CSE 167:
Introduction to Computer Graphics
Lecture #10: Advanced Texture Mapping

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Fall Quarter 2020

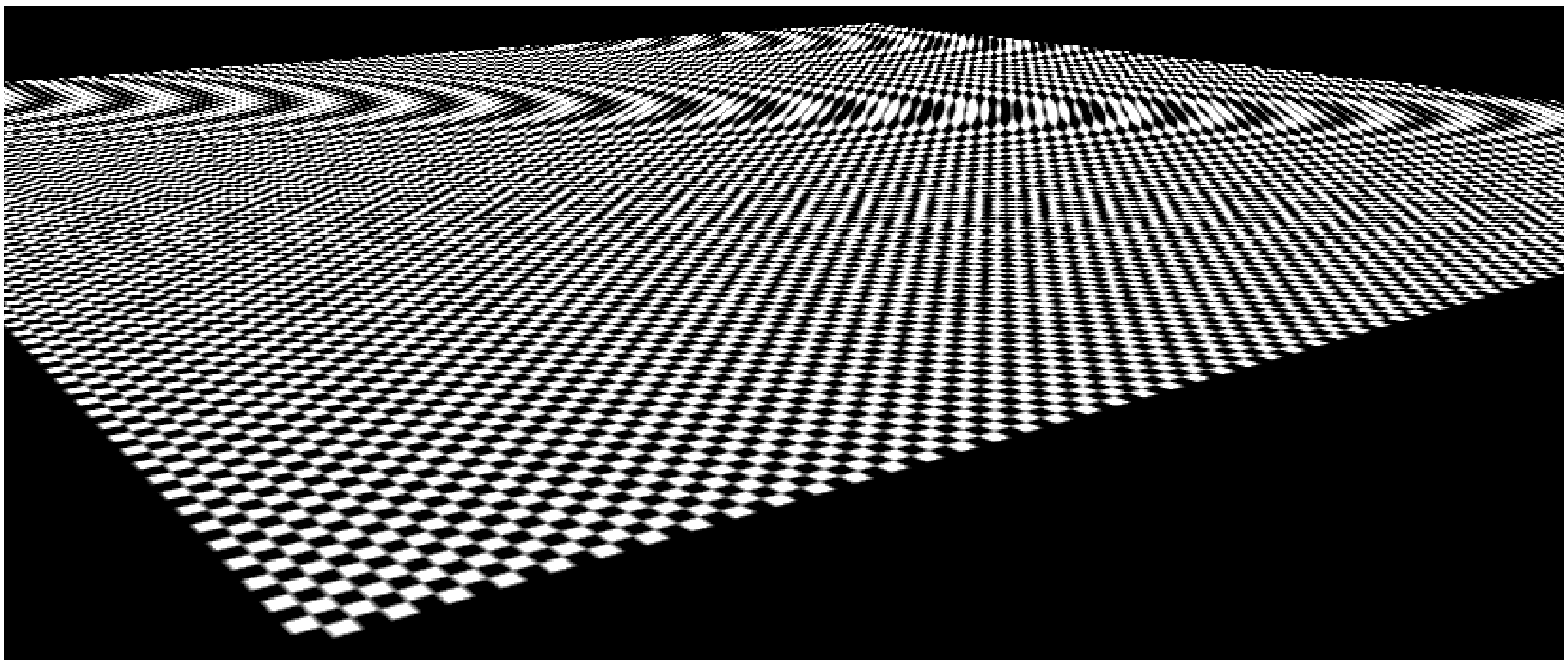
Announcements

- Sunday, November 8th at 11:59pm:
  - Homework Project 2 due

MIP Mapping

Aliasing

- What could cause this aliasing effect?



Aliasing

Sufficiently sampled, no aliasing

Insufficiently sampled, aliasing

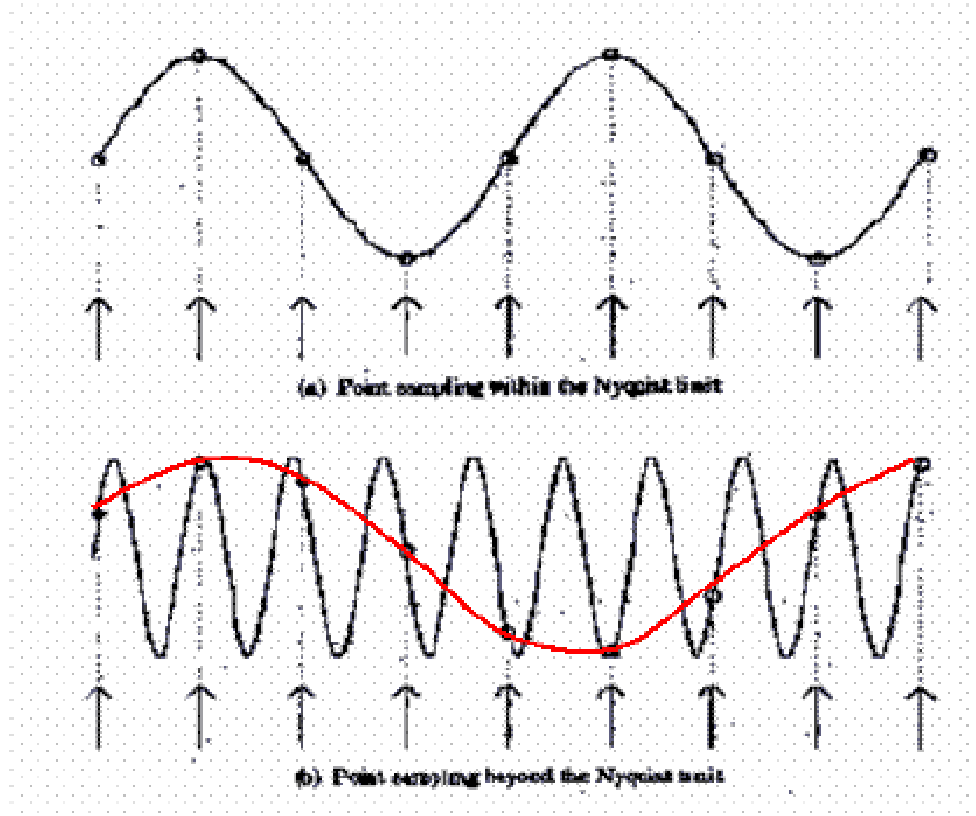
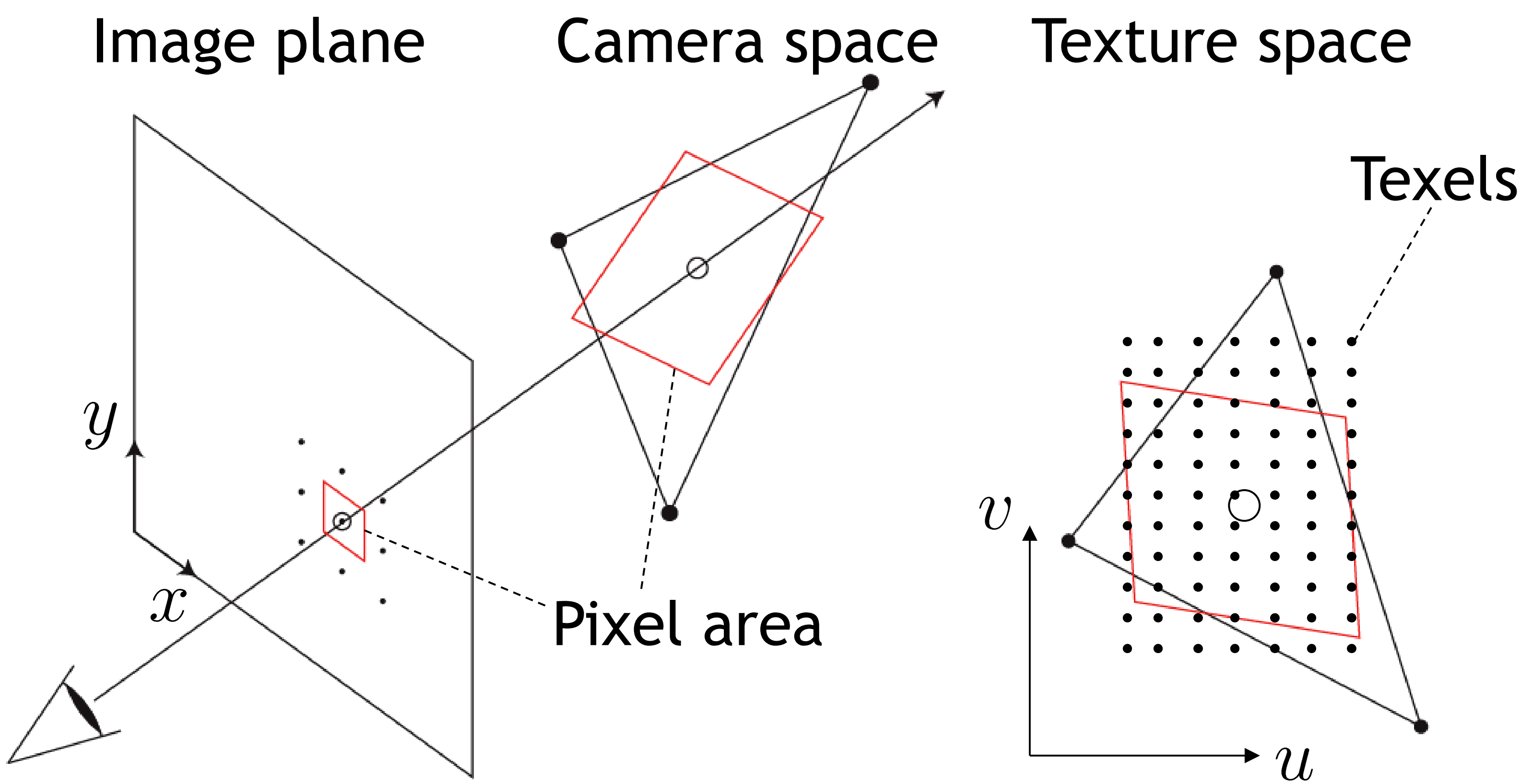


Image: Robert L. Cook

High frequencies in the input data can appear as lower frequencies in the sampled signal

Antialiasing: Intuition

- Pixel may cover large area on triangle in camera space
- Corresponds to many texels in texture space
- Need to compute average



Antialiasing Using Mip-Maps

- Averaging over texels is expensive
  - Many texels as objects get smaller
  - Large memory access and compuation cost
- Precompute filtered (averaged) textures
  - Mip-maps
- Practical solution to aliasing problem
  - Fast and simple
  - Available in OpenGL, implemented in GPUs
  - Reasonable quality

Mipmaps

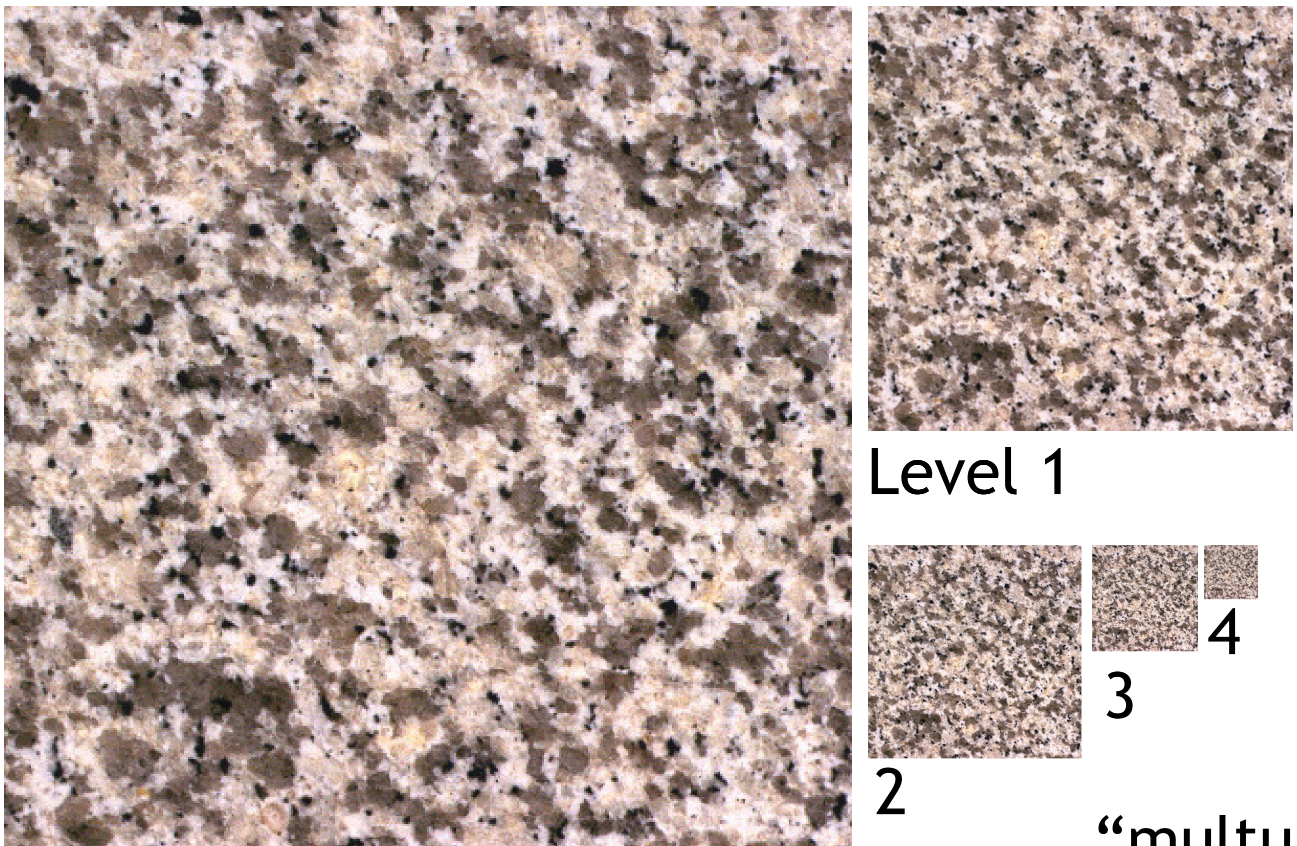
- MIP stands for *multum in parvo* = "*much in little*" (Williams 1983)

Before rendering

- Pre-compute and store down scaled versions of textures
  - Reduce resolution by factors of two successively
  - Use high quality filtering (averaging) scheme
- Increases memory cost by 1/3
  - 1/3 = ¼+1/16+1/64+…
- Width and height of texture should be powers of two (non-power of two supported since OpenGL 2.0)

Mipmaps

- Example: resolutions 512x512, 256x256, 128x128, 64x64, 32x32 pixels

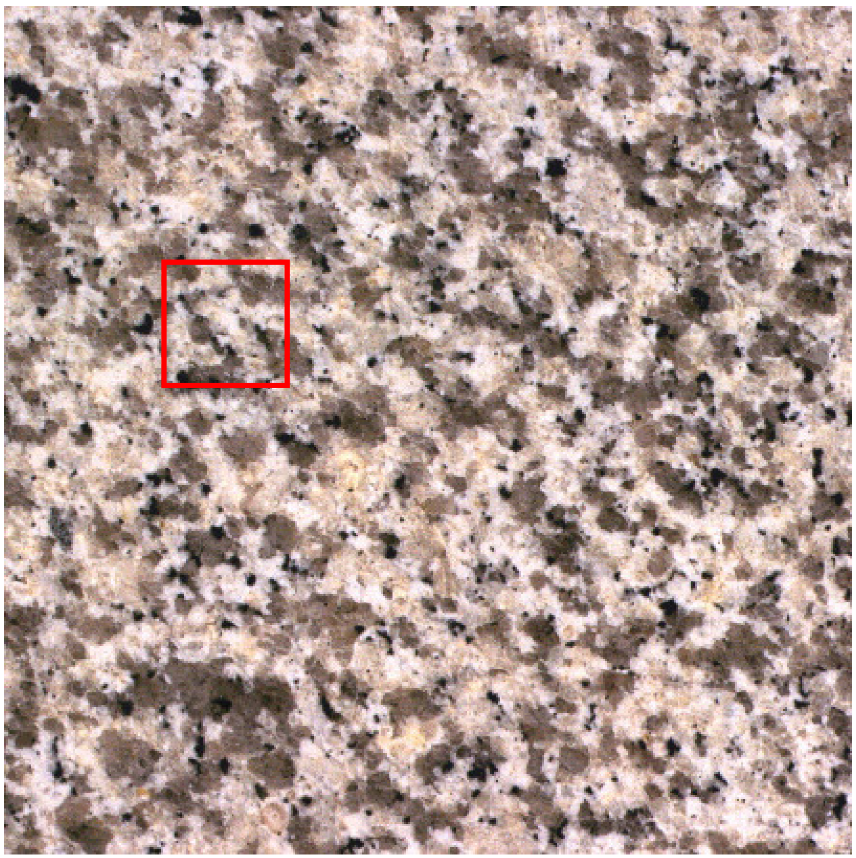


"multum in parvo"

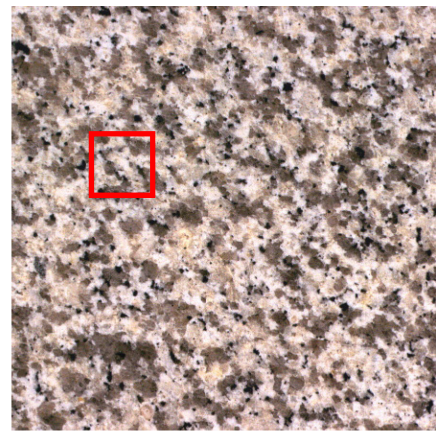
Level 0

Mipmaps

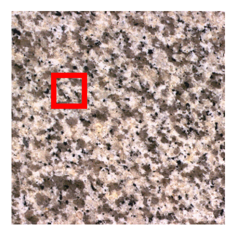
- One texel in level 4 is the average of 4^4=256 texels in level 0



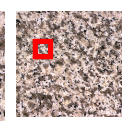
Level 0



Level 1



2

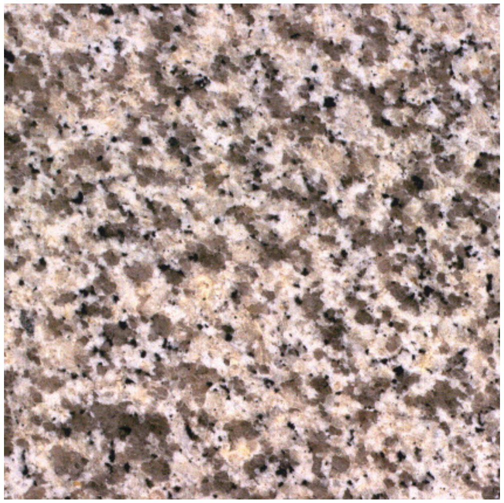


3

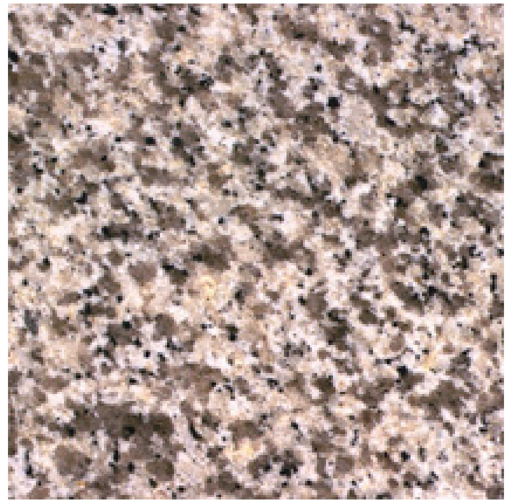
4

“multum in parvo”

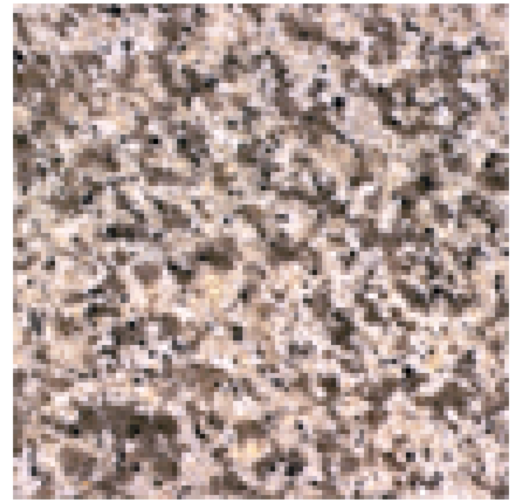
Mipmaps



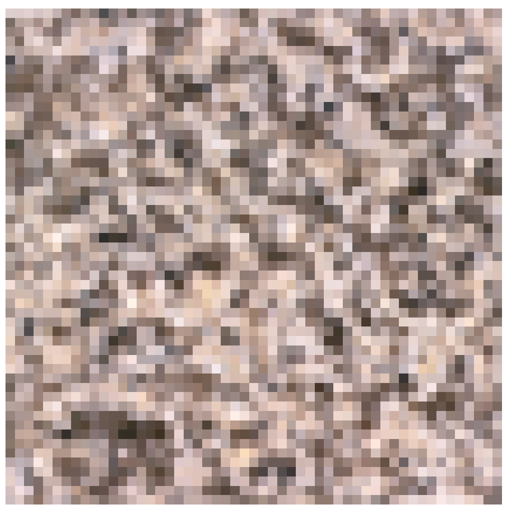
Level 0



Level 1



Level 2



Level 3

Level 4

Rendering With Mipmaps

- "Mipmapping"
- Interpolate texture coordinates of each pixel as without mipmapping
- Compute approximate size of pixel in texture space
- Look up color in nearest mipmap
  - E.g., if pixel corresponds to 10x10 texels use mipmap level 3
  - Use nearest neighbor or bilinear interpolation as before

Mipmapping

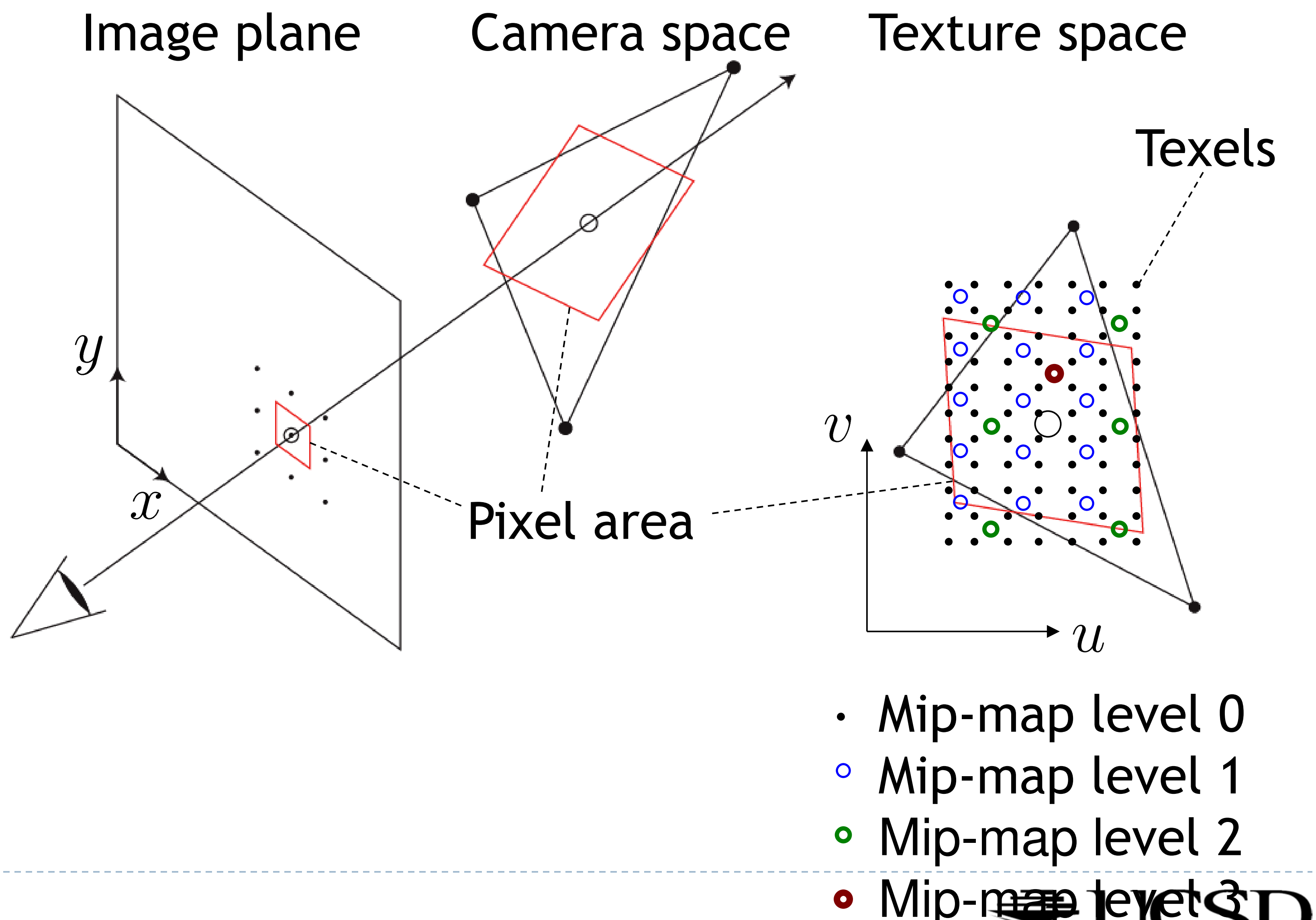
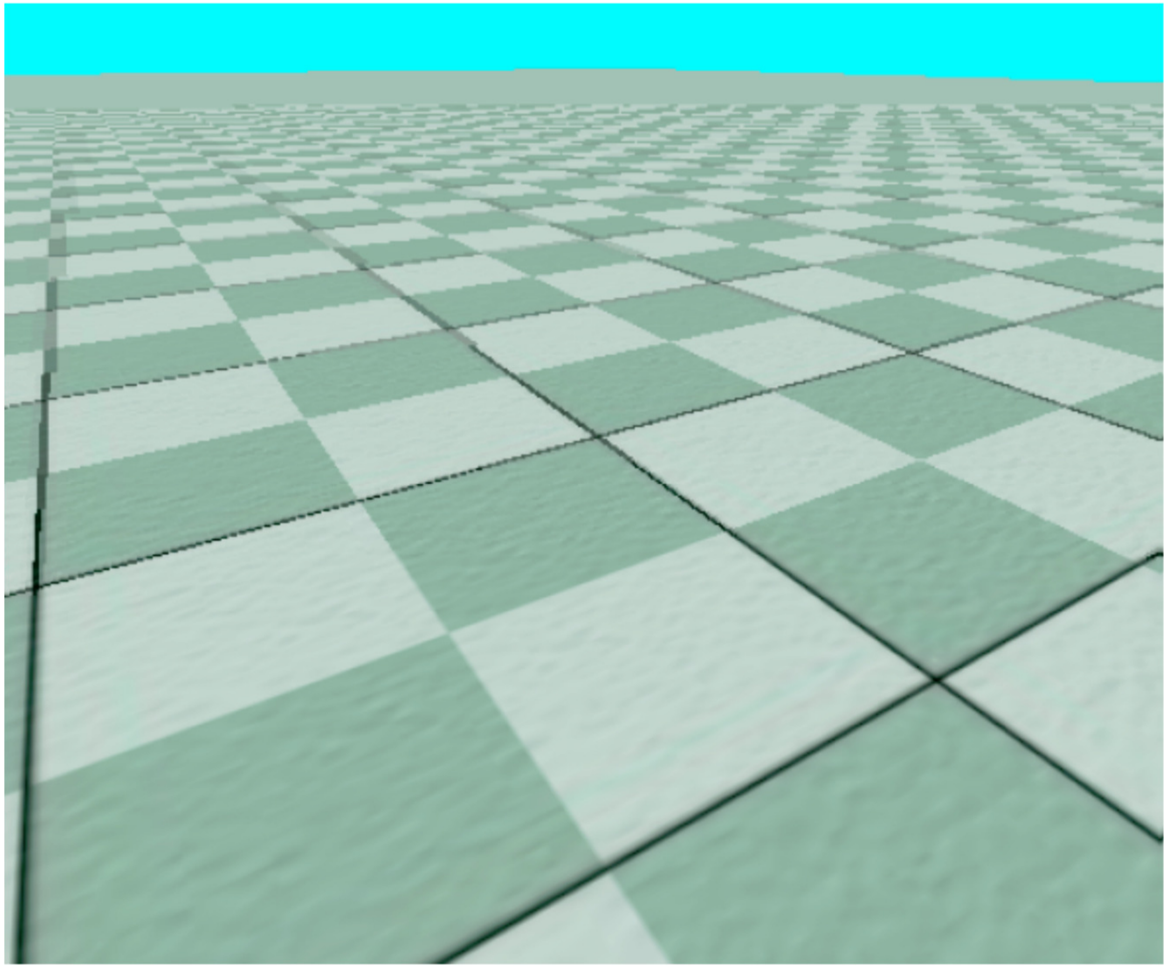


Image plane
Camera space
Texture space
Texels
y
x
v
u
Pixel area
Mip-map level 0
Mip-map level 1
Mip-map level 2
Mip-map level 3

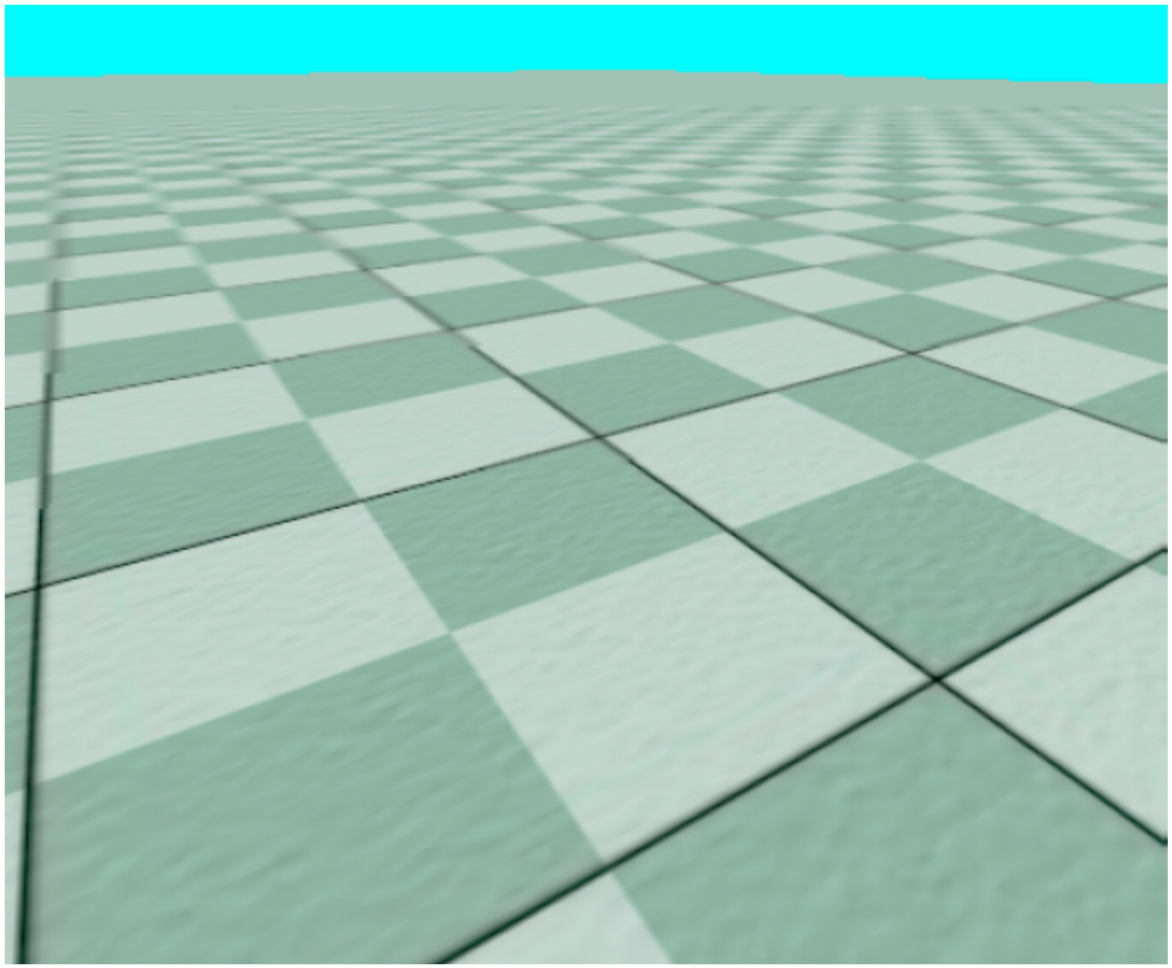
Nearest Mipmap, Nearest Neighbor

- Visible transition between mipmap levels



Nearest Mipmap, Bilinear

- Visible transition between mipmap levels



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Trilinear Mipmapping

- Use two nearest mipmap levels
  - E.g., if pixel corresponds to 10x10 texels, use mipmap levels 3 (8x8) and 4 (16x16)
- 2-Step approach:
  - Step 1: perform bilinear interpolation in both mip-maps
  - Step 2: linearly interpolate between the results
- Requires access to 8 texels for each pixel
- Supported by hardware without performance penalty

Anisotropic Filtering

- Method of enhancing the image quality of textures on surfaces that are at oblique viewing angles
- Different degrees or ratios of anisotropic filtering can be applied
- The degree refers to the maximum ratio of anisotropy supported by the filtering process. For example, 4:1 anisotropic filtering supports pre-sampled textures up to four times wider than tall

More Info

- Mipmapping tutorial w/source code:
  - http://www.videotutorialsrock.com/opengl_tutorial/mipmapping/text.php

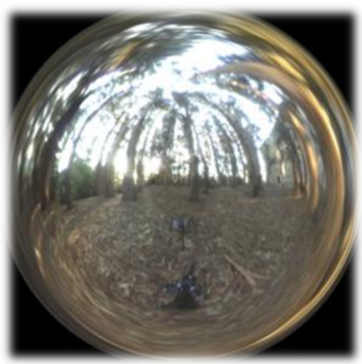
Environment Mapping

More Realistic Illumination

- In the real world:
  At each point in scene light arrives from all directions
  - Not just from a few point light sources
  - → Global Illumination is a solution, but computationally expensive
- Environment Maps
  - Store "omni-directional" illumination as images
  - Each pixel corresponds to light from a certain direction
  - Sky boxes make for great environment maps

Capturing Environment Maps

- Environment map = surround panoramic image
- Creating 360 degrees panoramic images:
  - 360 degree camera
  - "light probe" image: take picture of mirror ball (e.g., silver Christmas ornament)



Light Probes by Paul Debevec
http://www.debevec.org/Probes/

Environment Maps as Light Sources

Simplifying Assumption

- Assume light captured by environment map is emitted from infinitely far away
- Environment map consists of directional light sources
  - Value of environment map is defined for each **direction**, independent of position in scene
- Approach uses same environment map at each point in scene
  → Approximation!

Applications for Environment Maps

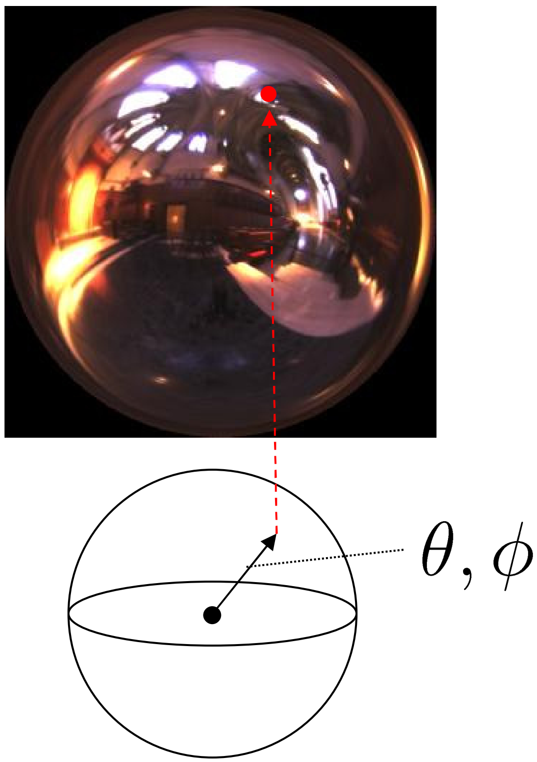
- Use environment map as "light source"

Global illumination with pre-computed radiance transfer [Sloan et al. 2002]

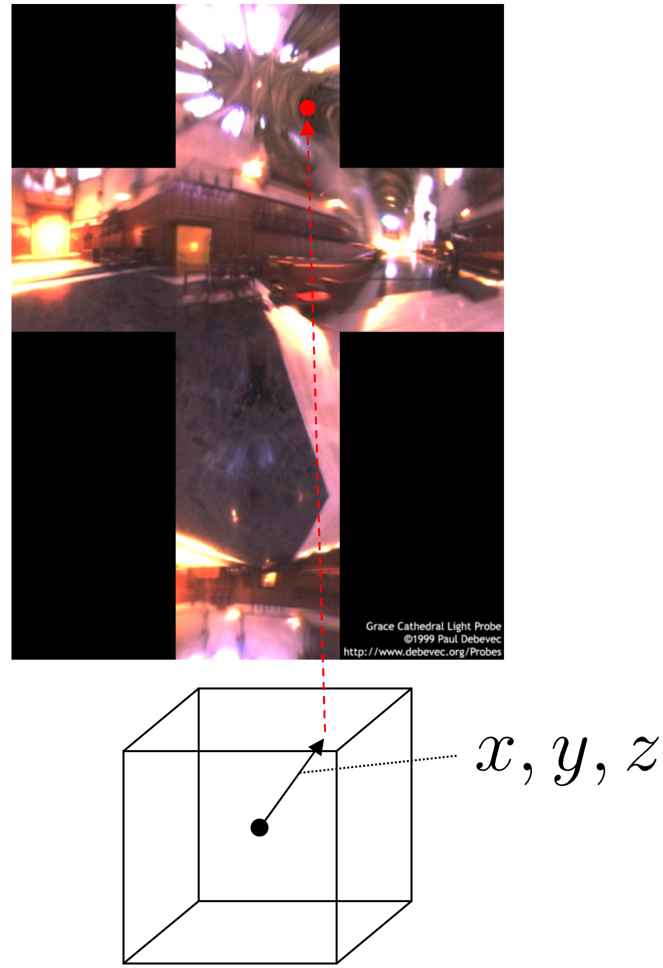
Reflection mapping [Georg-Simon Ohm University of Applied Sciences]

Cubic Environment Maps

- Store incident light on six faces of a cube instead of on sphere



Spherical map



Cube map

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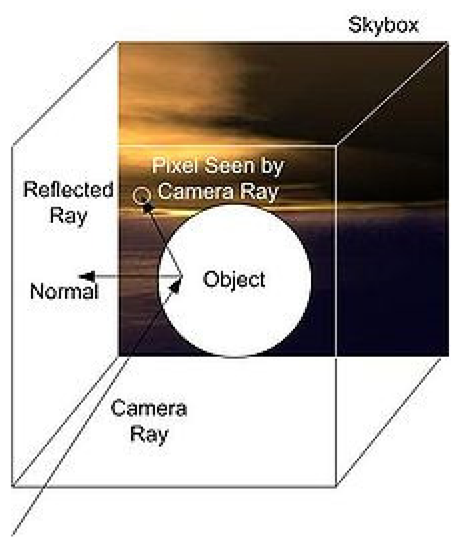
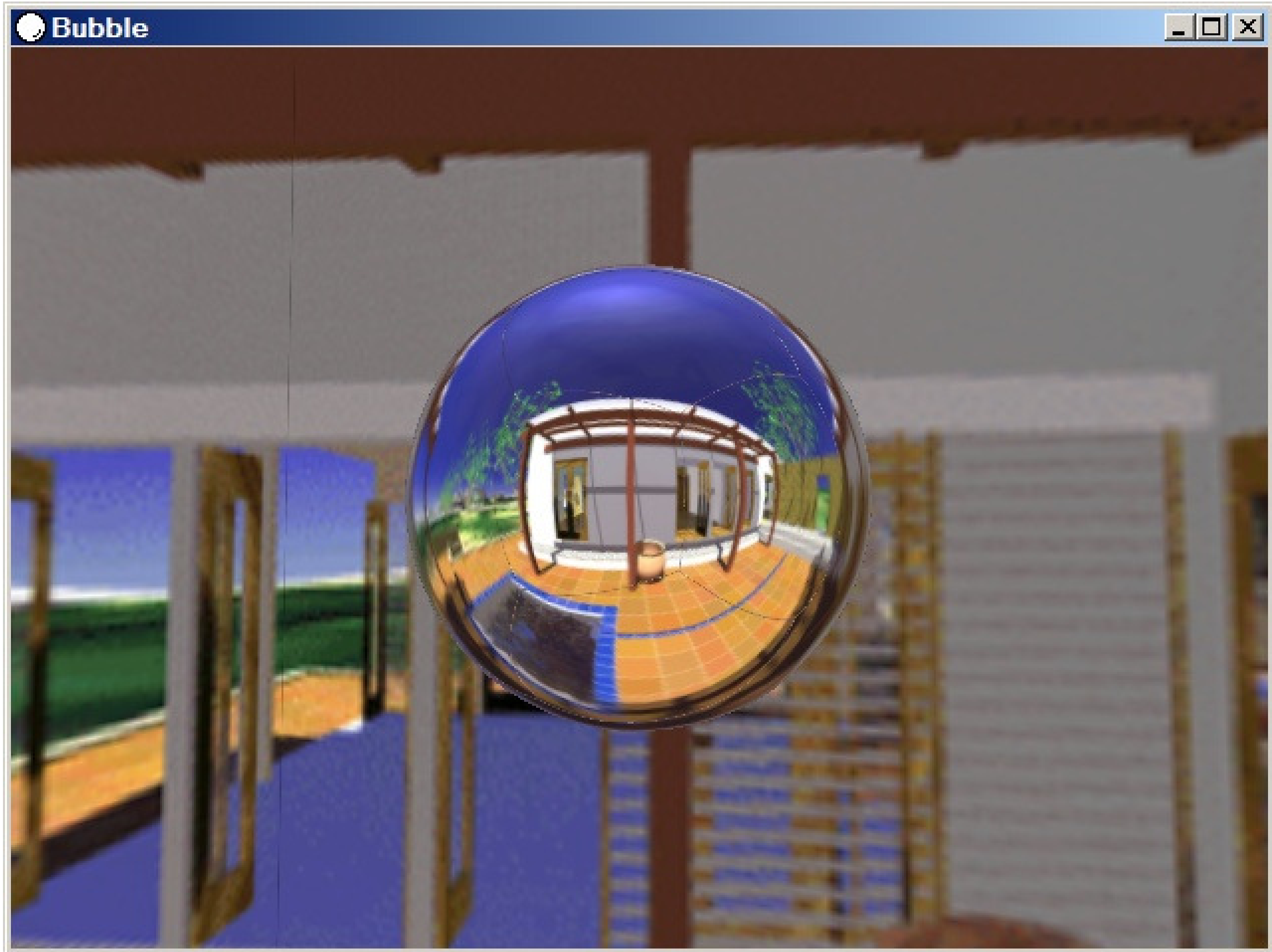
Cubic vs. Spherical Maps

- Advantages of cube maps:
  - More even texel sample density causes less distortion, allowing for lower resolution maps
  - Easier to dynamically generate cube maps for real-time simulated reflections



Bubble Demo



http://download.nvidia.com/downloads/nZone/demos/nvidia/Bubble.zip

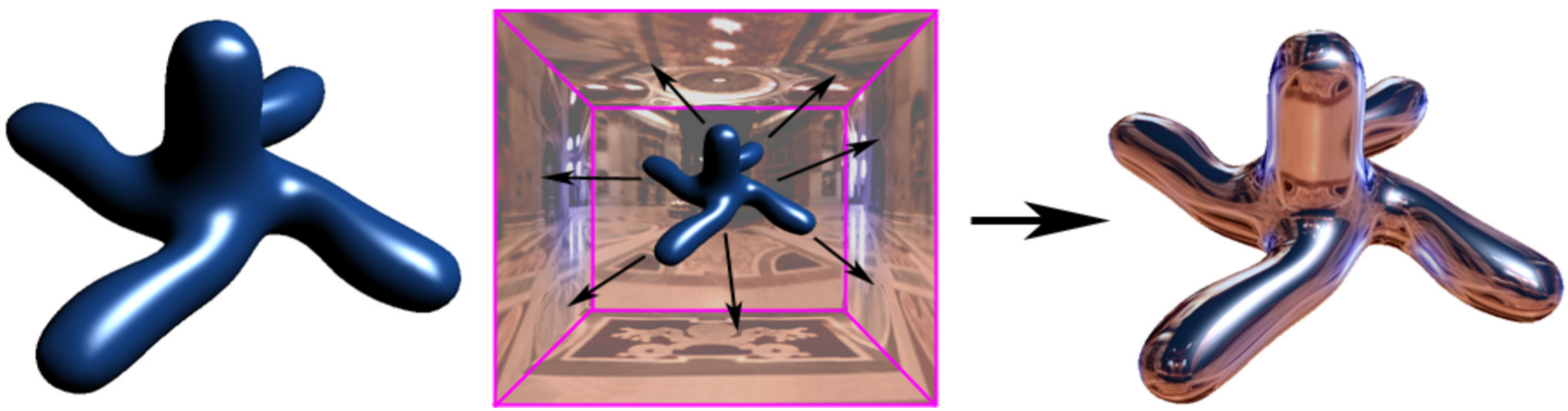
Cubic Environment Maps

Cube map look-up

- Given: light direction (x,y,z)
- Largest coordinate component determines cube map face
- Dividing by magnitude of largest component yields coordinates within face
- In GLSL:
  - Use (x,y,z) direction as texture coordinates to `samplerCube`

Reflection Mapping

- Simulates mirror reflection
- Computes reflection vector at each pixel
- Use reflection vector to look up cube map
- Rendering cube map itself is optional (application dependent)



Reflection mapping

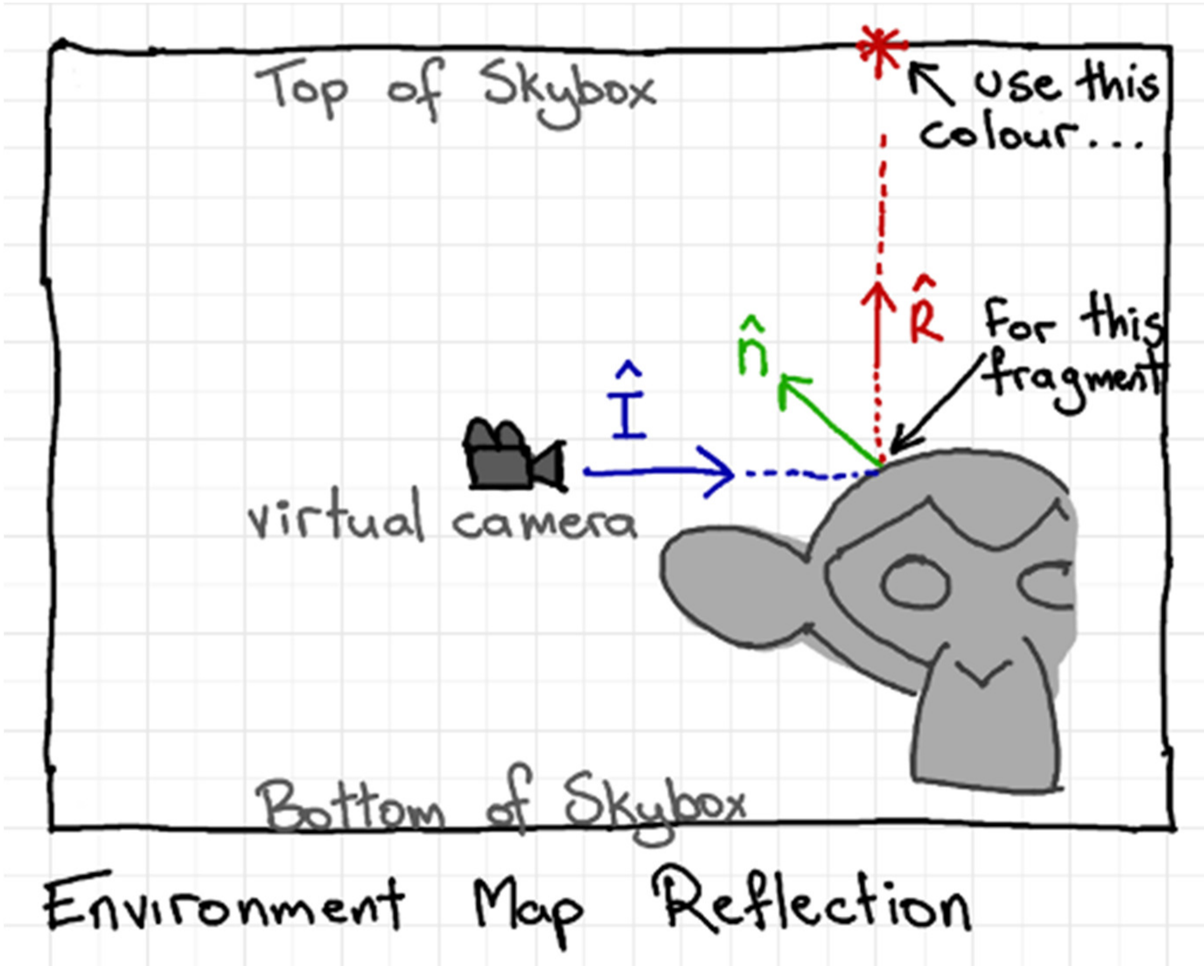
Reflection Mapping in GLSL

Application Setup

- Load and bind a cube environment map

```
glBindTexture(GL_TEXTURE_CUBE_MAP, …);
glTexImage2D(GL_TEXTURE_CUBE_MAP_POSITIVE_X,…);
glTexImage2D(GL_TEXTURE_CUBE_MAP_NEGATIVE_X,…);
glTexImage2D(GL_TEXTURE_CUBE_MAP_POSITIVE_Y,…);
…
glEnable(GL_TEXTURE_CUBE_MAP);
```

Environment Mapping: Concept



Source: http://antongerdelan.net/opengl/cubemaps.html

Environment Mapping: Vertex Shader

```
#version 400

in vec3 vp; // positions from mesh
in vec3 vn; // normals from mesh
uniform mat4 P, V, M; // proj, view, model matrices
out vec3 pos_eye;
out vec3 n_eye;

void main()
{
  pos_eye = vec3(V * M * vec4(vp, 1.0));
  n_eye = vec3(V * M * vec4(vn, 0.0));
  gl_Position = P * V * M * vec4(vp, 1.0);
}
```

Environment Mapping: Fragment Shader

```
#version 400

in vec3 pos_eye;
in vec3 n_eye;
uniform samplerCube cube_texture;
uniform mat4 V; // view matrix
out vec4 frag_colour;

void main()
{
  // reflect ray around normal from eye to surface
  vec3 incident_eye = normalize(pos_eye);
  vec3 normal = normalize(n_eye);

  vec3 reflected = reflect(incident_eye, normal);
  // convert from eye to world space
  reflected = vec3(inverse(V) * vec4(reflected, 0.0));

  frag_colour = texture(cube_texture, reflected);
}
```

Environment Maps as Light Sources

- Covered so far: shading of a specular surface

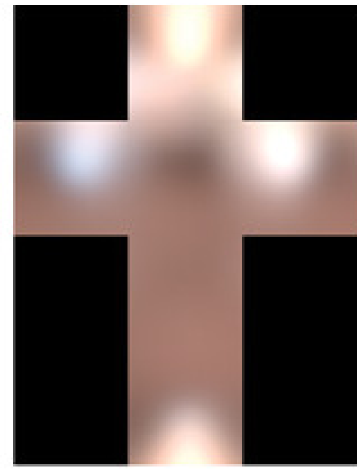
→ How do you compute shading of a diffuse surface?

Diffuse Irradiance Environment Map

- Given a scene with k directional lights, light directions $d_1..d_k$ and intensities $i_1..i_k$, illuminating a diffuse surface with normal n and color c
- Pixel intensity B is computed as: $B = c \sum_{j=1..k} \max(0, d_j \cdot n) i_j$
- Cost of computing B proportional to number of texels in environment map!
- → Precomputation of diffuse reflection
- Observations:
  - All surfaces with normal direction n will return the same value for the sum
  - The sum is dependent on just the lights in the scene and the surface normal
- Precompute sum for any normal n and store result in a second environment map, indexed by surface normal
- Second environment map is called *diffuse irradiance environment map*
- Allows to illuminate objects with arbitrarily complex lighting environments with single texture lookup

Diffuse Irradiance Environment Map

- Two cubic environment maps:
  - Reflection map
  - Diffuse map

- Diffuse shading vs. shading w/diffuse map


Image source: [*http://http.developer.nvidia.com/GPUGems2/gpugems2_chapter10.html*](http://http.developer.nvidia.com/GPUGems2/gpugems2_chapter10.html)