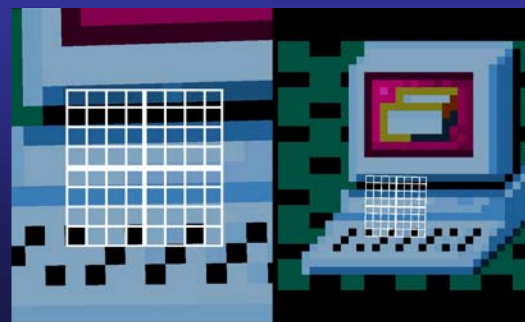
Texture Filtering

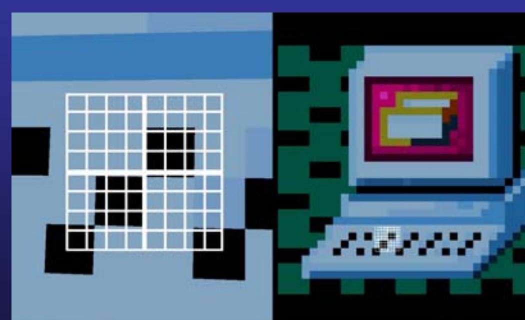
MipMaps

“Optimal” case



Minification

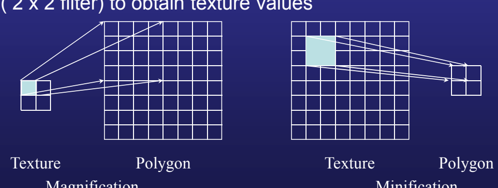
Magnification



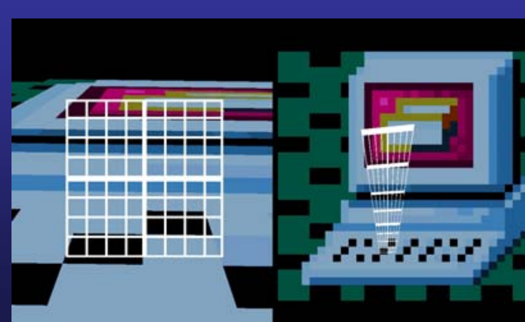
Magnification and Minification

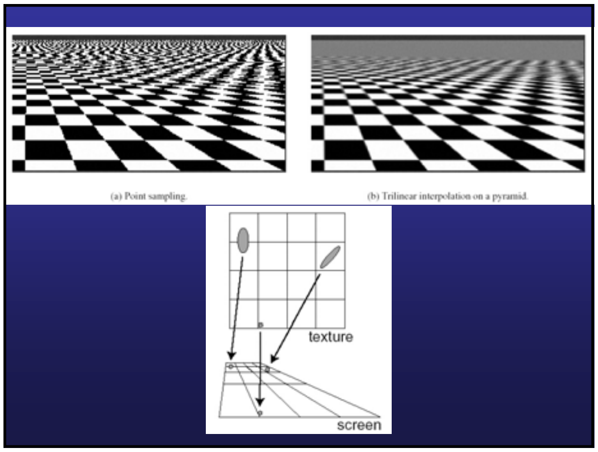
More than one texel can cover a pixel (*minification*) or more than one pixel can cover a texel (*magnification*)

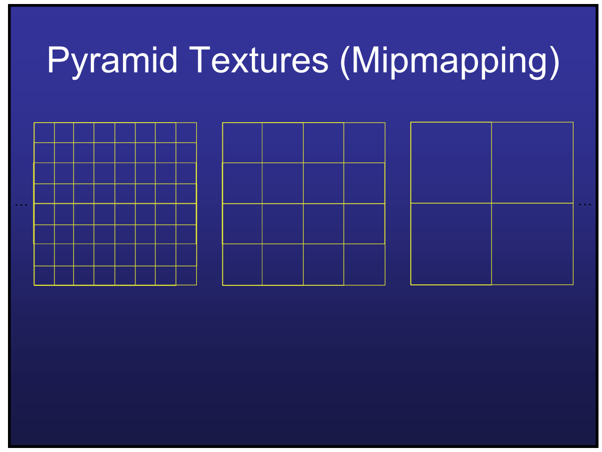
Can use point sampling (nearest texel) or linear filtering (2 x 2 filter) to obtain texture values

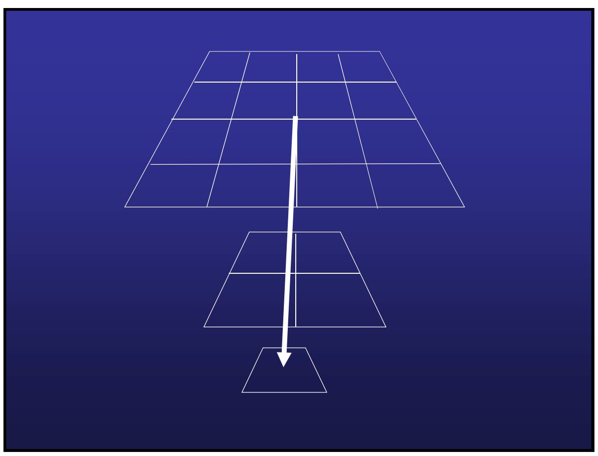


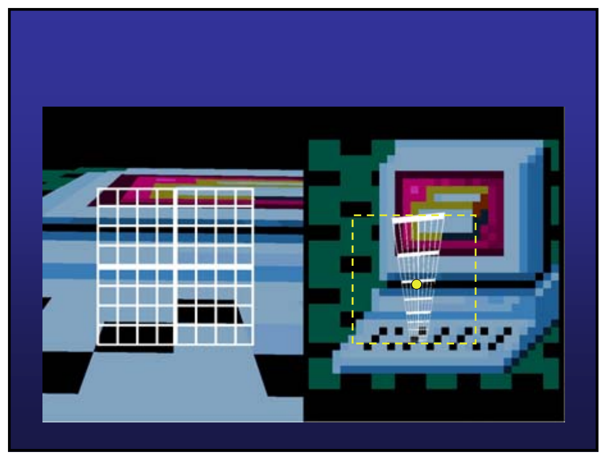
Pixel Footprint

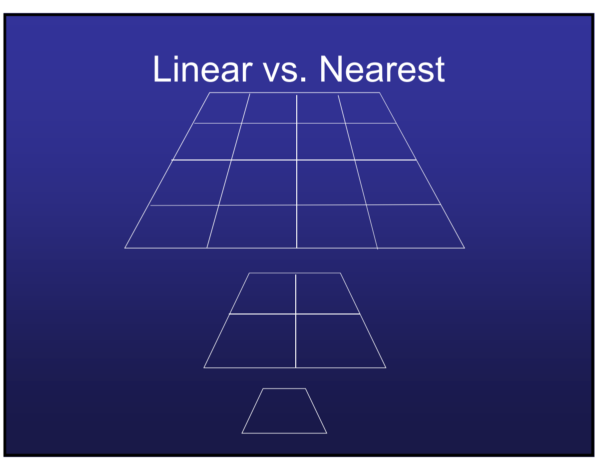


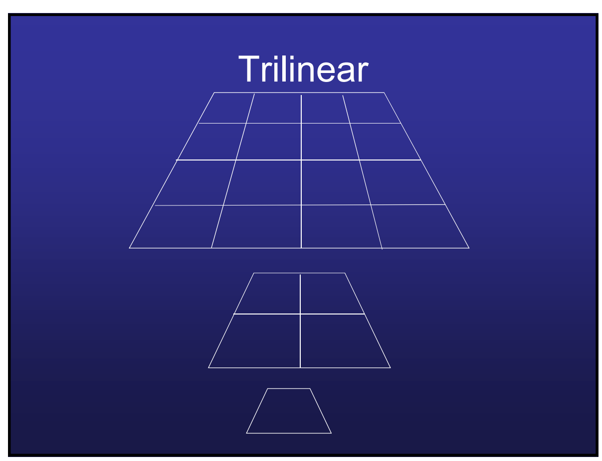

(a) Point sampling.
(b) Trilinear interpolation on a pyramid.
texture
screen


Pyramid Textures (Mipmapping)

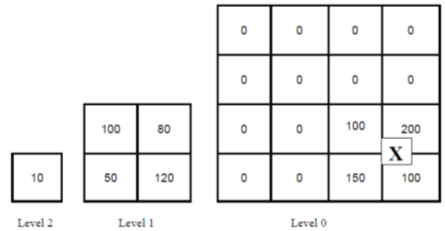





Linear vs. Nearest


Trilinear

DEMO



Given the above luminance texture.
Counting from zero at **Level 0**,
a fragment's center falls at the X (75% away from the left-most texel).
The texel values shown are at the center of the texels (as shown)

It's projection is **d=0.75**.

Mipmapped Textures

- *Mipmapping* allows for prefiltered texture maps of decreasing resolutions
- Lessens interpolation errors for smaller textured objects
- Declare mipmap level during texture definition

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

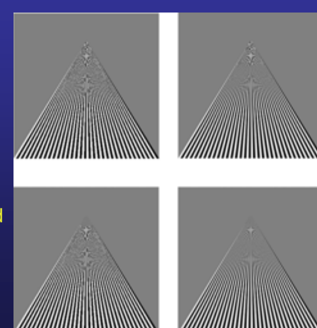
- GL mipmap builder routines will build all the textures from a given image

```
glGenerateMipmap(GL_TEXTURE_*D)
```

Example

point sampling

linear filtering

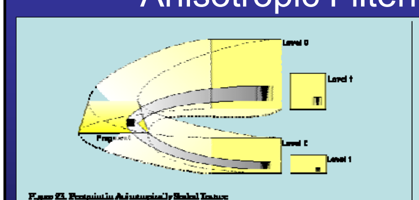


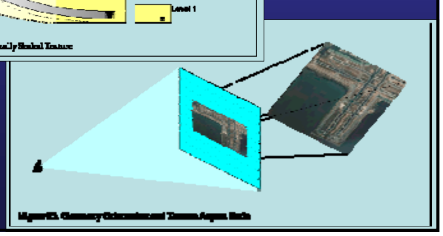
mipmapped point sampling

mipmapped linear filtering

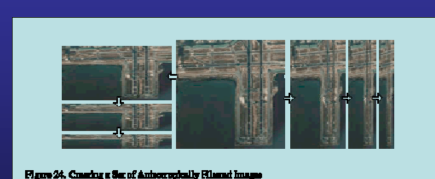
Demo

Anisotropic Filtering

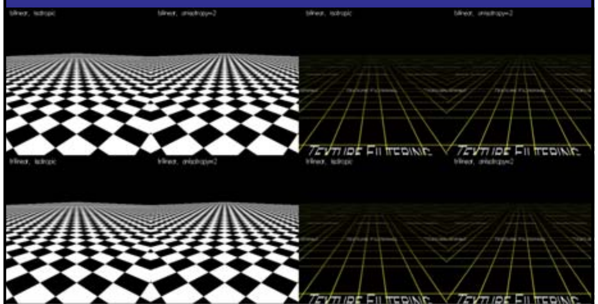


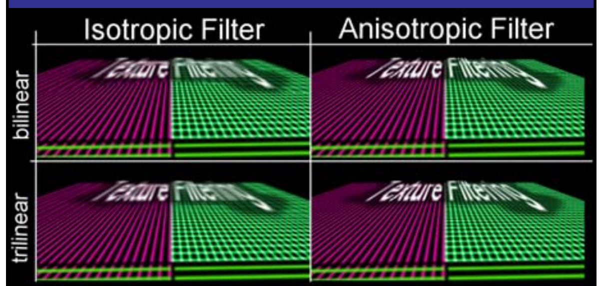


Anisotropic Filtering



Anisotropic Filtering



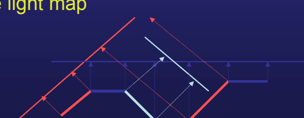


Light Mapping

- In order to keep the texture and light maps separate, we need to be able to perform multitexturing – application of multiple textures in a single rendering pass

Light Mapping

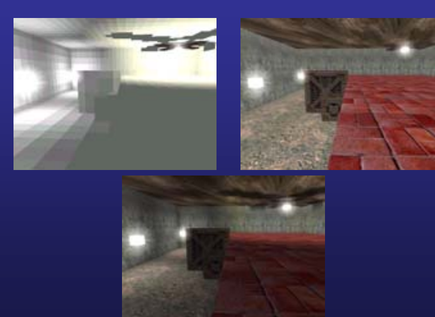
- How do you create light maps?
- Trying to create a light map that will be used on a non-planar object things get complex fast:
  - Need to find a divide object into triangles with similar orientations
  - These similarly oriented triangles can all be mapped with a single light map



Light Mapping

- Things for standard games are usually much easier since the objects being light mapped are usually planar:
  - Walls
  - Ceilings
  - Boxes
  - Tables
- Thus, the entire planar object can be mapped with a single texture map

Light Mapping



Light Mapping

- Can dynamic lighting be simulated by using a light map?
- If the light is moving (perhaps attached to the viewer or a projectile) then the lighting will change on the surface as the light moves
  - Moving 'flashlight' (use texture coordinate transformation matrix)
  - The light map values can be partially updated dynamically as the program runs
  - Several light maps at different levels of intensity could be pre-computed and selected depending on the light's distance from the surface

Lightmaps

- Creating local contribution

Lightmap

Unlit Scene

Lightmap Intensity

Local Light Contribution

Lightmaps

- Adding local light to scene

OpenGL Lighting

Combined Image

- Demo

Lightmaps

- Cached Lighting Results
  - Reuse lighting calculations
    - Multiple local lights (same type)
    - Static portion of scene's light field
    - Sample region with texture instead of tessellating
  - Low resolution sampling
    - Local lighting; rapid change over small area
    - Global lighting; slow change over large area

Lightmaps

- Segmenting Scene Lighting
  - Static vs. dynamic light fields
  - Global vs. local lighting
  - Similar light shape

Lightmaps

- Segmenting the lighting

Dominant Lighting

Local lighting

Lightmaps

- Moving Local Lights
  - Recreate the texture; simple but slow
  - Manipulate the lightmap
    - Translate to move relative to the surface
    - Scale to change spot size
    - Change base polygon color to adjust intensity
  - Projective textures ideal for spotlights
  - 3D textures easy to use (if available)

Spotlights as Lightmap Special Case

- Mapping Single Spotlight Texture Pattern

Original | Translate Spotlight Texture Coordinates | Scale Spotlight Texture Coordinates | Change Base Polygon Intensity

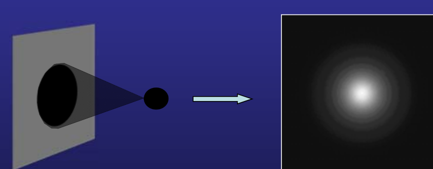
Use texture transformation matrix to perform spotlight texture coordinates transformations.

Lightmaps

- Creating a lightmap
  - Light white, tesselated surface with local light
  - Render, capture image as texture
  - Texture contains ambient and diffuse lighting
  - Lighting parameters should match light
  - Texture can also be computed analytically

Lightmaps

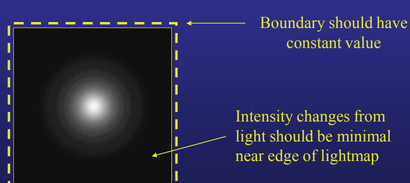
- Creating a lightmap



Render surface lit by local light | Create a Texture Map from Image

Lightmaps

- Lightmap building tips

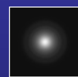


Lightmaps

- Lighting with a Lightmap
  - Local light is affected by surface color and texture
  - Two step process adds local light contribution:
    - Modulate textured, unlit surfaces with lightmap
    - Add locally lit image to scene
  - Can mix OpenGL, lightmap lighting in same scene (just fragment programming)

Lightmaps

- Creating local contribution

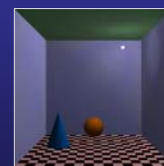

Lightmap


Unlit Scene — Lightmap Intensity — Local Light Contribution

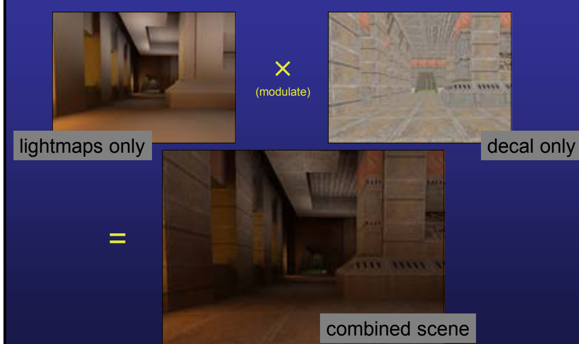
Lightmaps

- Adding local light to scene


OpenGL Lighting

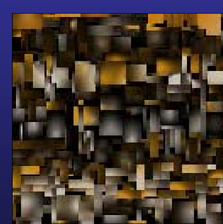

Combined Image

Lightmaps in Quake2



Packing Many Lightmaps into a Single Texture

- Quake 2 light map texture image example



  - Lightmaps typically heavily magnified.
  - Permits multiple lightmaps packed into a single texture.
  - Quake 2 computes lightmaps via off-line radiosity solver.

Lightmaps

- Lightmap considerations
  - Lightmaps are good:
    - Under-tessellated surfaces
    - Custom lighting
    - Multiple identical lights
    - Static scene lighting

Lightmaps

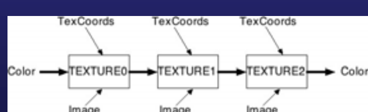
- Lightmap considerations
  - Lightmaps less helpful:
    - Highly tessellated surfaces
    - Directional lights
    - Combine with other surface effects (e.g. bump-mapping)
      - *not a big problem*
        - » *eats a texture unit/access in fragment programs*
        - » *may need to go to multi-pass rendering (fill-bound app)*

Multitexturing

- **Multitexturing** allows the use of multiple textures at one time.
- It is a standard feature of OpenGL 1.3 and later.
- An ordinary texture combines the base color of a polygon with color from the texture image. In multitexturing, this result of the first texturing can be combined with color from another texture.
- Each texture can be applied with different texture coordinates.

Texture Units

- Multitexturing uses multiple **texture units**.
- A texture unit is a sampler in the fragment program.
- Each unit has a texture, a texture environment, and optional texgen mode. That is, its own *complete* and *independent* OpenGL texture state
- Most current hardware has from 2 to 16 texture units.
- To get the number of units available: glGetIntegerv(GL_MAX_COMBINED_TEXTURE_IMAGE_UNITS)



Texture Units

- Texture units are named GL_TEXTURE0, GL_TEXTURE1, etc.
- The unit names are used with two new functions.
- glActiveTexture(texture_unit)
  - selects the current unit to be affected by texture calls (such as glBindTexture, glTexEnv, glTexGen).
- Use vertex attributes to set texture coordinates for each unit

OpenGL Multitexture Quick Tutorial

– Configuring multitextures:

```
GLuint textures[3];
glGenTextures(3, &textures);

glActiveTexture(GL_TEXTURE0);
glBindTexture(GL_TEXTURE_2D, textures[0]);
glActiveTexture(GL_TEXTURE1);
glBindTexture(GL_TEXTURE_2D, textures[1]);
glActiveTexture(GL_TEXTURE2);
glBindTexture(GL_TEXTURE_2D, textures[2]);

tex0_uniform_loc = glGetUniformLocation(prog, “tex0”);
glUniform1i(tex0_uniform_loc, 0);
tex1_uniform_loc = glGetUniformLocation(prog, “tex1”);
glUniform1i(tex1_uniform_loc, 1);
tex2_uniform_loc = glGetUniformLocation(prog, “tex2”);
glUniform1i(tex2_uniform_loc, 2);
```

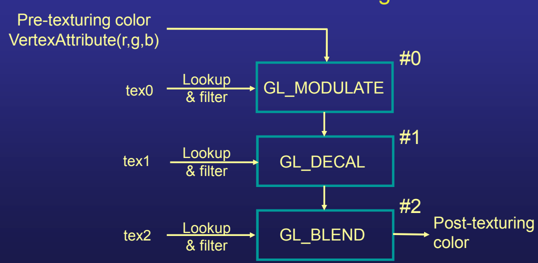
OpenGL Multitexture Quick Tutorial

– Configuring multitextures:

```
GLuint textures[3];
glGenTextures(3, &textures);

glActiveTexture(GL_TEXTURE0);
glBindTexture(GL_TEXTURE_2D, textures[0]);
glActiveTexture(GL_TEXTURE1);
glBindTexture(GL_TEXTURE_2D, textures[1]);
glActiveTexture(GL_TEXTURE2);
glBindTexture(GL_TEXTURE_2D, textures[2]);

layout (binding = 0) uniform sampler tex0;
layout (binding = 1) uniform sampler tex1;
layout (binding = 2) uniform sampler tex2;
```

OpenGL Multitexture Texture Environments (old way)

- Chain of Texture Environment Stages

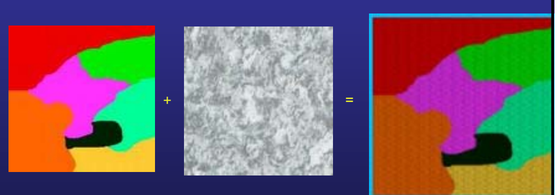


OpenGL Multitexture Texture Environments (new way)

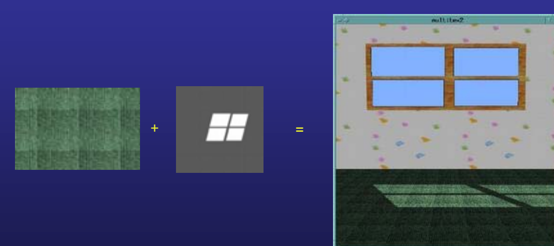
- Chain of Texture Environment Stages: put it in the shaders!

```
varying vec3 lightDir, normal, TexCoord[2];
void main(){
	TexCoord[0] = TextureMatrix[0] *  MultiTexCoord0;
	TexCoord[1] = TextureMatrix[1] *  MultiTexCoord1;
	gl_Position = ftransform();
}

varying vec3 lightDir, normal, TexCoord[2];
uniform sampler2D tex0, tex1;
void main(){
	vec3  ct, cf;
	vec4 texel;
	float intensity, at, af;
	intensity = max(dot(lightDir, normalize(normal)),0.0);
	cf = intensity * gl_FrontMaterial.diffuse.rgb + gl_FrontMaterial.ambient.rgb;
	af = gl_FrontMaterial.diffuse.a
	texel = texture2D(tex0, TexCoord[0].st) + texture2D(tex0, TexCoord[1].st);
	ct = texel.rgb;
	at = texel.a;
	gl_FragColor = vec4(ct*cf, at*af);
}
```

Detail Texture



Multitexture Lightmapping

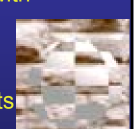


Look at SuperBible Example

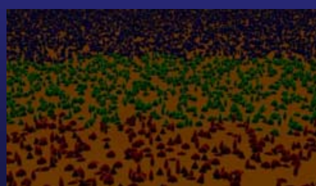
Dflandscape =
Distance Field Landscape

Alpha Mapping

- An Alpha Map contains a single value with transparency information
  - 0 → fully transparent
  - 1 → fully opaque
- Can be used to make sections of objects transparent
- Can be used in combination with standard texture maps to produce cutouts
  - Trees
  - Torches



Alpha Mapping



Alpha Mapping

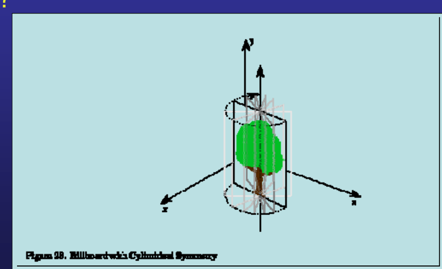
- In the previous tree example, all the trees are texture mapped onto flat polygons
- The illusion breaks down if the viewer sees the tree from the side
- Thus, this technique is usually used with another technique called "billboarding"
  - Simply automatically rotating the polygon so it always faces the viewer
- Note that if the alpha map is used to provide transparency for texture map colors, one can often combine the 4 pieces of information (R,G,B,A) into a single texture map

Alpha Mapping

- The only issue as far as the rendering pipeline is concerned is that the pixels of the object made transparent by the alpha map cannot change the value in the z-buffer
  - We saw similar issues when talking about whole objects that were partially transparent → render them last with the z-buffer in read-only mode
  - However, alpha mapping requires changing z-buffer modes *per pixel* based on texel information
  - This implies that we need some simple hardware support to make this happen properly

Bill Boarding

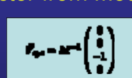
- How?



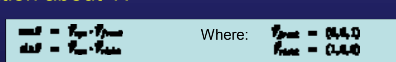
Demo

Bill Boarding

- Eye looking down –Z axis, UP = +Y axis
- Compute eye-vector from ModelView:

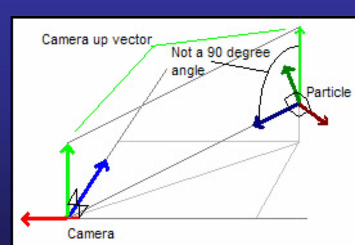


- Rotation about Y:



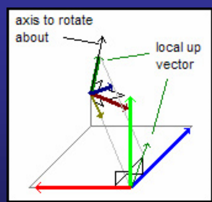
- Build rotation matrix (R) with theta
- Transform geometry: MR (Modelview * Rotation)

Billboards



look = camera_pos - point_pos;
right = up x look;
up = look x right;

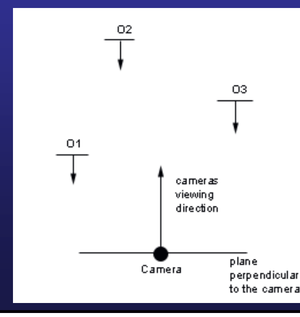
Billboards



up = arbitrary axis
look = camera_pos - point_pos;
right = up x look;
look = right x up;

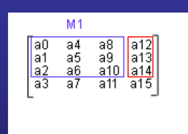
Billboards Hack

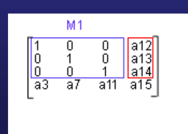
- Trees don't face camera



Billboards Hack

- Trees don't face camera
- Use the Modelview
- Set rotation to identity
- Spherical Billboarding

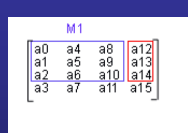


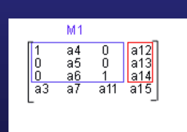



```
#version 150
in vec4 gxl3d_Position;
in vec4 gxl3d_TexCoord0;

// GLSL uniforms:
uniform mat4 gxl3d_ModelViewProjectionMatrix;
uniform mat4 gxl3d_ModelViewMatrix;
uniform mat4 gxl3d_ProjectionMatrix;
uniform mat4 gxl3d_ViewMatrix;
uniform mat4 gxl3d_ModelMatrix;

out vec4 Vertex_UV;
void main()
{
  //mat4 modelView = gxl3d_ViewMatrix*gxl3d_ModelMatrix;
  mat4 modelView = gxl3d_ModelViewMatrix;

  // First column.
  modelView[0][0] = 1.0;
  modelView[0][1] = 0.0;
  modelView[0][2] = 0.0;
  // Second column.
  modelView[1][0] = 0.0;
  modelView[1][1] = 1.0;
  modelView[1][2] = 0.0;
  // Thrid column.
  modelView[2][0] = 0.0;
  modelView[2][1] = 0.0;
  modelView[2][2] = 1.0;

  vec4 P = modelView * gxl3d_Position;
  gl_Position = gxl3d_ProjectionMatrix * P;

  Vertex_UV = gxl3d_TexCoord0;
}
```

Billboards Hack 2

- Trees don't face camera
- Use the Modelview
- Make billboard cylindrical
- Set part of rotation to identity



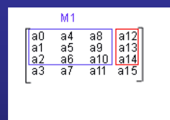


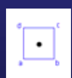

```
#version 150
in vec4 gxl3d_Position;
in vec4 gxl3d_TexCoord0;

// GLSL uniforms:
uniform mat4 gxl3d_ModelViewProjectionMatrix;
uniform mat4 gxl3d_ModelViewMatrix;
uniform mat4 gxl3d_ProjectionMatrix;
uniform mat4 gxl3d_ViewMatrix;
uniform mat4 gxl3d_ModelMatrix;

out vec4 Vertex_UV;
void main()
{
  //mat4 modelView = gxl3d_ViewMatrix*gxl3d_ModelMatrix;
  mat4 modelView = gxl3d_ModelViewMatrix;

  // First column.
  modelView[0][0] = 1.0;
  modelView[0][1] = 0.0;
  modelView[0][2] = 0.0;
//  // Second column.
//  modelView[1][0] = 0.0;
//  modelView[1][1] = 1.0;
//  modelView[1][2] = 0.0;
  // Thrid column.
  modelView[2][0] = 0.0;
  modelView[2][1] = 0.0;
  modelView[2][2] = 1.0;

  vec4 P = modelView * gxl3d_Position;
  gl_Position = gxl3d_ProjectionMatrix * P;

  Vertex_UV = gxl3d_TexCoord0;
}
```

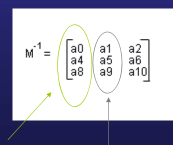
Billboards Hack 3

- Modify the verticies of the Billboard quad
- Reverses the orientations in the Modelview Maxtrix
- Draw quad using right/up offsets

+ only get modelview once
- Must xform all verticies







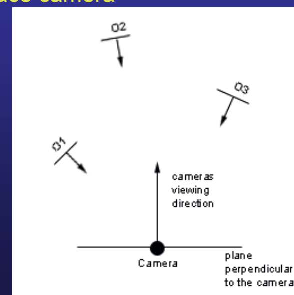
a = center - (right + up) * size;
b = center + (right - up) * size;
c = center + (right + up) * size;
d = center - (right - up) * size;

right up

How to do cylindrical?

Billboards Correct

- Trees face camera



Billboards Correct

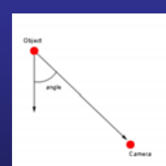
- Trees face camera
- Need
  - Object in world coords
  - Target position (camera) in world coords
- Assume for the object (billboard)

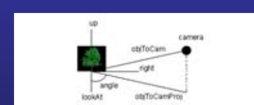
  Right = [1,0,0]

  Up = [0,1,0]

  LookAt = [0,0,1] {which is the normal}

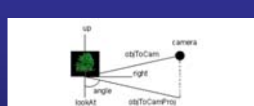
Billboards Correct





Billboards Correct

objToCamProj is the projection to the XZ plane (set y=0)



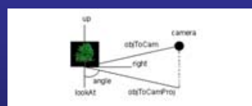
1. **Normalize objToCamProj**
2. **aux=LookAt dot objToCamProj**
3. **Up'= lookAt X objToCamProj**
4. **glRotate(acos(aux), Up'[0], Up'[1], Up'[2]**

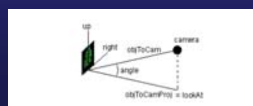
```
void billboardCylindricalBegin(
                        float camX, float camY, float camZ,
                        float objPosX, float objPosY, float objPosZ) {

        float lookAt[3],objToCamProj[3],upAux[3];
        float modelview[16],angleCosine;

        glPushMatrix();

// objToCamProj is the vector in world coordinates from the
// local origin to the camera projected in the XZ plane
        objToCamProj[0] = camX - objPosX ;
        objToCamProj[1] = 0;
        objToCamProj[2] = camZ - objPosZ ;

// This is the original lookAt vector for the object
// in world coordinates
        lookAt[0] = 0;
        lookAt[1] = 0;
        lookAt[2] = 1;


// normalize both vectors to get the cosine directly afterwards
        mathsNormalize(objToCamProj);

// easy fix to determine wether the angle is negative or positive
// for positive angles upAux will be a vector pointing in the
// positive y direction, otherwise upAux will point downwards
// effectively reversing the rotation.

        mathsCrossProduct(upAux,lookAt,objToCamProj);

// compute the angle
        angleCosine = mathsInnerProduct(lookAt,objToCamProj);

// perform the rotation. The if statement is used for stability reasons
// if the lookAt and objToCamProj vectors are too close together then
// |angleCosine| could be bigger than 1 due to lack of precision
   if ((angleCosine < 0.99990) && (angleCosine > -0.9999))
      glRotatef(acos(angleCosine)*180/3.14,upAux[0], upAux[1], upAux[2]);
}
```

Billboards Correct

objToCamProj is the projection to the XZ plane (y=0)

1. **Normalize objToCamProj**
2. **aux=LookAt dot objToCamProj**
3. **Up'= lookAt X objToCamProj**
4. **glRotate(acos(aux), Up'[0], Up'[1], Up'[2]**

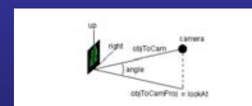




Billboards Correct

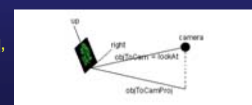
objToCamProj is the projection to the XZ plane (y=0)

1. **Normalize objToCamProj**
2. **aux=LookAt dot objToCamProj**
3. **Up'= lookAt X objToCamProj**
4. **glRotate(acos(aux), Up'[0], Up'[1], Up'[2]**



Tilt towards Camera

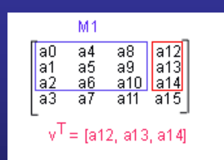
1. **Aux'= objToCamProj dot objToCam**
2. **glRotate(acos(aux'), right[0], right[1], right[2])**



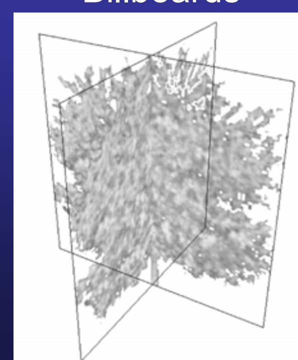
Billboards Correct

Object Position in world space

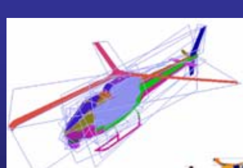
objPosWC = camPos + ($M1^{-1}$) * V

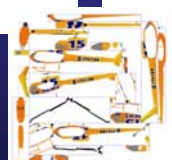


Billboards



Billboard Clouds





Point Sprites

See Example

starfield