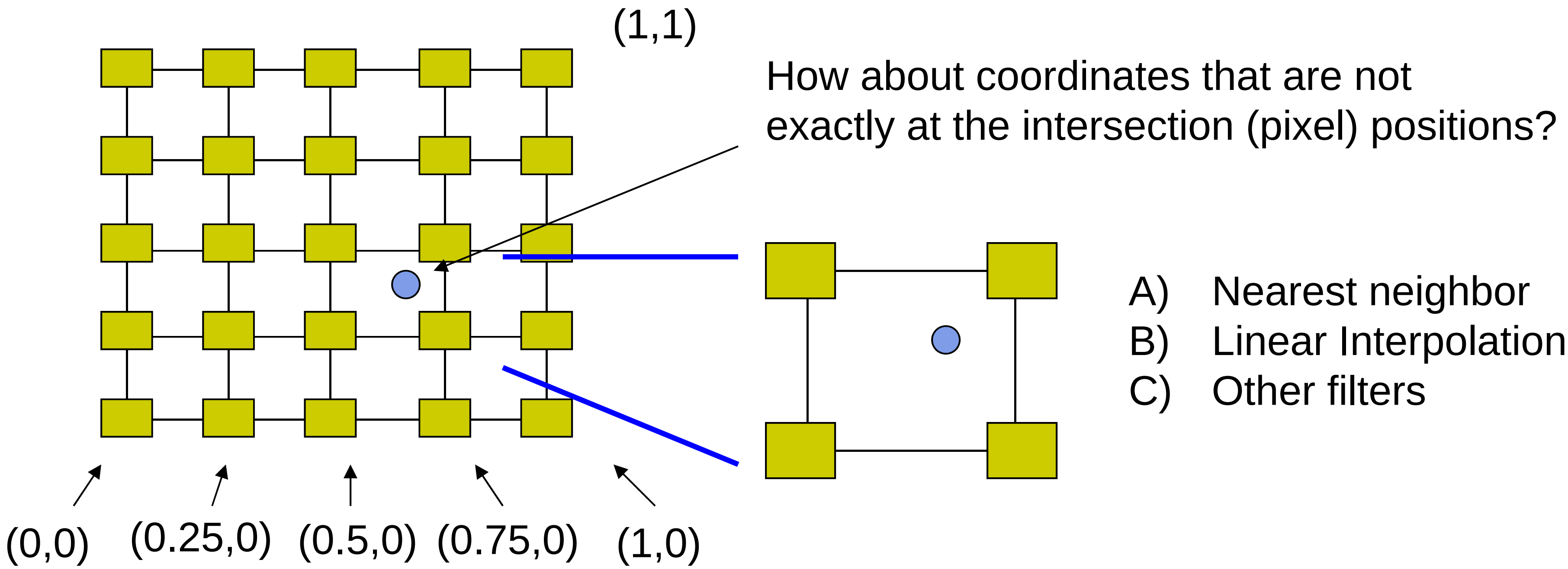


Texture Polygon
Magnification



Texture Polygon
Minification

Step 4: Specify Texture Parameters
Texture Value Lookup



A) Nearest neighbor
B) Linear Interpolation
C) Other filters

Example: Texture Magnification

- 48 x 48 image projected (stretched) onto 320 x 320 pixels

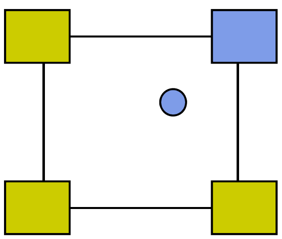
Nearest neighbor filter

Bilinear filter (avg 4 nearest texels)

Cubic filter (weighted avg. 5 nearest texels)

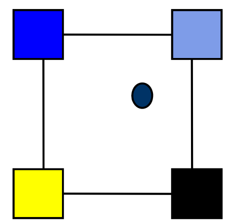
Texture mapping parameters

1) Nearest Neighbor (lower image quality)



glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_NEAREST);

2) Linear interpolate the neighbors (better quality, slower)

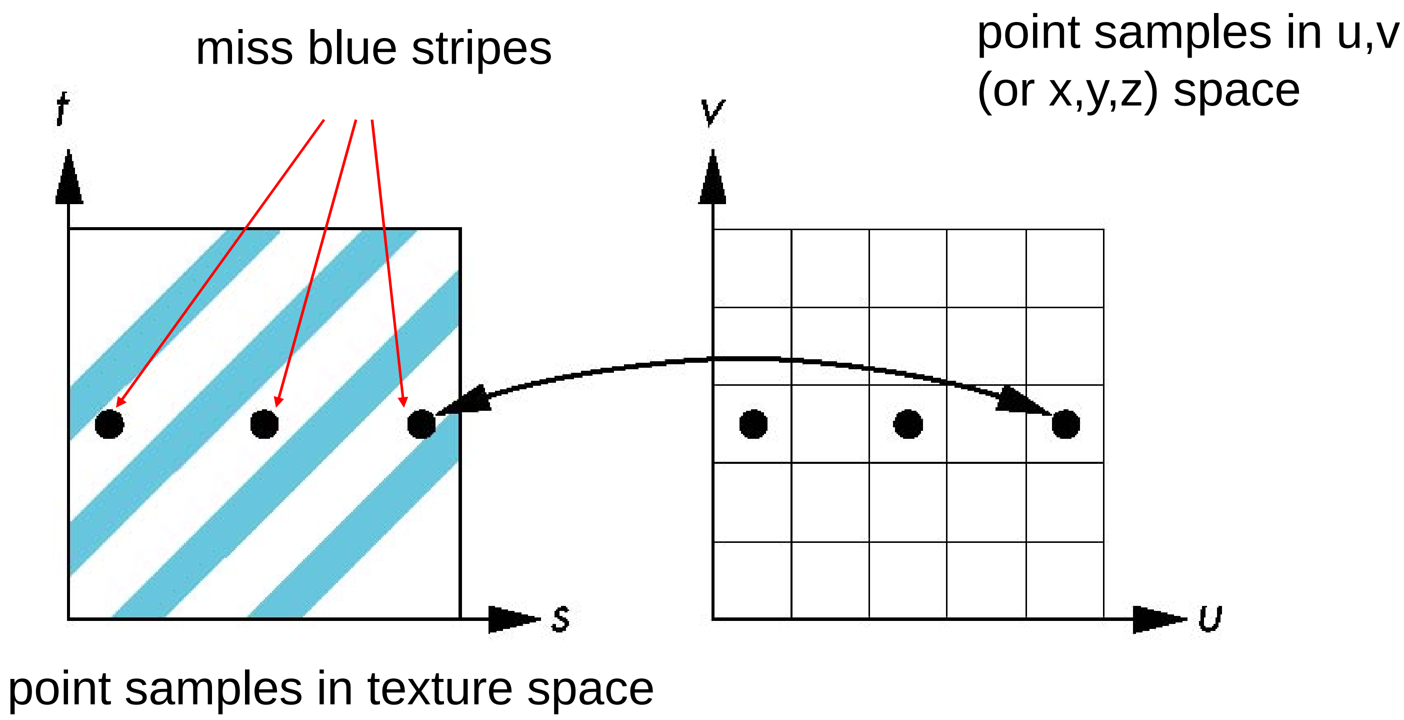


glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR)

Or GL_TEXTURE_MAX_FILTER

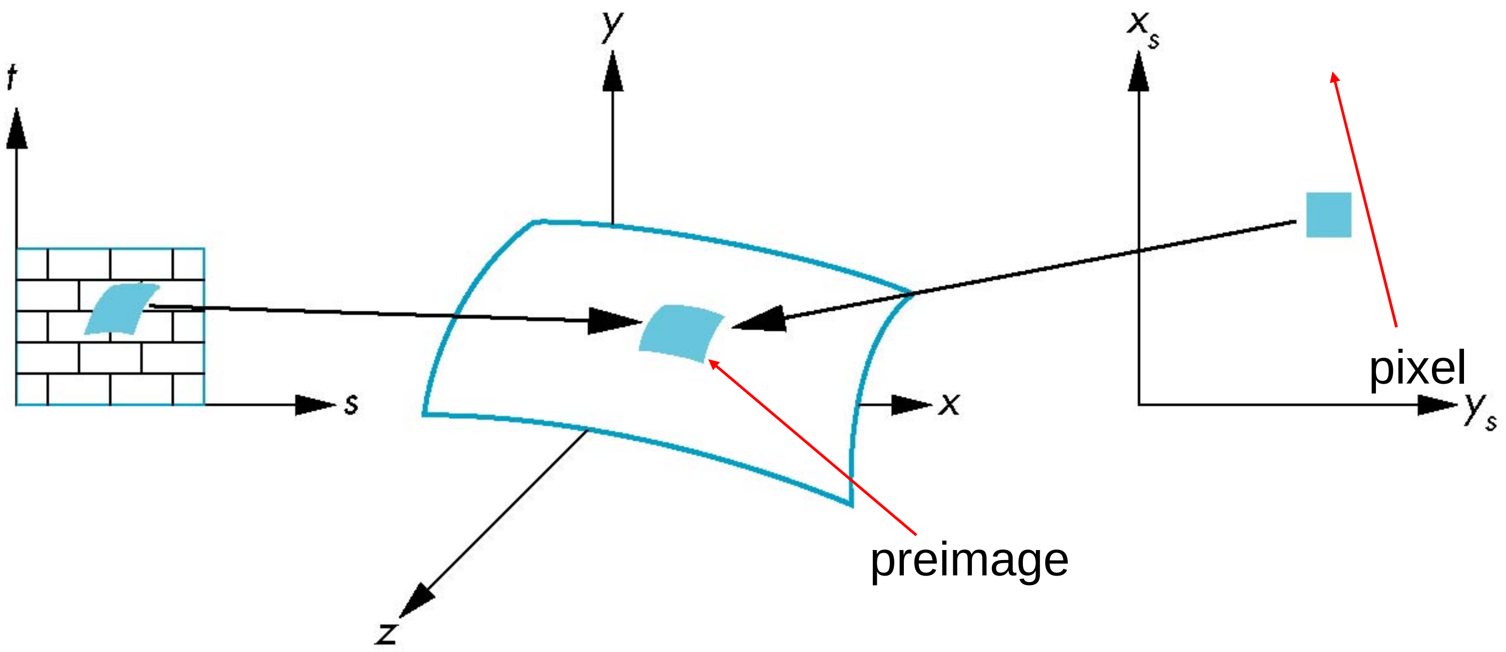
Dealing with Aliasing

- Point sampling of texture can lead to aliasing errors



Area Averaging

Better but slower option is ***area averaging***



Other Stuff

- Wrapping texture onto curved surfaces. E.g. cylinder, can, etc

$$s = \frac{\theta - \theta_a}{\theta_b - \theta_a} \qquad t = \frac{z - z_a}{z_b - z_a}$$

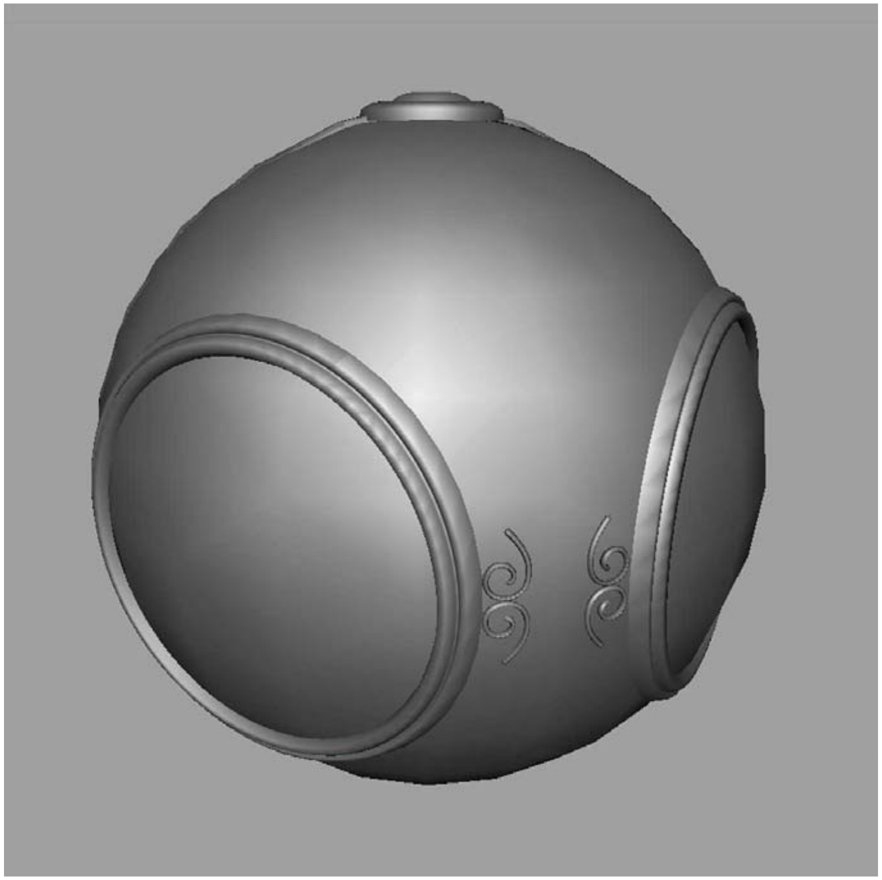
- Wrapping texture onto sphere

$$s = \frac{\theta - \theta_a}{\theta_b - \theta_a} \qquad s = \frac{\phi - \phi_a}{\phi_b - \phi_a}$$

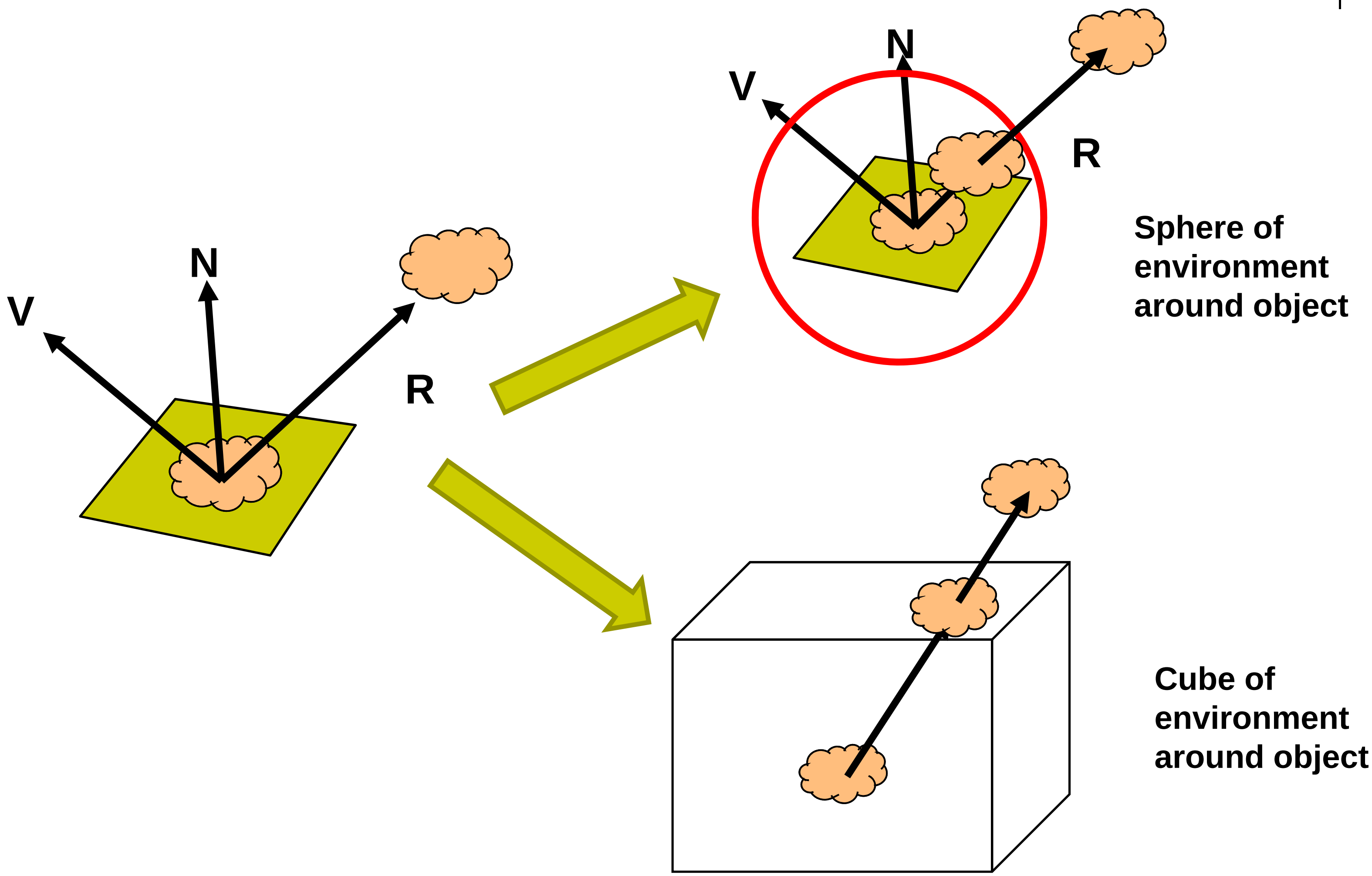
- Bump mapping: perturb surface normal by a quantity proportional to texture

Environment Mapping

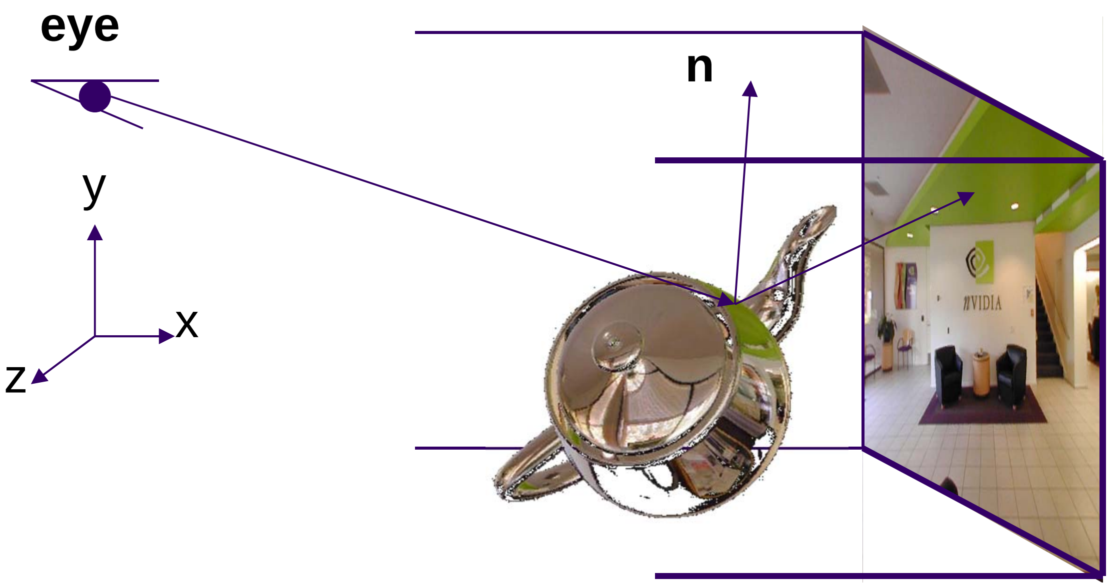
- Environmental mapping is way to create the appearance of highly reflective surfaces

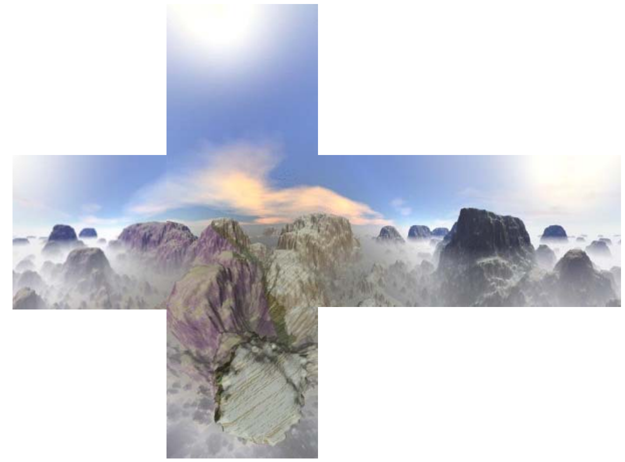


Reflecting the Environment



Cube mapping

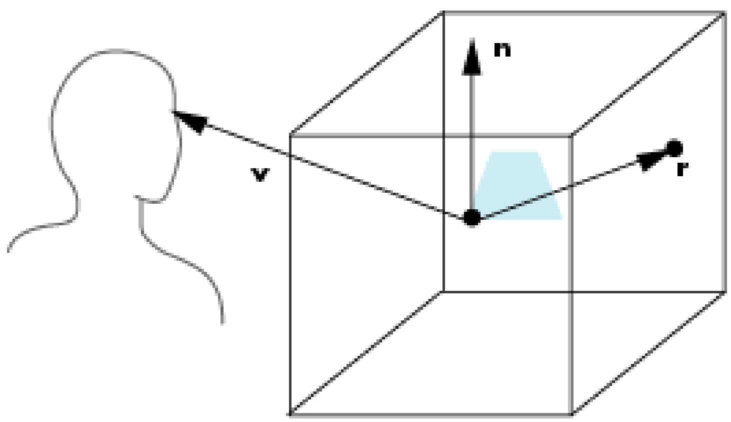




- Need to compute reflection vector, $\mathbf{r}$
- Use $\mathbf{r}$ by for lookup
- OpenGL: hardware support for cube maps

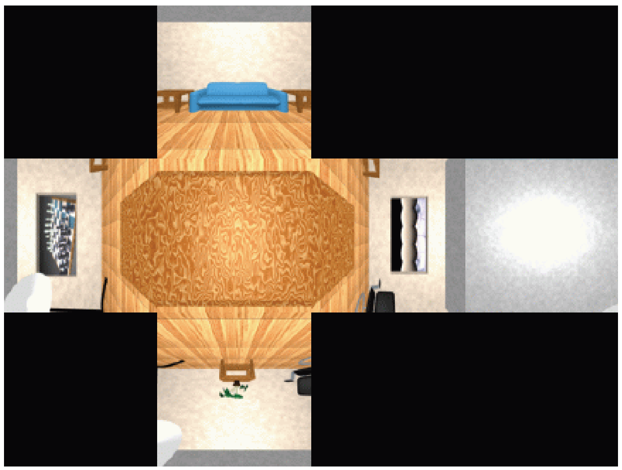
Environment Map

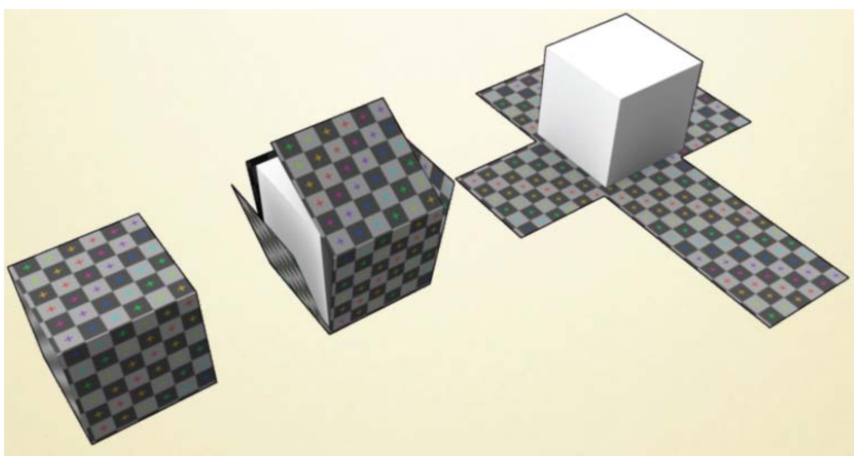
Use reflection vector to locate texture in cube map



Cube Environment Map Example

- Six textures: one for each face cube surrounding object
- Load 6 textures separately into 1 OpenGL cubemap





Cube Maps

- Loaded cube map texture can be accessed in GLSL through cubemap sampler

```
vec4 texColor = textureCube(mycube, texcoord);
```

- Texture coordinates must be 3D

Computer Graphics (CS 4731)
Lecture 21: Clipping

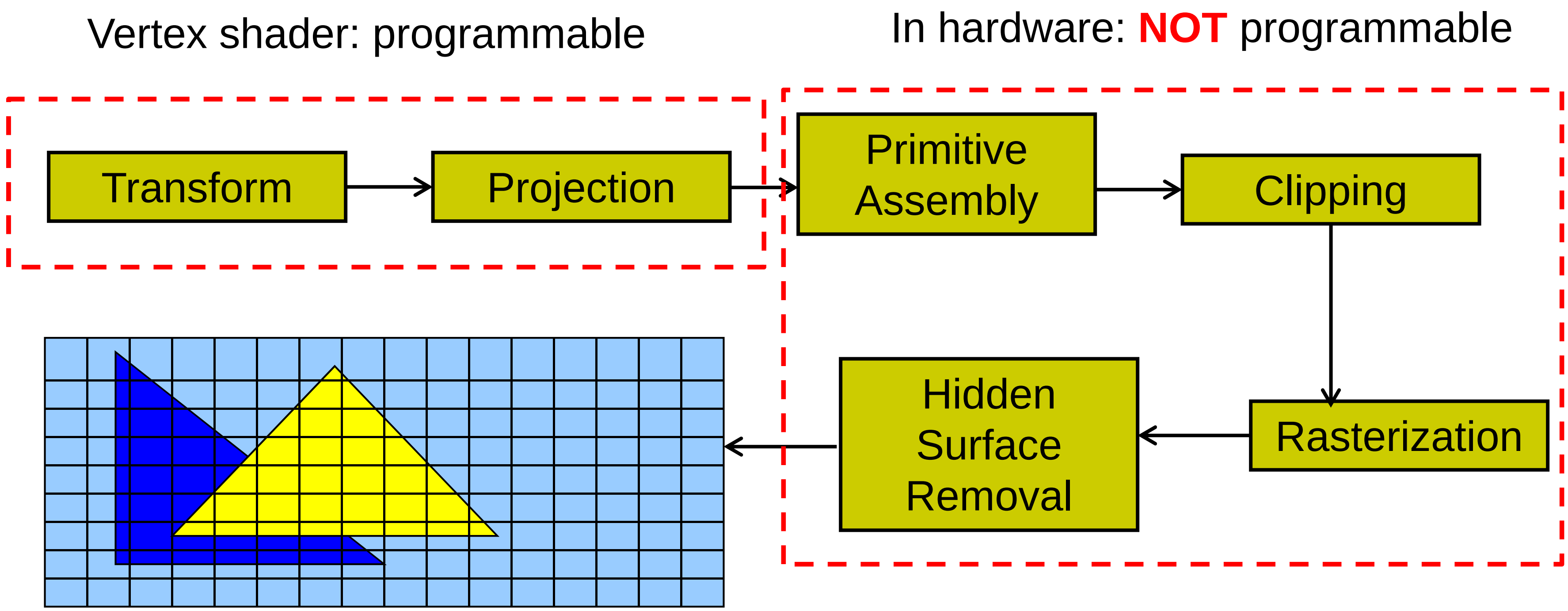
Prof Emmanuel Agu

Computer Science Dept.

Worcester Polytechnic Institute (WPI)

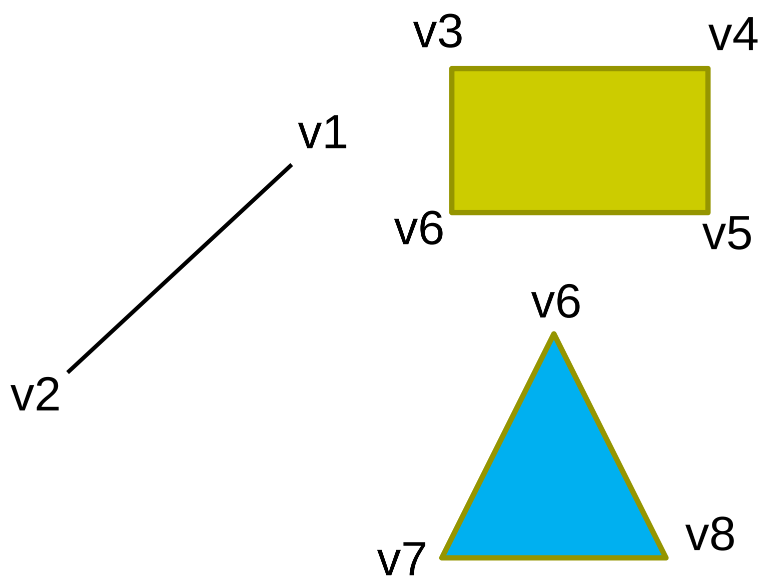
OpenGL Stages

- After projection, several stages before objects drawn to screen
- These stages are non-programmable



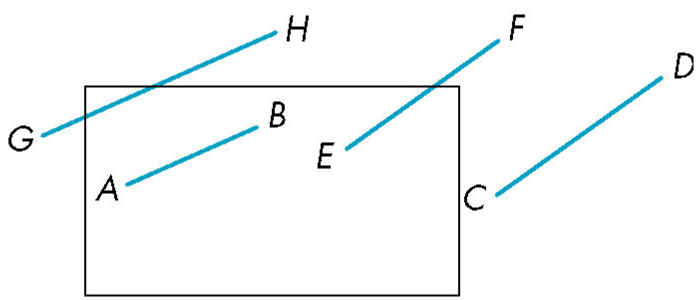
Hardware Stage: Primitive Assembly

- Up till now: Transformations and projections applied to vertices individually
- **Primitive assembly:** After transforms, projections, individual vertices grouped back into primitives
- **E.g. v6, v7 and v8** grouped back into triangle

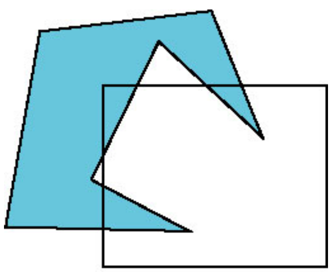


Hardware Stage: Clipping

- After primitive assembly, subsequent operations are per-primitive
- **Clipping:** Remove primitives (lines, polygons, text, curves) outside view frustum (canonical view volume)



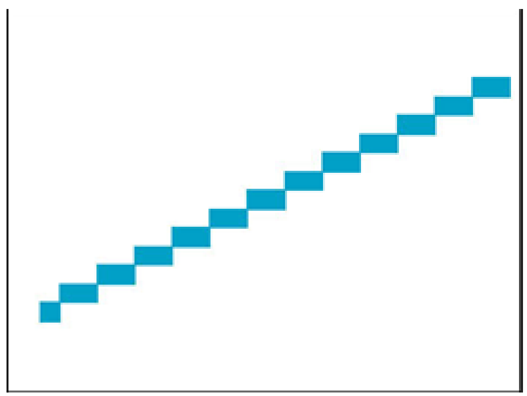
Clipping lines



Clipping polygons

Rasterization

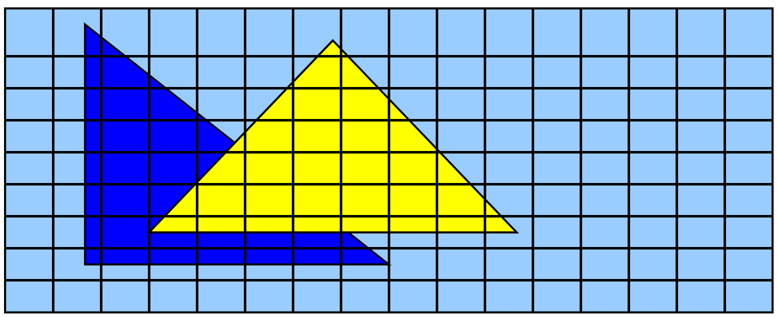
- Determine which pixels that primitives map to
  - Fragment generation
  - Rasterization or scan conversion



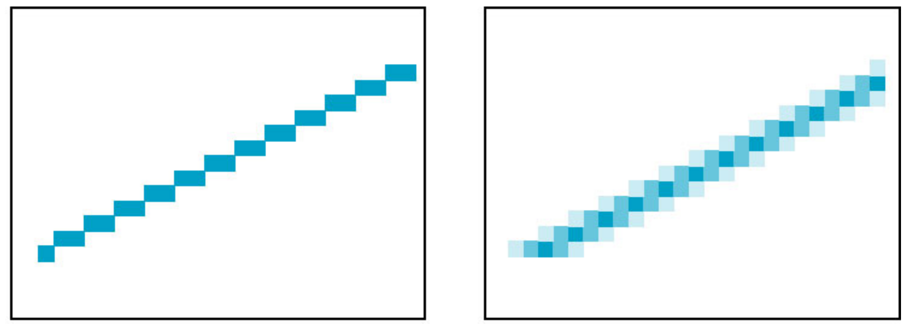
Fragment Processing

- Some tasks deferred until fragment processing

Hidden Surface Removal



Antialiasing

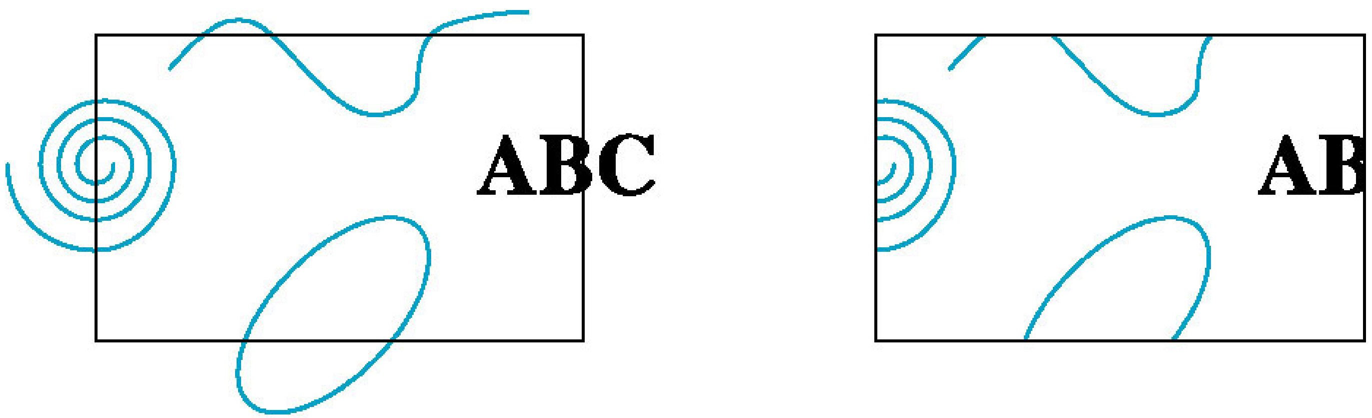


Transformation
Projection

Hidden surface Removal
Antialiasing

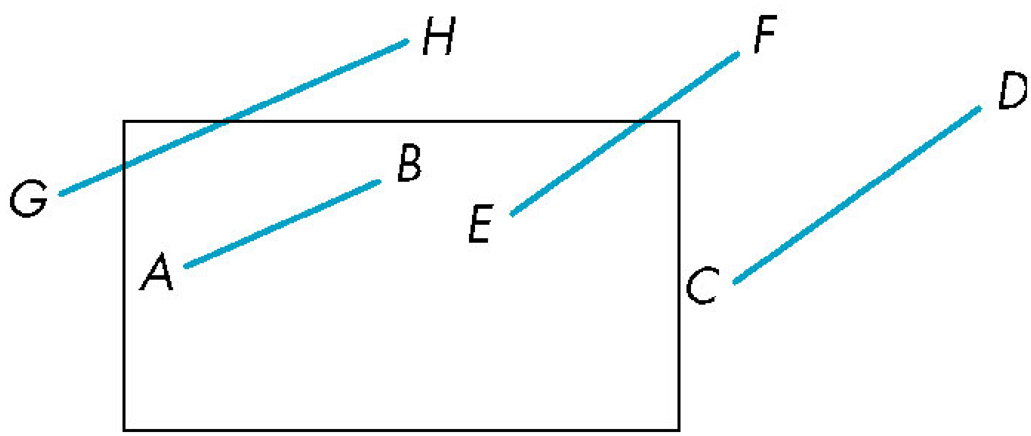
Clipping

- 2D and 3D clipping algorithms
  - 2D against clipping window
  - 3D against clipping volume
- 2D clipping
  - Lines (e.g. dino.dat)
  - Polygons
  - Curves
  - Text



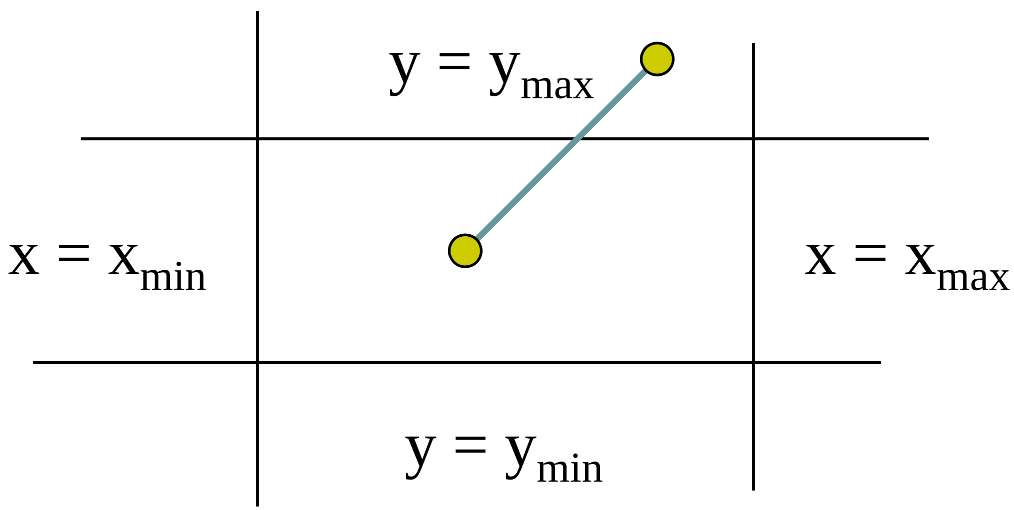
Clipping 2D Line Segments

- **Brute force approach:** compute intersections with all sides of clipping window
  - Inefficient: one division per intersection

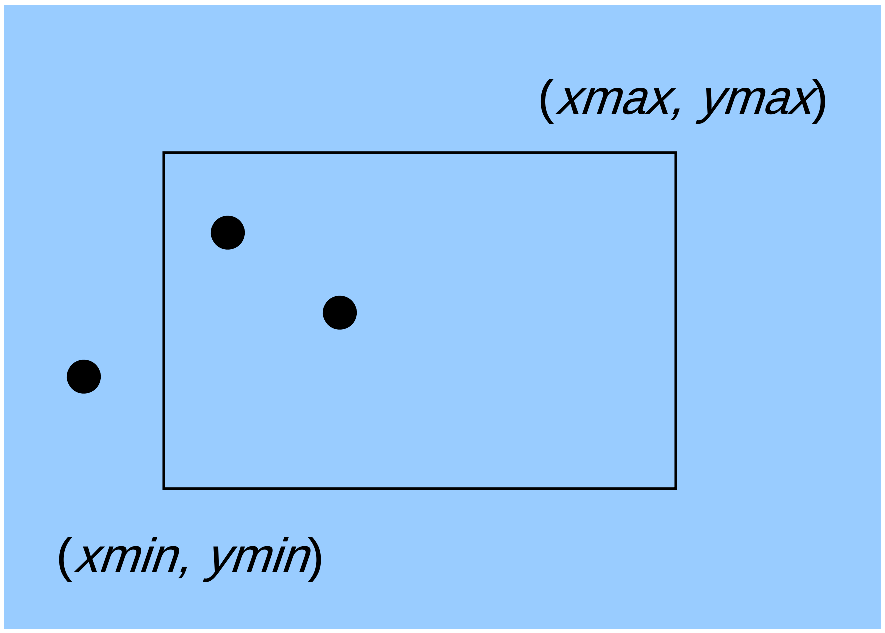


2D Clipping

- **Better Idea:** eliminate as many cases as possible without computing intersections
- Cohen-Sutherland Clipping algorithm



Clipping Points

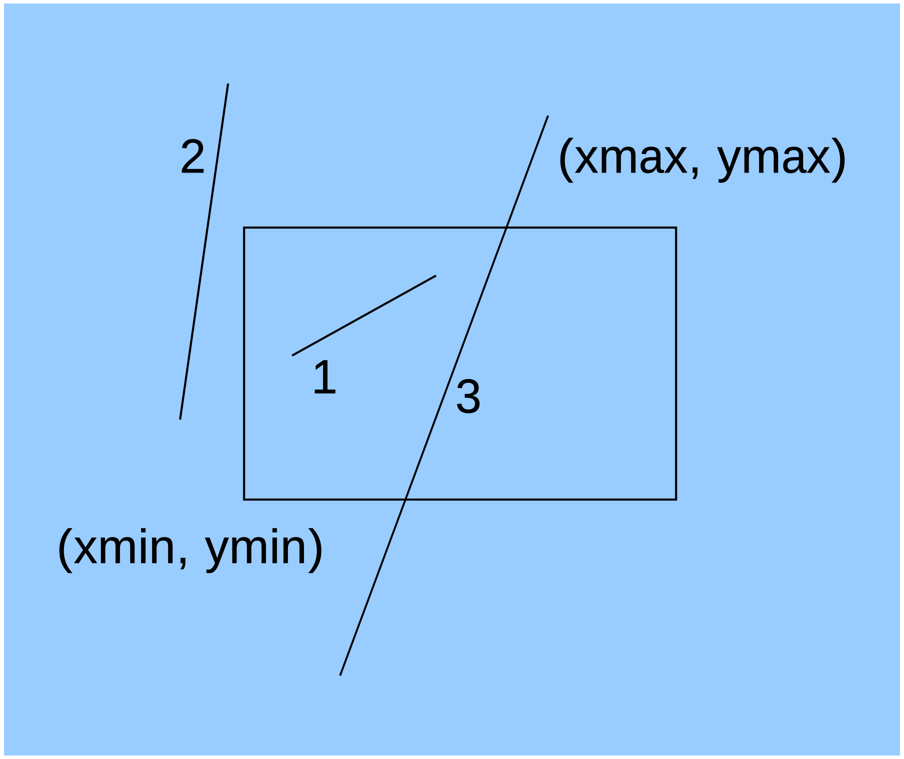


Determine whether a point (x,y) is inside or outside of the world window?

If (xmin <= x <= xmax)
and (ymin <= y <= ymax)

then the point (x,y) is inside
else the point is outside

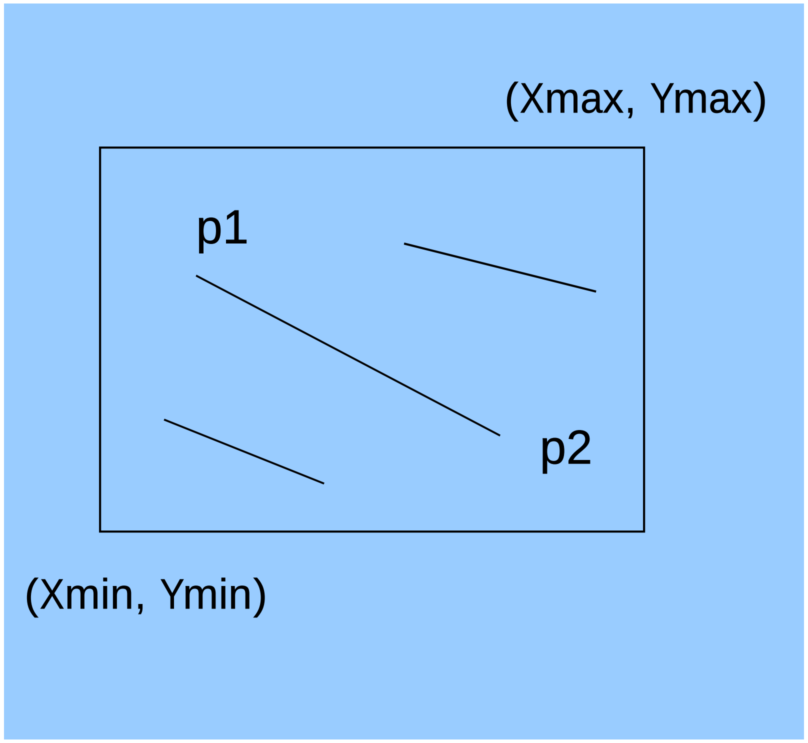
Clipping Lines



3 cases:

Case 1: All of line in
Case 2: All of line out
Case 3: Part in, part out

Clipping Lines: Trivial Accept



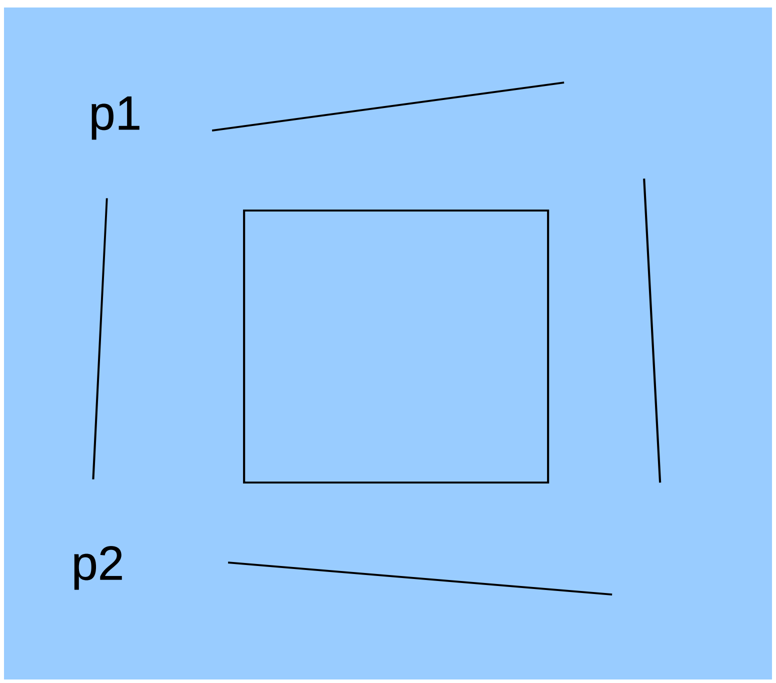
Case 1: All of line in
Test line endpoints:

Xmin <= P1.x, P2.x <= Xmax and
Ymin <= P1.y, P2.y <= Ymax

Note: simply comparing x,y values of endpoints to x,y values of rectangle

Result: trivially accept.
Draw line in completely

Clipping Lines: Trivial Reject



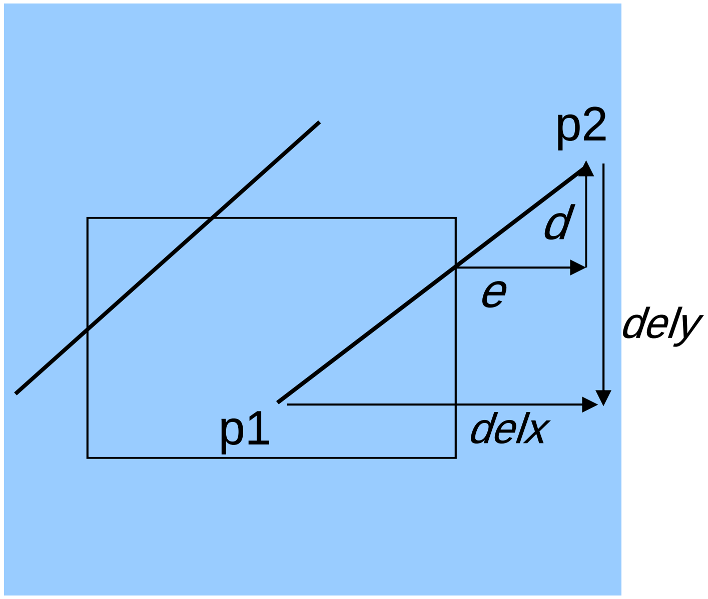
Case 2: All of line out
Test line endpoints:

- ***p1.x, p2.x <= Xmin*** **OR**
- ***p1.x, p2.x >= Xmax*** **OR**
- ***p1.y, p2.y <= ymin*** **OR**
- ***p1.y, p2.y >= ymax***

Note: simply comparing x,y values of endpoints to x,y values of rectangle

Result: trivially reject.
Don't draw line in

Clipping Lines: Non-Trivial Cases



Case 3: Part in, part out

Two variations:

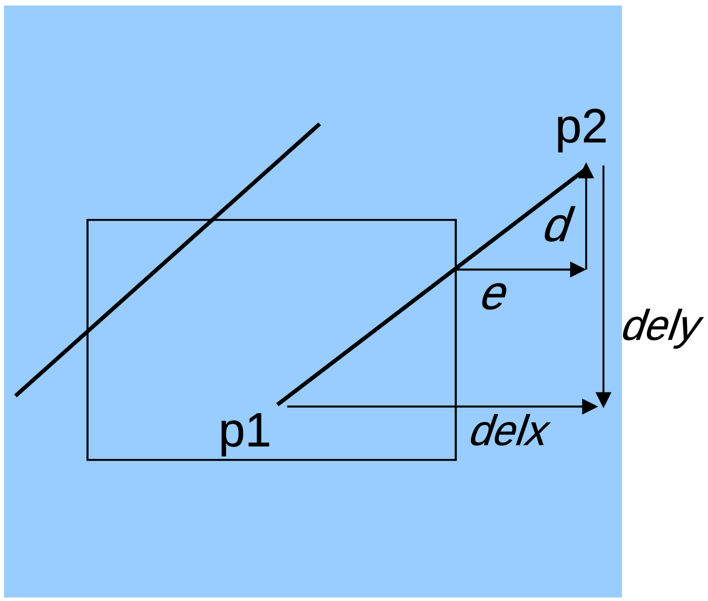
- One point in, other out
- Both points out, but part of line cuts through viewport

Need to find inside segments

Use similar triangles to figure out length of inside segments

$$\frac{d}{dely} = \frac{e}{delx}$$

Clipping Lines: Calculation example



$$\frac{d}{dely} = \frac{e}{delx}$$

If chopping window has
(left, right, bottom, top) = (30, 220, 50, 240),
what happens when the following lines are chopped?

(a) p1 = (40,140), p2 = (100, 200)

(b) p1 = (20,10), p2 = (20, 200)

(c) p1 = (100,180), p2 = (200, 250)

Cohen-Sutherland pseudocode (Hill)

```
int clipSegment(Point2& p1, Point2& p2, RealRect W)
{
   do{
        if(trivial accept) return 1; // whole line survives
        if(trivial reject) return 0;  // no portion survives
        // now chop
        if(p1 is outside)
        //  find surviving segment
        {
            if(p1 is to the left) chop against left edge
            else if(p1 is to the right) chop against right edge
            else if(p1 is below) chop against the bottom edge
           else if(p1 is above) chop against the top edge
        }
```

Cohen-Sutherland pseudocode (Hill)

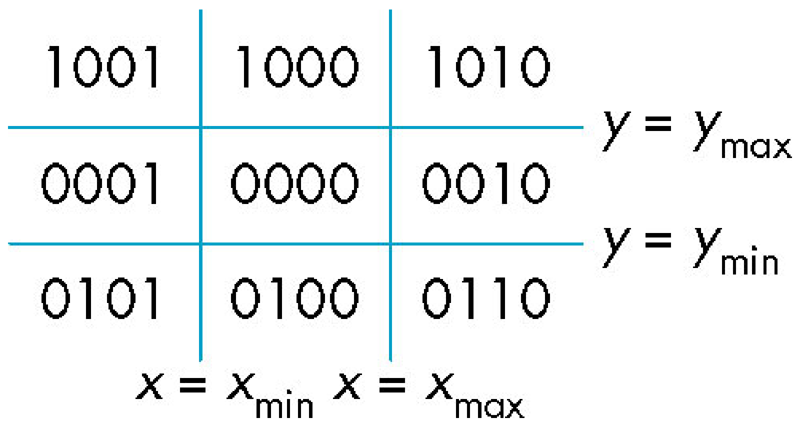
```
        else // p2 is outside
                // find surviving segment
        {
            if(p2 is to the left) chop against left edge
          else if(p2 is to right) chop against right edge
          else if(p2 is below) chop against the bottom edge
          else if(p2 is above) chop against the top edge
        }
   }while(1);
}
```

Using Outcodes to Speed Up Comparisons

- Encode each endpoint into outcode (what quadrant)

$b_0 b_1 b_2 b_3$

$b_0 = 1$ if $y > y_{max}$, 0 otherwise
$b_1 = 1$ if $y < y_{min}$, 0 otherwise
$b_2 = 1$ if $x > x_{max}$, 0 otherwise
$b_3 = 1$ if $x < x_{min}$, 0 otherwise



- Outcodes divide space into 9 regions
- Trivial accept/reject becomes bit-wise comparison

References

- Angel and Shreiner, Interactive Computer Graphics, 6th edition
- Hill and Kelley, Computer Graphics using OpenGL, 3rd edition