Computer Graphics

Texture Mapping

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Objectives

- Introduce Mapping Methods
  - Texture Mapping
  - Environment Mapping
  - Bump Mapping
- Consider basic strategies
  - Forward vs backward mapping
  - Point sampling vs area averaging

The Limits of Geometric Modeling

- Although graphics cards can render over 10 million polygons per second, that number is insufficient for many phenomena
  - Clouds
  - Grass
  - Terrain
  - Skin

Modeling an Orange

- Consider the problem of modeling an orange (the fruit)
- Start with an orange-colored sphere
  - Too simple
- Replace sphere with a more complex shape
  - Does not capture surface characteristics (small dimples)
  - Takes too many polygons to model all the dimples

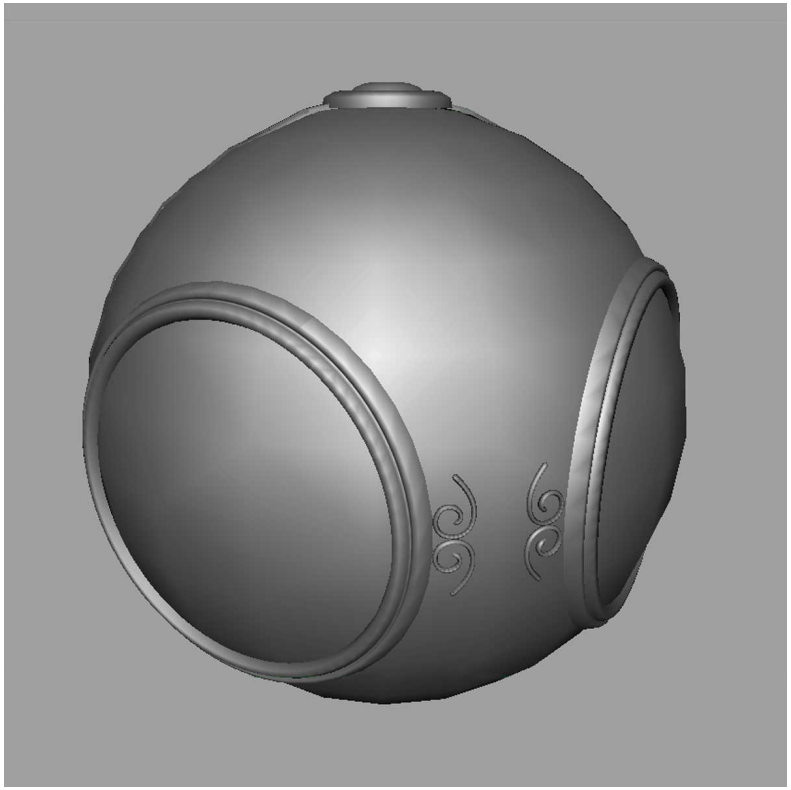
Modeling an Orange (2)

- Take a picture of a real orange, and “paste” the picture on a simple geometric model
  - This process is known as texture mapping
- Still might not be sufficient because resulting surface will be smooth
  - Need to change local shape
  - Bump mapping

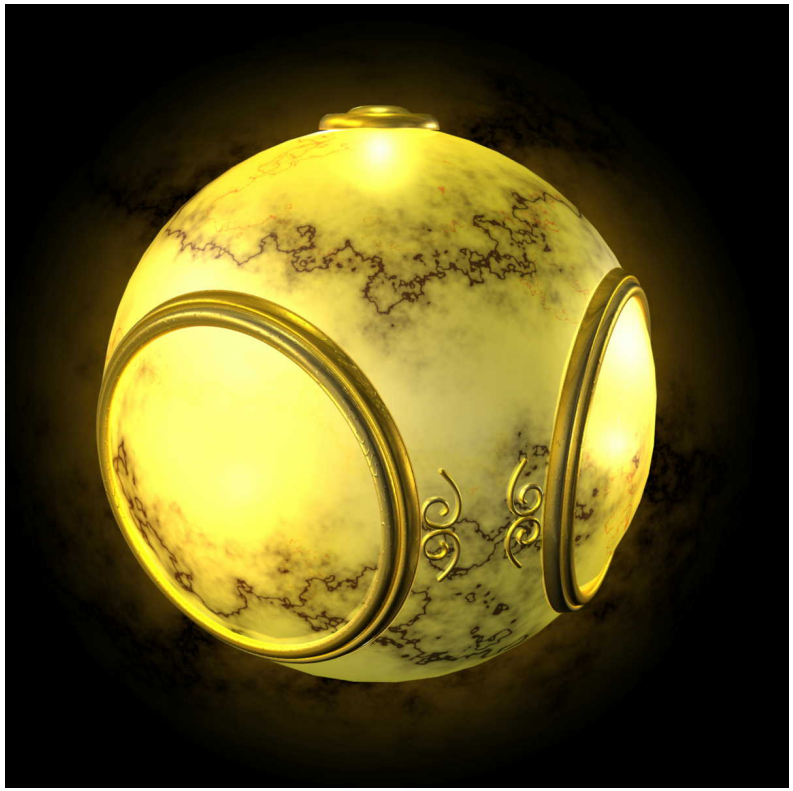
Three Types of Mapping

- Texture Mapping
  - Use images to fill polygons
- Environment (reflection mapping)
  - Use the picture of an environment for texture map
  - Allow simulation of highly specular surfaces
- Bump mapping
  - Emulate altering normal vectors during the rendering process

Texture Mapping



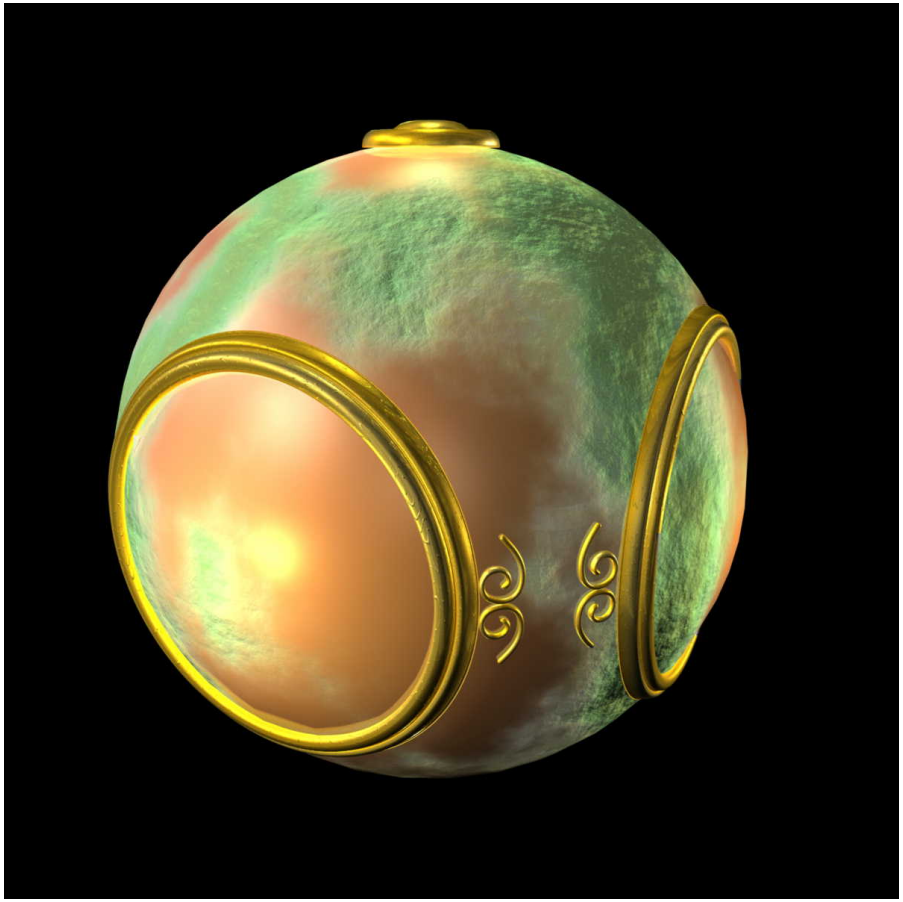
geometric model



texture mapped

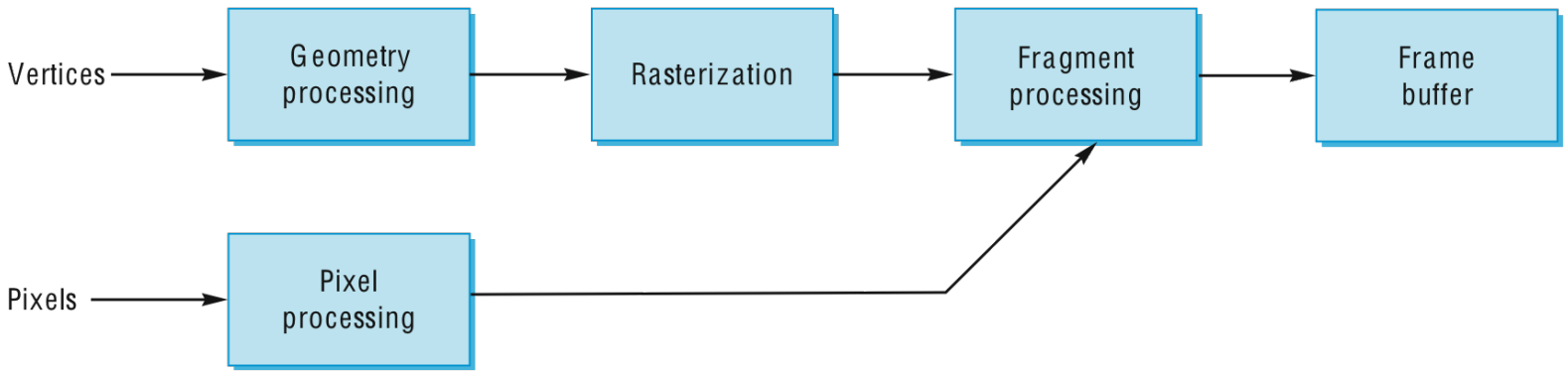
Environment Mapping

Bump Mapping



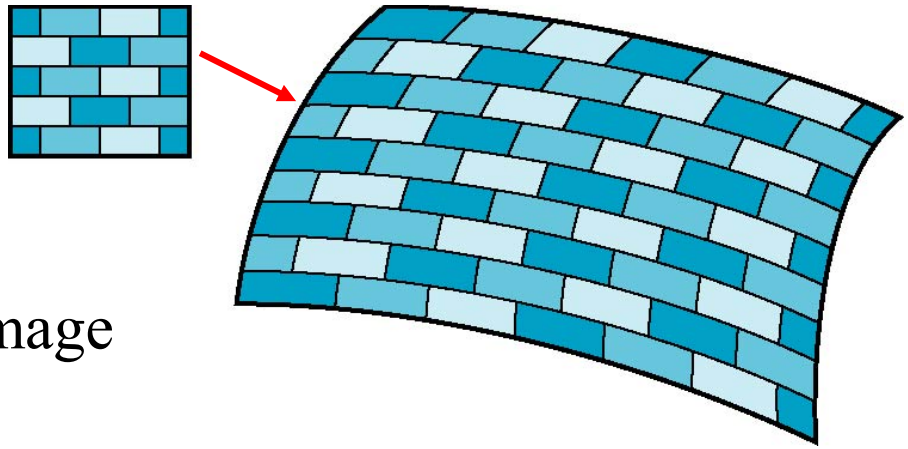
Where does mapping take place?

- Mapping techniques are implemented at the end of the rendering pipeline
  - Very efficient because few polygons make it past the clipper



Is it simple?

- Although the idea is simple---map an image to a surface---there are 3 or 4 coordinate systems involved



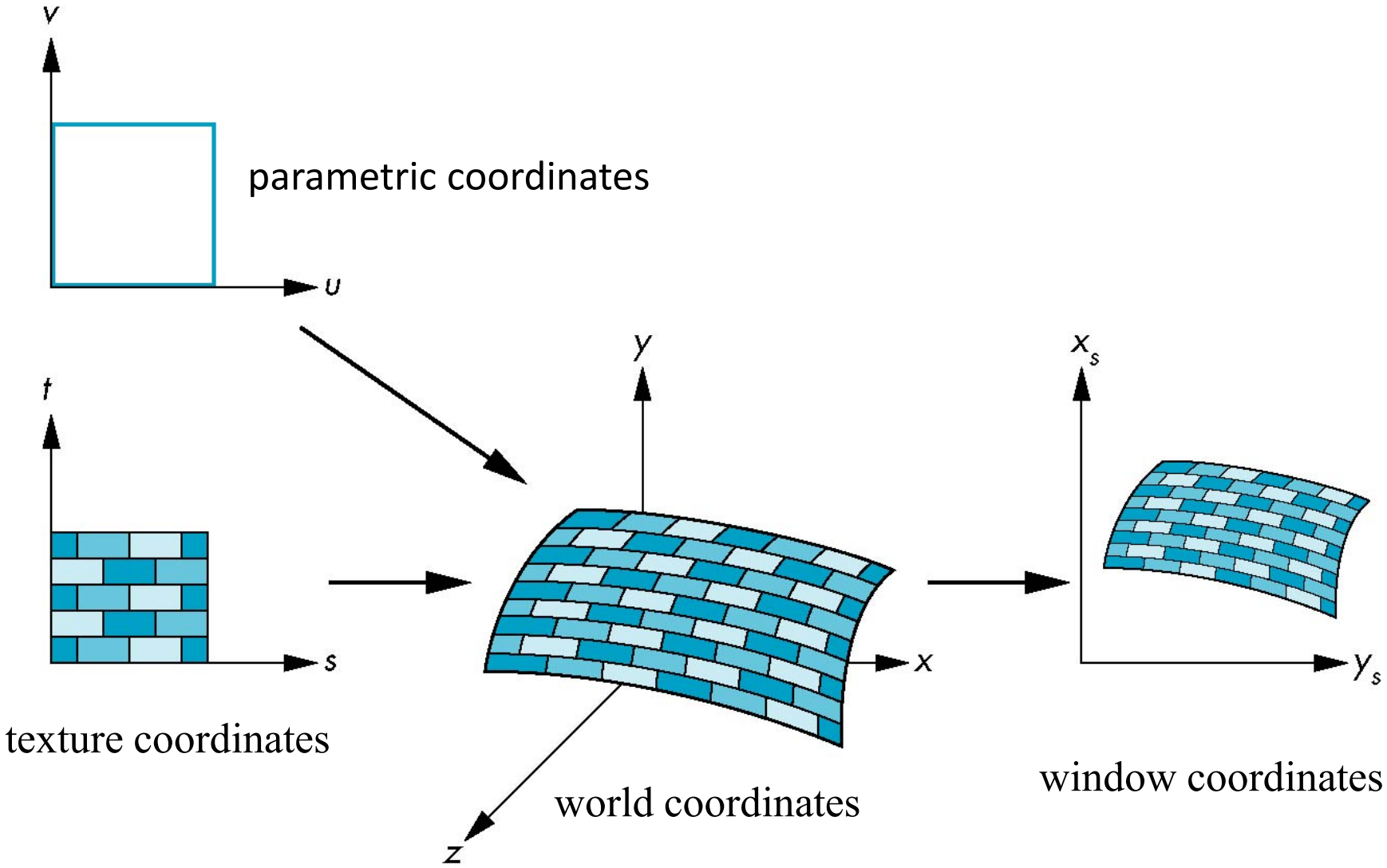
2D image

3D surface

Coordinate Systems

- Parametric coordinates
  - May be used to model curves and surfaces
- Texture coordinates
  - Used to identify points in the image to be mapped
- Object or World Coordinates
  - Conceptually, where the mapping takes place
- Window Coordinates
  - Where the final image is really produced

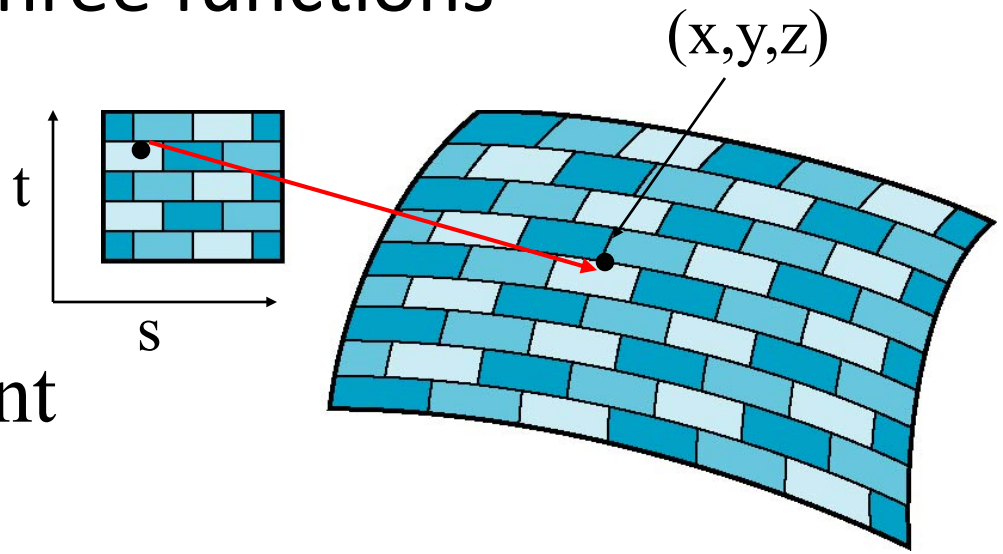
Texture Mapping



Mapping Functions

- Basic problem is how to find the maps
- Consider mapping from texture coordinates to a point a surface
- Appear to need three functions

$$x = x(s,t)$$
$$y = y(s,t)$$
$$z = z(s,t)$$



- But we really want

to go the other way

Backward Mapping

- We really want to go backwards
  - Given a pixel, we want to know to which point on an object it corresponds
  - Given a point on an object, we want to know to which point in the texture it corresponds
- Need a map of the form

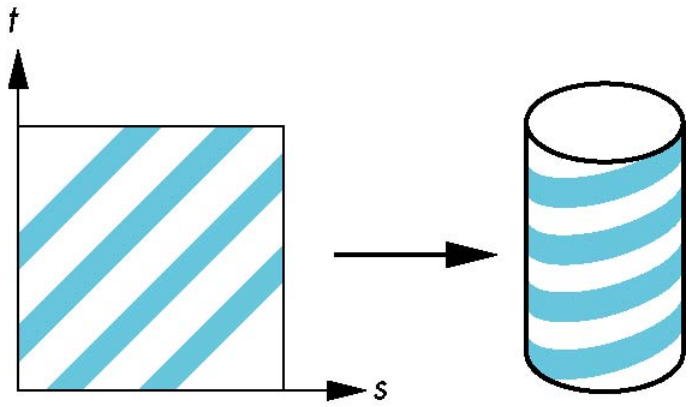
$$s = s(x,y,z)$$

$$t = t(x,y,z)$$

- Such functions are difficult to find in general

Two-part mapping

- One solution to the mapping problem is to first map the texture to a simple intermediate surface
- Example: map to cylinder



Cylindrical Mapping

parametric cylinder

$$x = r \cos 2\pi u$$
$$y = r \sin 2\pi u$$
$$z = v/h$$

maps rectangle in u,v space to cylinder
of radius r and height h in world coordinates

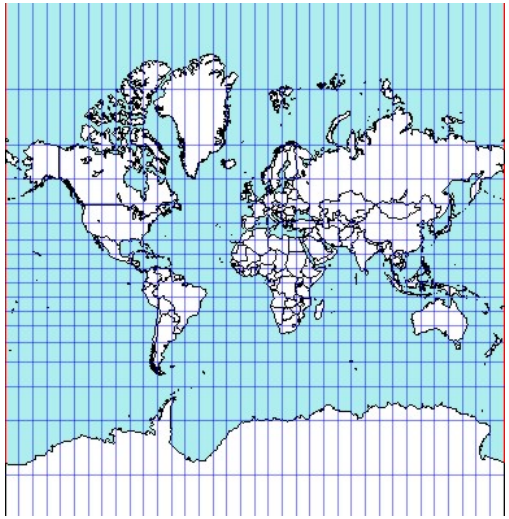
$$s = u$$
$$t = v$$

maps from texture space

Spherical Map

We can use a parametric sphere

$$x = r \cos 2\pi u$$
$$y = r \sin 2\pi u \cos 2\pi v$$
$$z = r \sin 2\pi u \sin 2\pi v$$

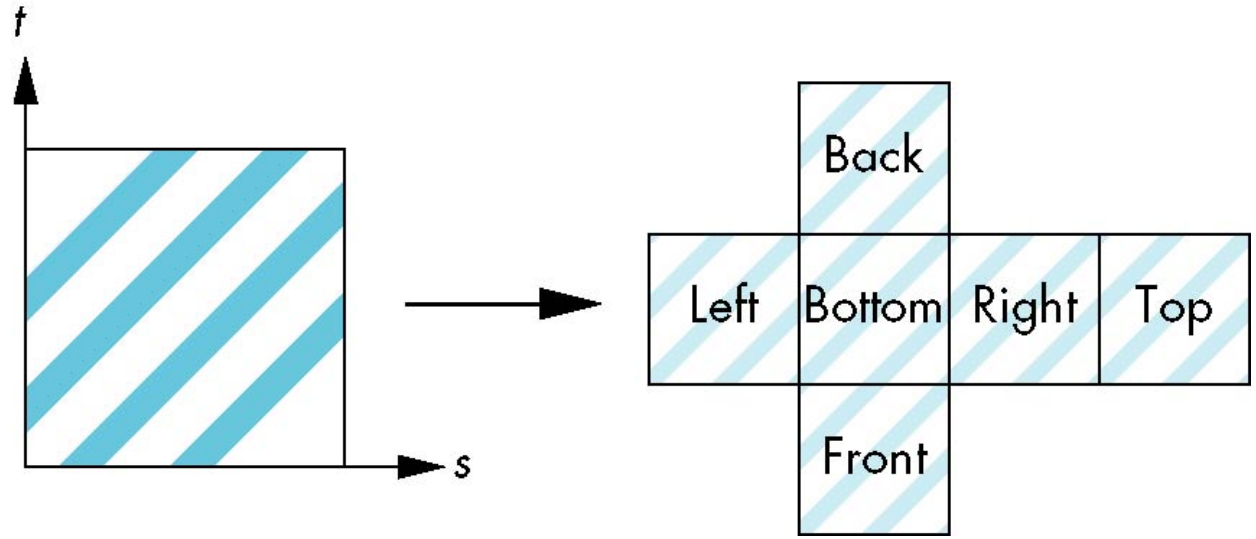


in a similar manner to the cylinder but have to decide where to put the distortion

Spheres are used in environmental maps

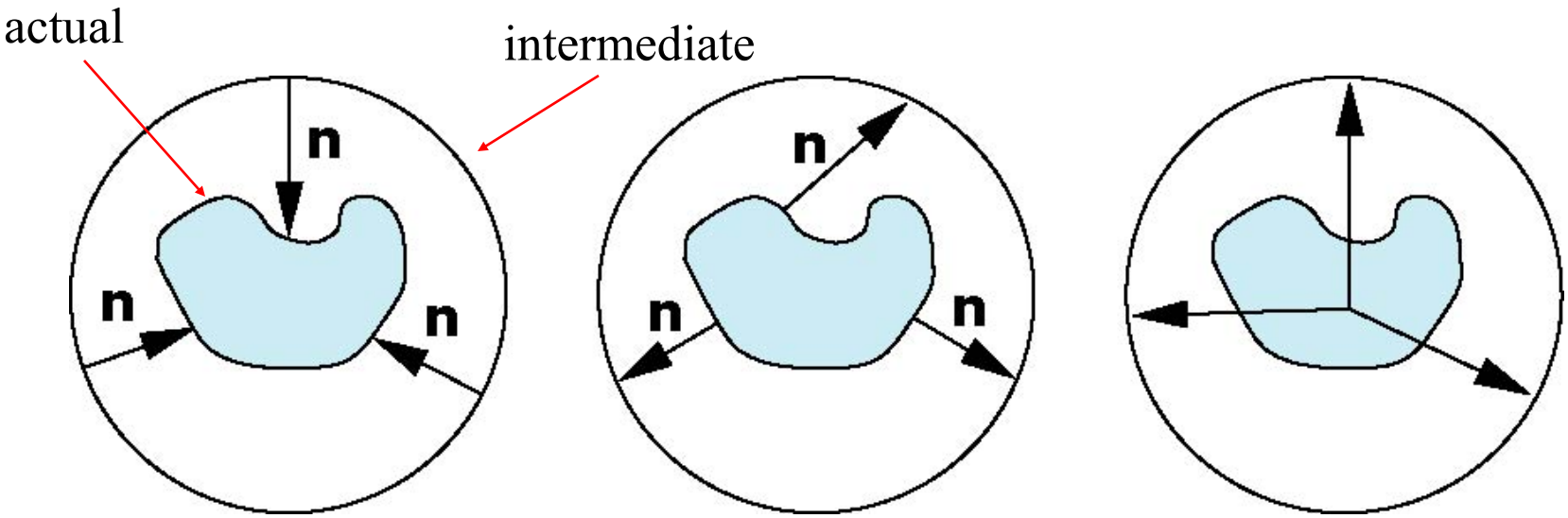
Box Mapping

- Easy to use with simple orthographic projection
- Also used in environment maps



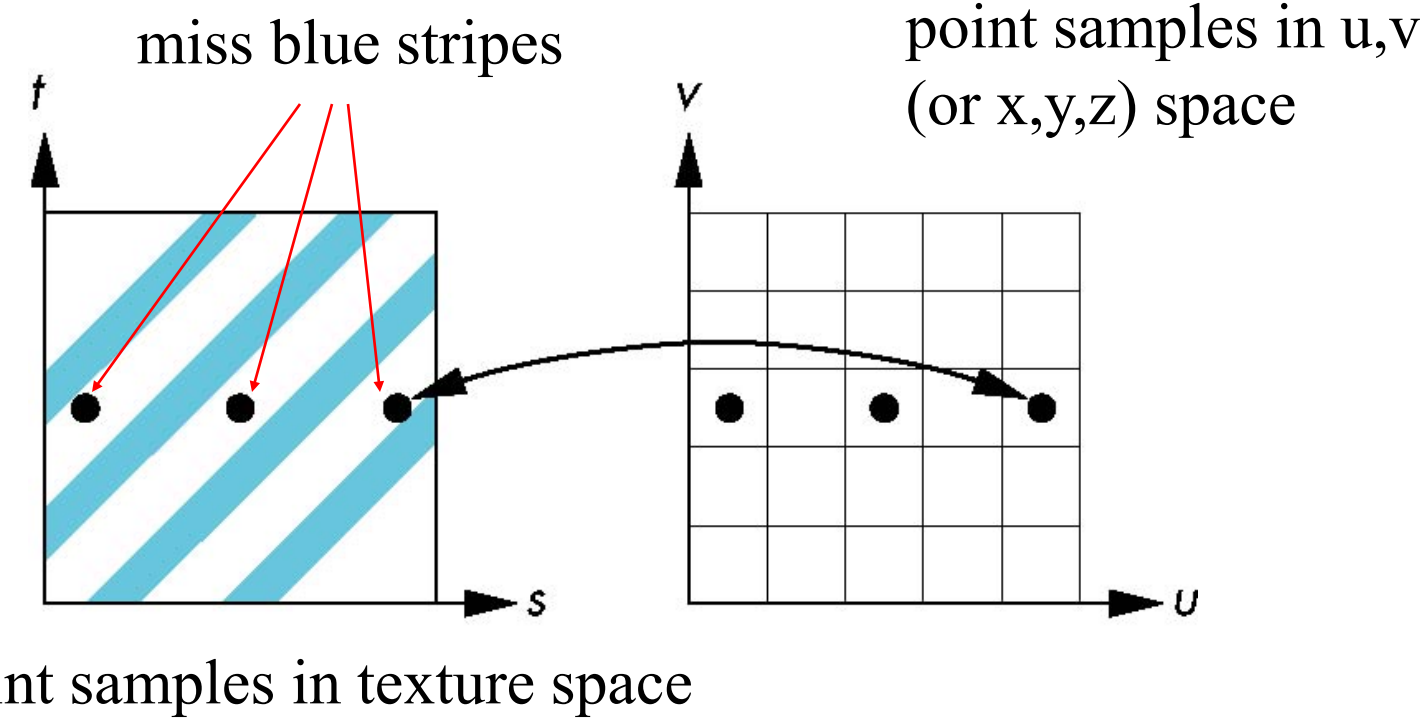
Second Mapping

- Map from intermediate object to actual object
  - Normals from intermediate to actual
  - Normals from actual to intermediate
  - Vectors from center of intermediate



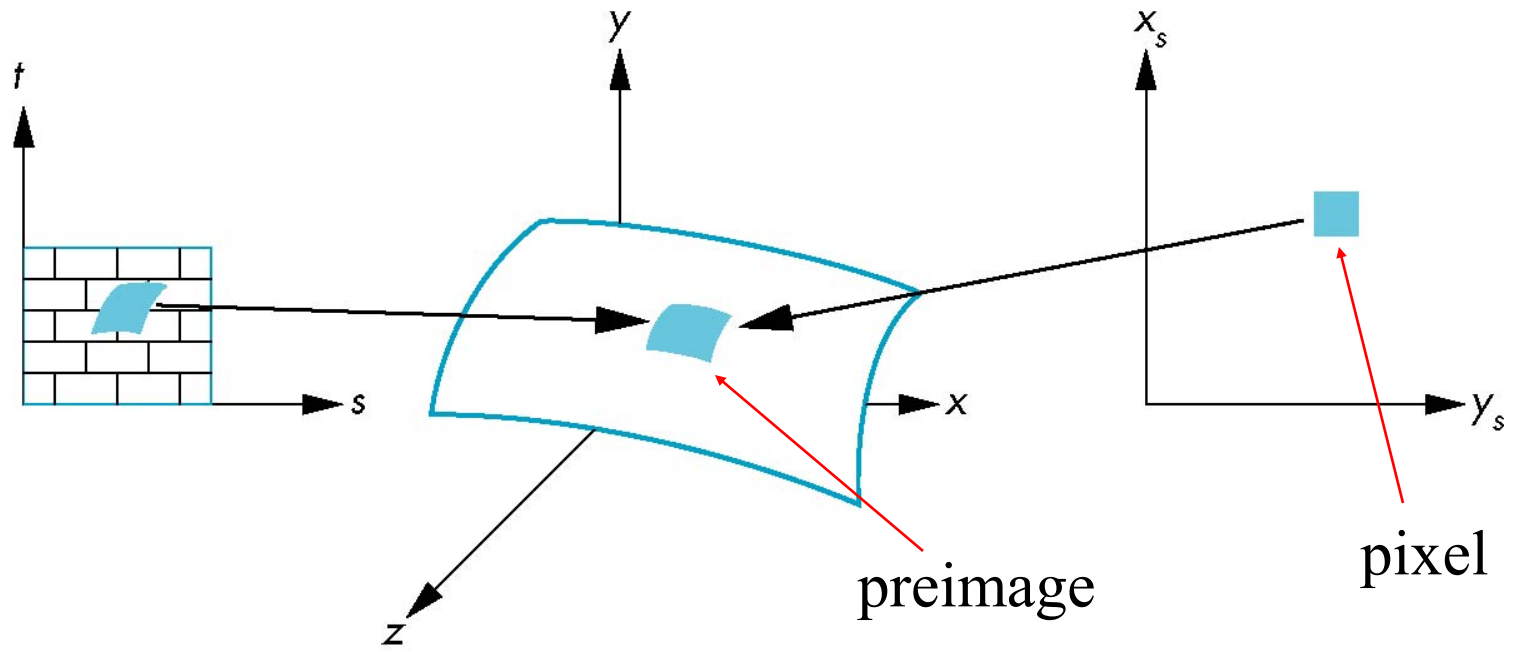
Aliasing

- Point sampling of the texture can lead to aliasing errors



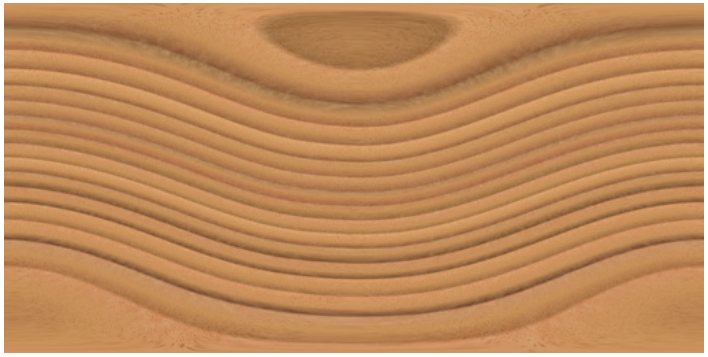
Area Averaging

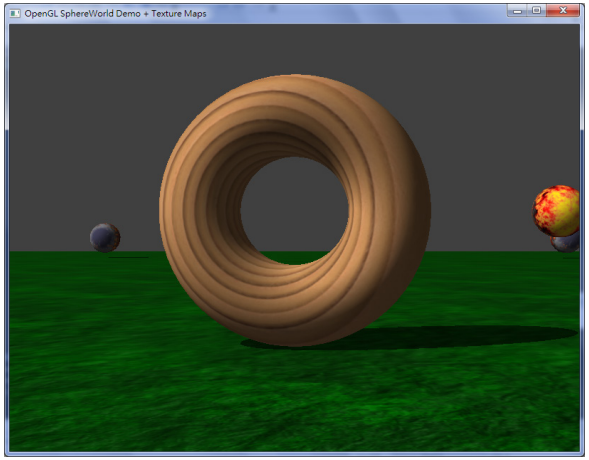
A better but slower option is to use *area averaging*

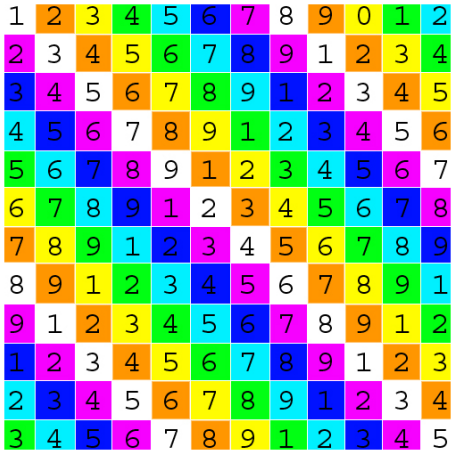


Note that *preimage* of pixel is curved

UV mapping




OpenGL SphereWorld Demo + Texture Maps


1 2 3 4 5 6 7 8 9 0 1 2
2 3 4 5 6 7 8 9 1 2 3 4
3 4 5 6 7 8 9 1 2 3 4 5
4 5 6 7 8 9 1 2 3 4 5 6
5 6 7 8 9 1 2 3 4 5 6 7
6 7 8 9 1 2 3 4 5 6 7 8
7 8 9 1 2 3 4 5 6 7 8 9
8 9 1 2 3 4 5 6 7 8 9 1
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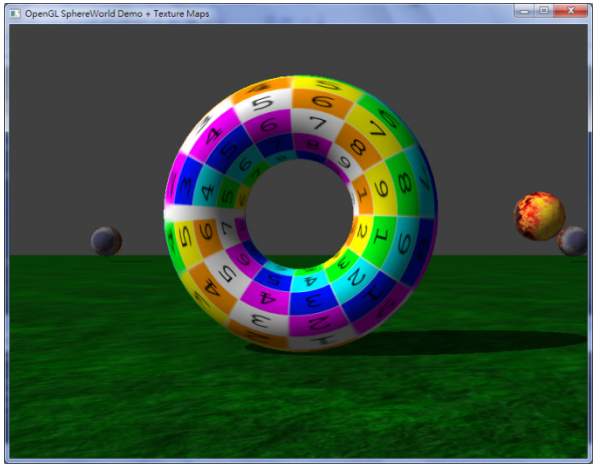
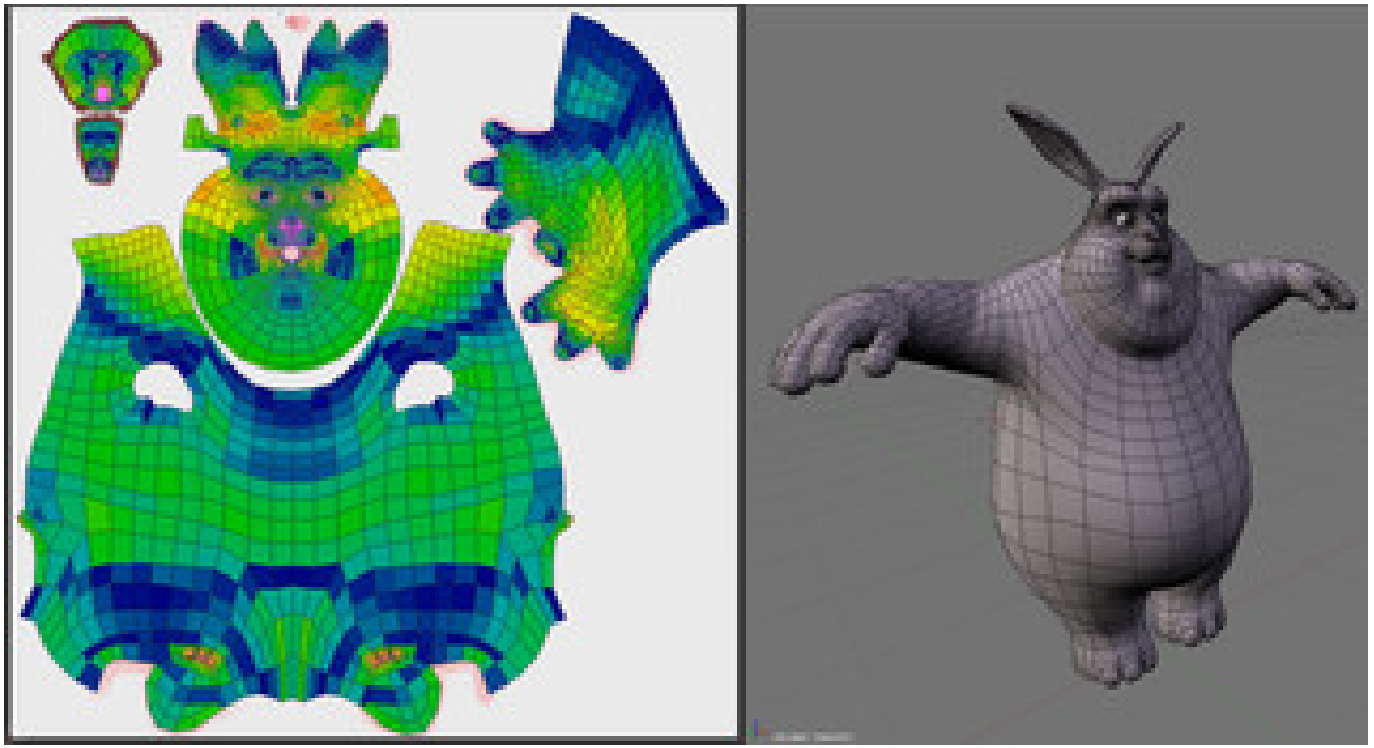
3 4 5 6 7 8 9 1 2 3 4 5


OpenGL SphereWorld Demo + Texture Maps

Complex model



Blender uv mapping

Perspective correctness

- Perspective correct mapping interpolates after dividing by depth , then uses its interpolated reciprocal to recover the correct coordinate:

$$u_\alpha = \frac{(1-\alpha)\frac{u_0}{z_0} + \alpha\frac{u_1}{z_1}}{(1-\alpha)\frac{1}{z_0} + \alpha\frac{1}{z_1}}$$

OpenGL Texture Mapping

Objectives

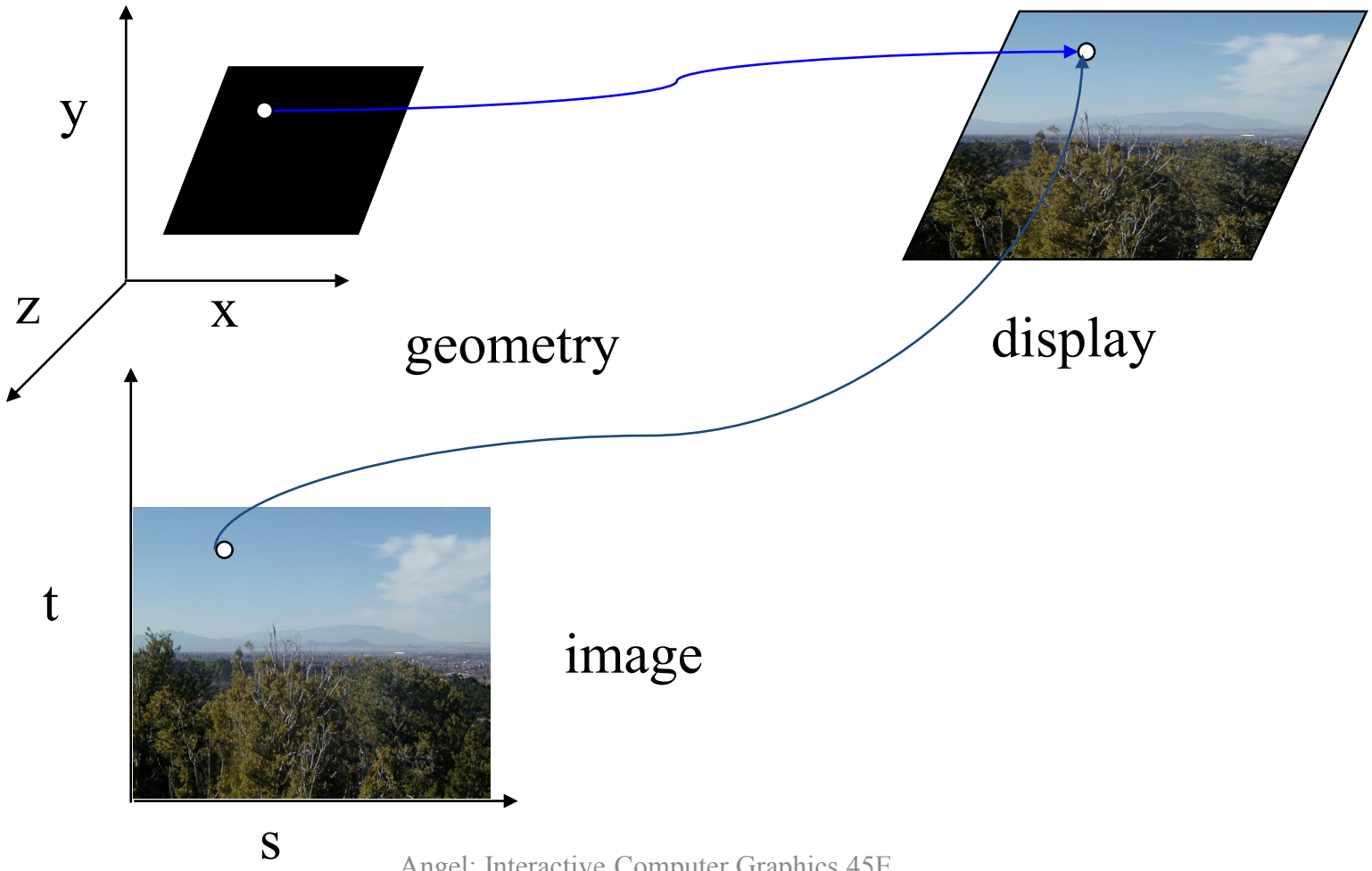
- Introduce the OpenGL texture functions and options

Basic Stragegy

Three steps to applying a texture

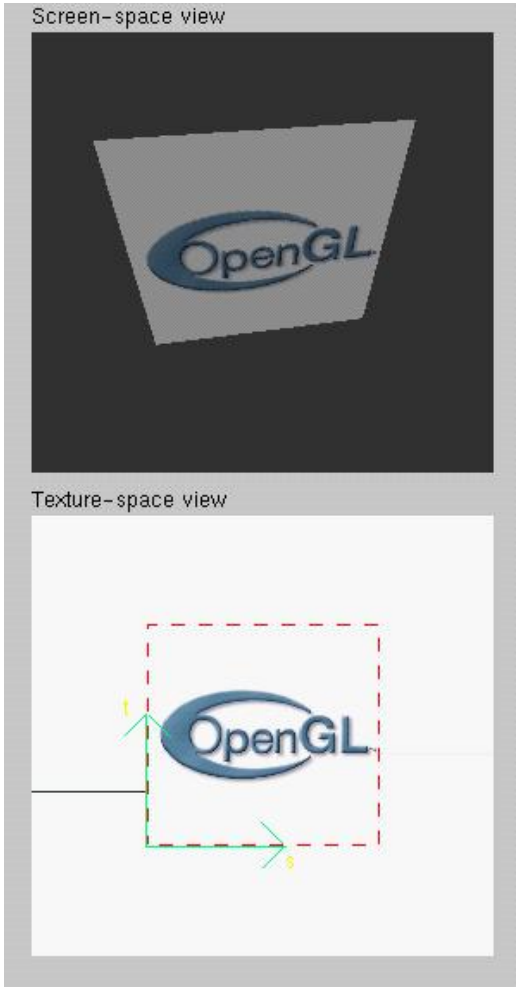
1. specify the texture
   - read or generate image
   - assign to texture
   - enable texturing
2. assign texture coordinates to vertices
   - Proper mapping function is left to application
3. specify texture parameters
   - wrapping, filtering

Texture Mapping



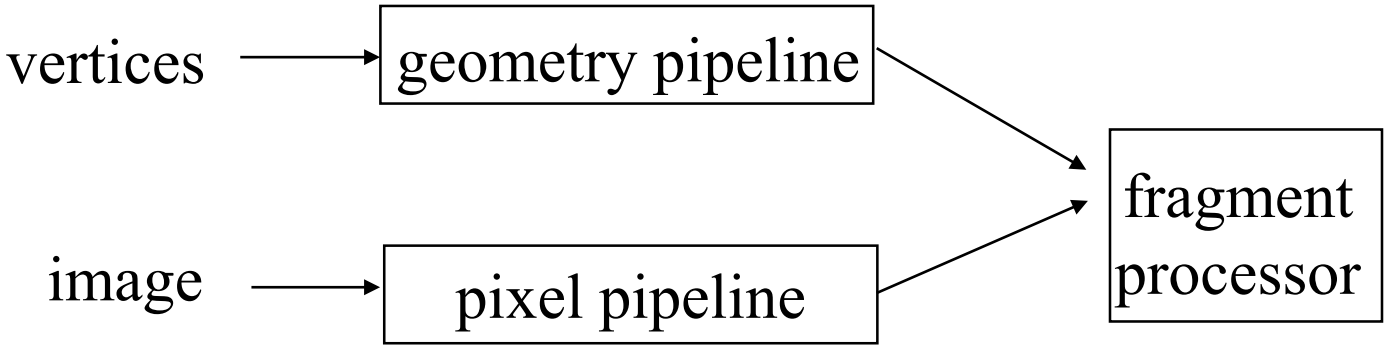
Texture Example

- The texture (below) is a 256 x 256 image that has been mapped to a rectangular polygon which is viewed in perspective



Texture Mapping and the OpenGL Pipeline

- Images and geometry flow through separate pipelines that join during fragment processing
  - "complex" textures do not affect geometric complexity



Specifying a Texture Image

- Define a texture image from an array of *texels* (texture elements) in CPU memory

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

- Define as any other pixel map
  - Scanned image
  - Generate by application code
- Enable texture mapping
  - **`glEnable(GL_TEXTURE_2D)`**
  - OpenGL supports 1-4 dimensional texture maps

Define Image as 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 (discussed later)

components: elements per texel

w, h: width and height of **texels** in pixels

border: used for smoothing (discussed later)

format and type: describe texels

texels: pointer to texel array

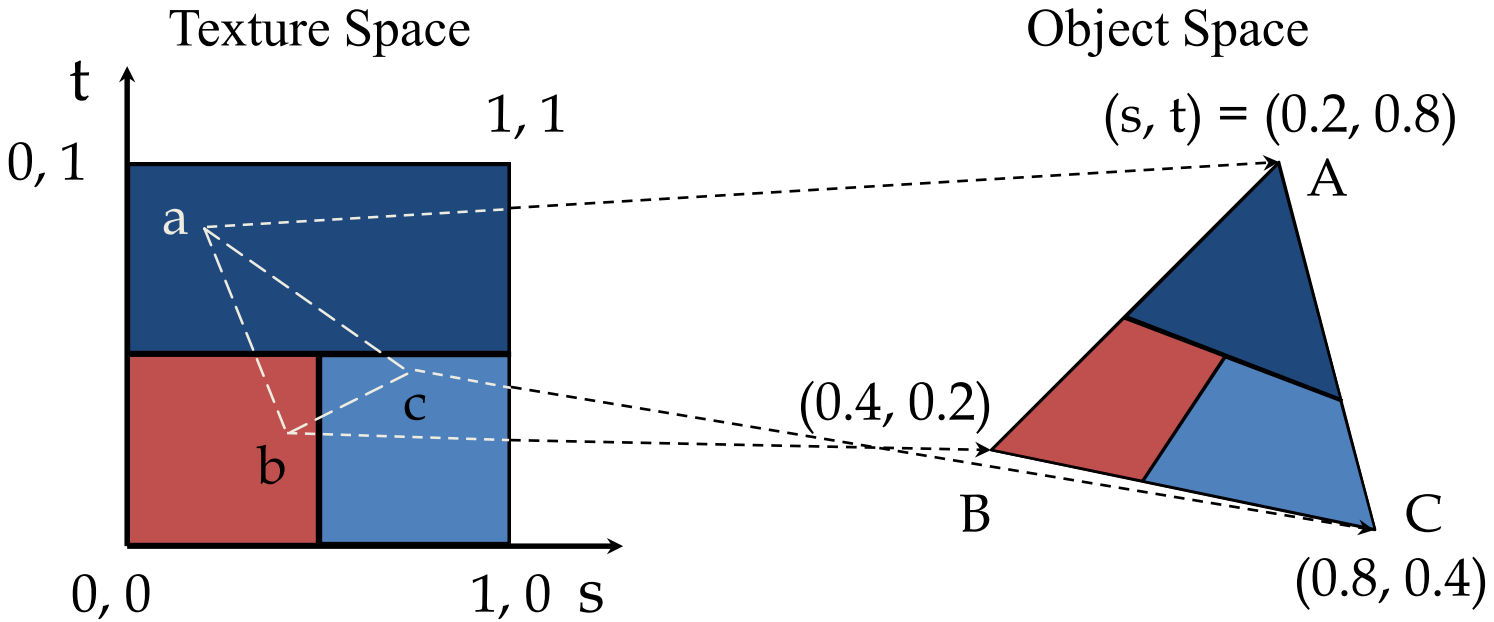
```
glTexImage2D(GL_TEXTURE_2D, 0, 3, 512, 512, 0,
  GL_RGB, GL_UNSIGNED_BYTE, my_texels);
```

Converting A Texture Image

- OpenGL requires texture dimensions to be powers of 2
- If dimensions of image are not powers of 2
  - **`gluScaleImage( format, w_in, h_in, type_in, *data_in, w_out, h_out, type_out, *data_out );`**
  - **`data_in`** is source image
  - **`data_out`** is for destination image
- Image interpolated and filtered during scaling

Mapping a Texture

- Based on parametric texture coordinates
- **`glTexCoord*()`** specified at each vertex



Typical Code

```
glBegin(GL_POLYGON);
   glColor3f(r0, g0, b0);
   glNormal3f(u0, v0, w0);
   glTexCoord2f(s0, t0);
   glVertex3f(x0, y0, z0);
   glColor3f(r1, g1, b1);
   glNormal3f(u1, v1, w1);
   glTexCoord2f(s1, t1);
   glVertex3f(x1, y1, z1);
        .
glEnd();
```

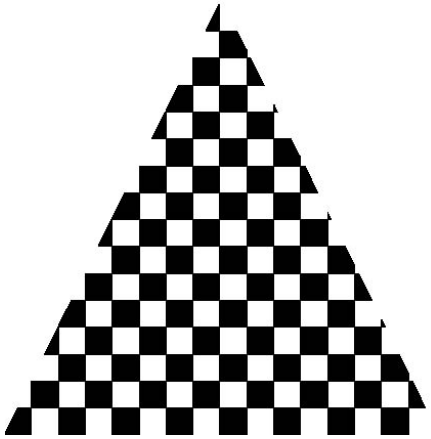
Note that we can use vertex arrays to increase efficiency

Interpolation

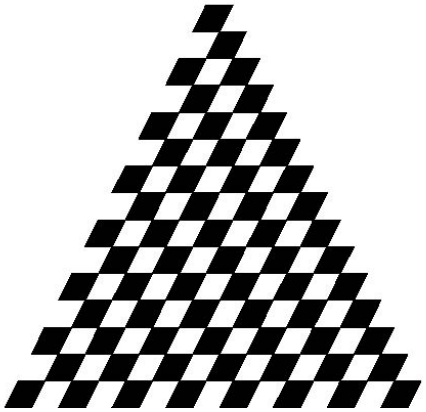
OpenGL uses interpolation to find proper texels from specified texture coordinates

Can be distortions

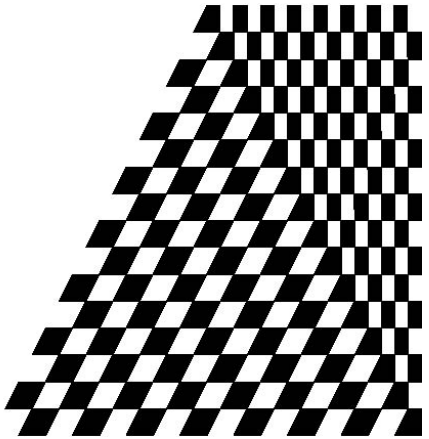
good selection of tex coordinates



poor selection of tex coordinates



texture stretched over trapezoid showing effects of bilinear interpolation



Texture Parameters

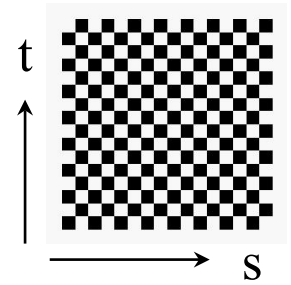
- OpenGL has a variety of parameters that determine how texture is applied
  - Wrapping parameters determine what happens if s and t are outside the (0,1) range
  - Filter modes allow us to use area averaging instead of point samples
  - Mipmapping allows us to use textures at multiple resolutions
  - Environment parameters determine how texture mapping interacts with shading

Wrapping Mode

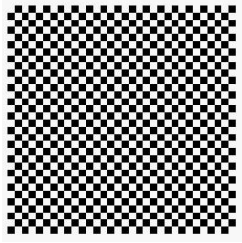
Clamping: if s,t > 1 use 1, if s,t <0 use 0

Wrapping: use s,t modulo 1

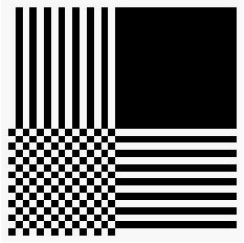
```
glTexParameteri( GL_TEXTURE_2D,
      GL_TEXTURE_WRAP_S, GL_CLAMP )
glTexParameteri( GL_TEXTURE_2D,
      GL_TEXTURE_WRAP_T, GL_REPEAT )
```



texture



GL_REPEAT wrapping

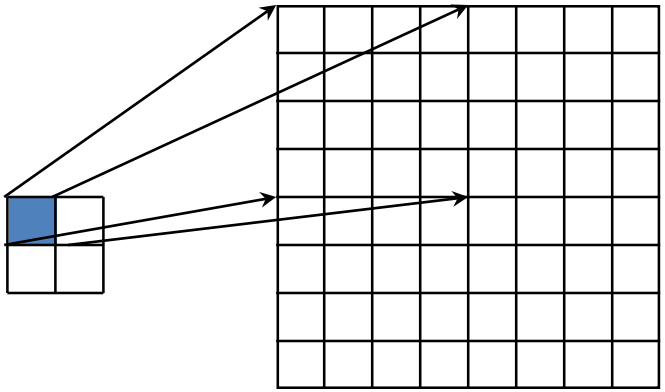


GL_CLAMP wrapping

Magnification and Minification

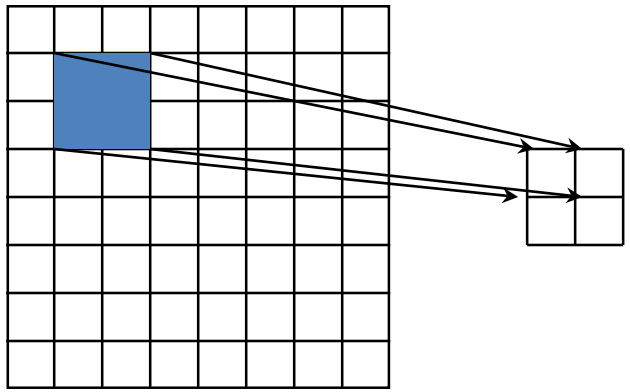
More than one texel can cover a pixel (*minification*) or more than one pixel can cover a texel (*magnification*)

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



Texture Polygon

Magnification



Texture Polygon

Minification

Filter Modes

Modes determined by

- **glTexParameteri(target, type, mode)**

```
glTexParameteri(GL_TEXTURE_2D, GL_TEXURE_MAG_FILTER,
                GL_NEAREST);

glTexParameteri(GL_TEXTURE_2D, GL_TEXURE_MIN_FILTER,
                GL_LINEAR);
```

Note that linear filtering requires a border of an extra texel for filtering at edges (border = 1)

Mipmapped Textures

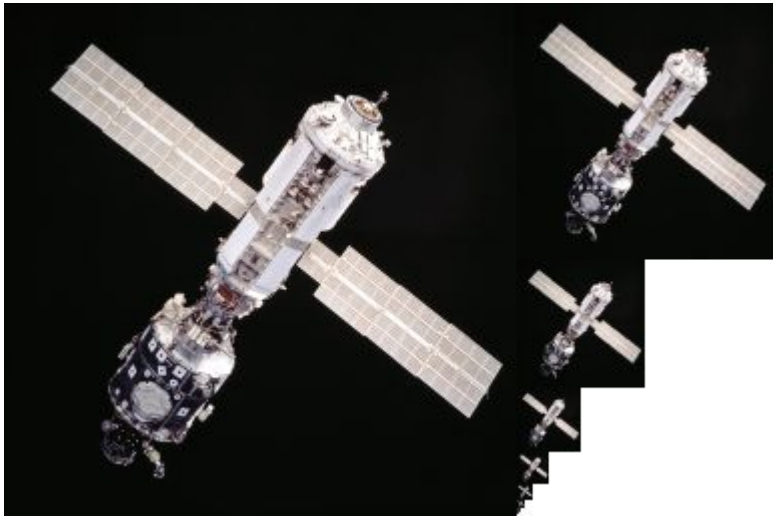
- *Mipmapping* allows for prefiltered texture maps of decreasing resolutions
- Lessens interpolation errors for smaller textured objects
- Declare mipmap level during texture definition

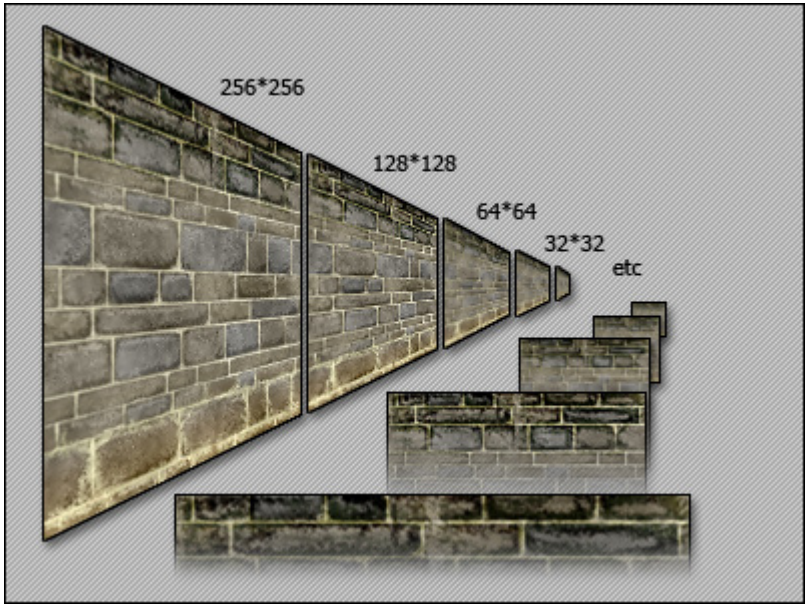
```
glTexImage2D( GL_TEXTURE_2D, level, … )
```

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

```
gluBuild*DMipmaps( … )
```

Mipmap example

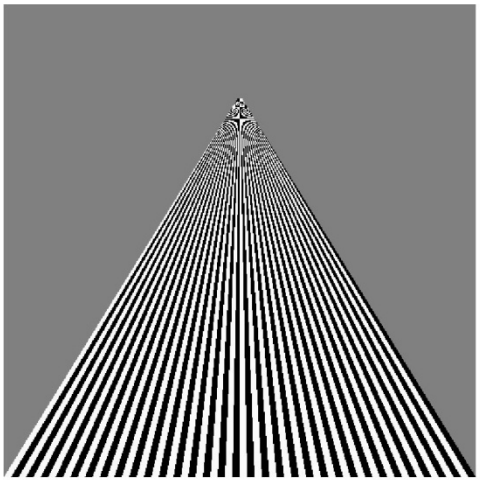


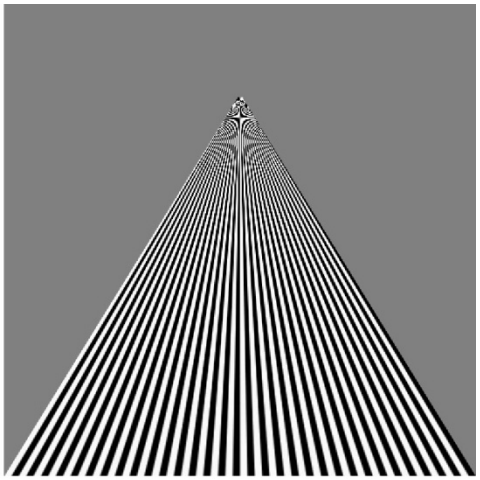


http://game-art.co.uk/agtec/html/mipmaps.html

Example

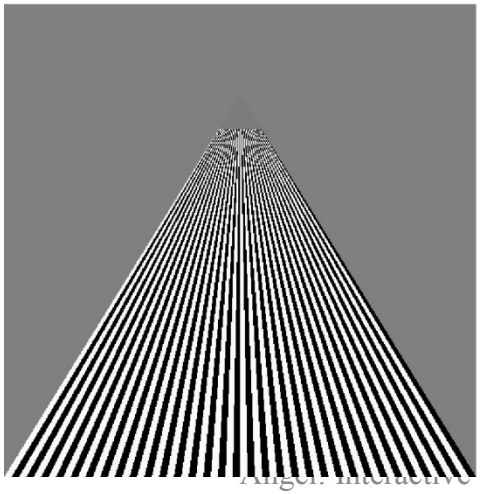
point sampling

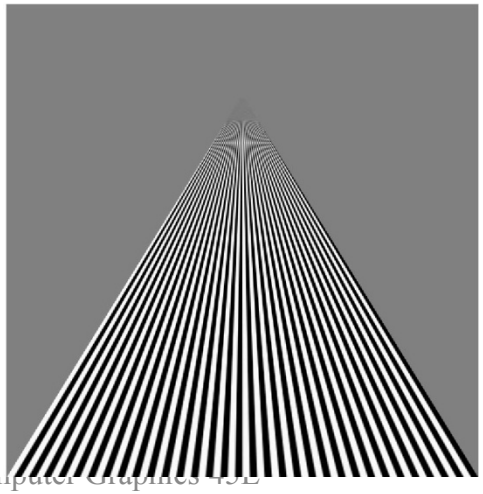




linear filtering

mipmapped point sampling





mipmapped linear filtering

Texture Functions

- Controls how texture is applied
  - **`glTexEnv{fi}[v]( GL_TEXTURE_ENV, prop, param )`**
- **`GL_TEXTURE_ENV_MODE`** modes
  - **`GL_MODULATE:`** modulates with computed shade
  - **`GL_BLEND:`** blends with an environmental color
  - **`GL_REPLACE:`** use only texture color
  - **`GL(GL_TEXTURE_ENV, GL_TEXTURE_ENV_MODE, GL_MODULATE);`**
- Set blend color with **`GL_TEXTURE_ENV_COLOR`**

Perspective Correction Hint

- Texture coordinate and color interpolation
  - either linearly in screen space
  - or using depth/perspective values (slower)
- Noticeable for polygons “on edge”
  - **`glHint( GL_PERSPECTIVE_CORRECTION_HINT, hint )`**

  where **`hint`** is one of
    - **`GL_DONT_CARE`**
    - **`GL_NICEST`**
    - **`GL_FASTEST`**

Generating Texture Coordinates

- OpenGL can generate texture coordinates automatically

  `glTexGen{ifd}[v]()`

- specify a plane
  - generate texture coordinates based upon distance from the plane
- generation modes
  - **`GL_OBJECT_LINEAR`**
  - **`GL_EYE_LINEAR`**
  - **`GL_SPHERE_MAP`** (used for environmental maps)

Texture Objects

- Texture is part of the OpenGL state
  - If we have different textures for different objects, OpenGL will be moving large amounts of data from processor memory to texture memory
- Recent versions of OpenGL have *texture objects*
  - one image per texture object
  - Texture memory can hold multiple texture objects

Applying Textures II

1. specify textures in texture objects
2. set texture filter
3. set texture function
4. set texture wrap mode
5. set optional perspective correction hint
6. bind texture object
7. enable texturing
8. supply texture coordinates for vertex
   - coordinates can also be generated

Other Texture Features

- Environment Maps
  - Start with image of environment through a wide angle lens
    - Can be either a real scanned image or an image created in OpenGL
  - Use this texture to generate a spherical map
  - Use automatic texture coordinate generation

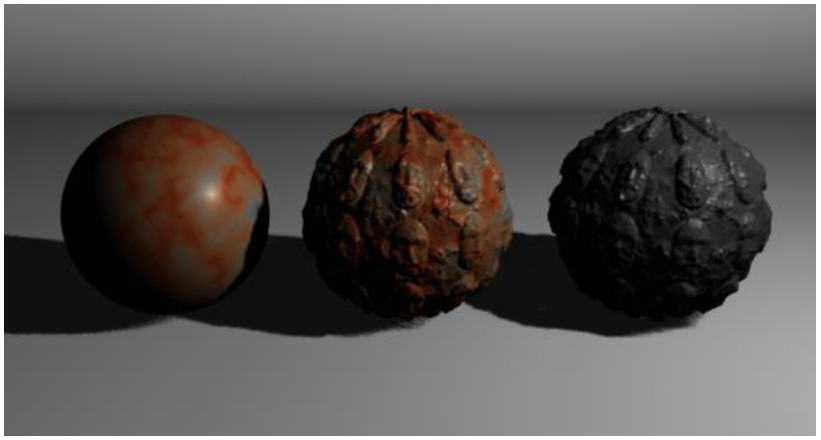
- Multitexturing
  - Apply a sequence of textures through cascaded texture units

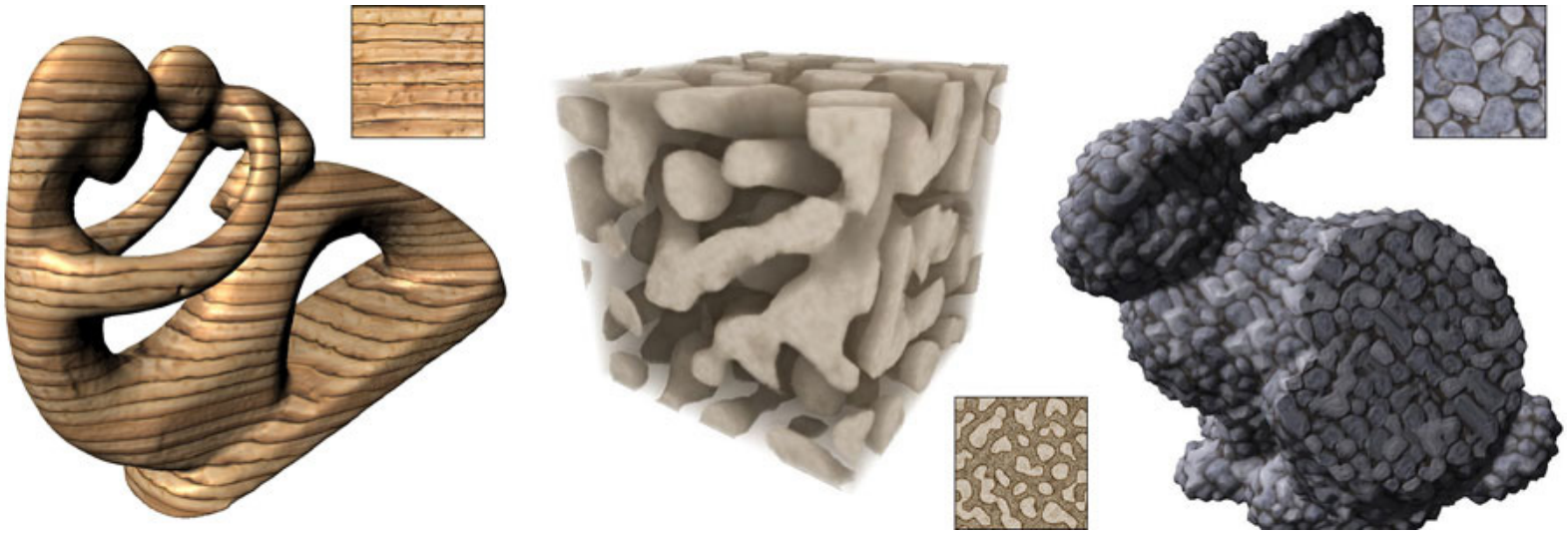
void glMultiTexCoord2f(GLenum target, GLfloat s, GLfloat t);

- Target: GL_TEXTURE*i*
- *Ex:*

```
glTexCoord2f(0, 1);
glMultiTexCoord2f(GL_TEXTURE1, 0.3, 0.6);
glVertex3f(20, 20, 0);
```

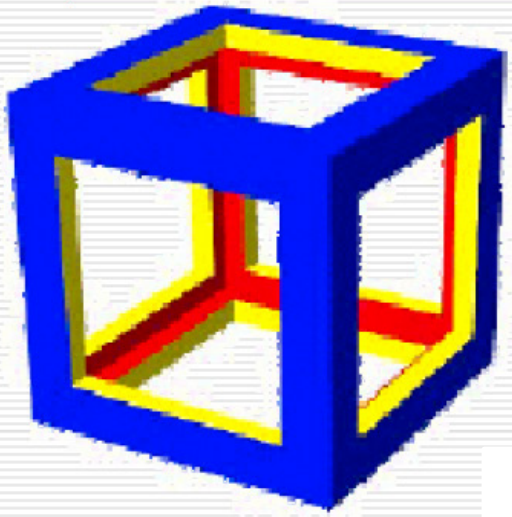
Solid texture

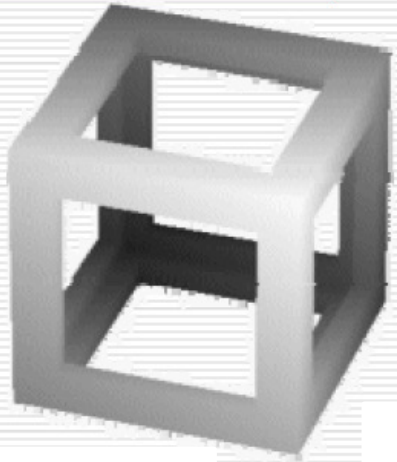




Solid Texture Synthesis from 2D Exemplars 2007

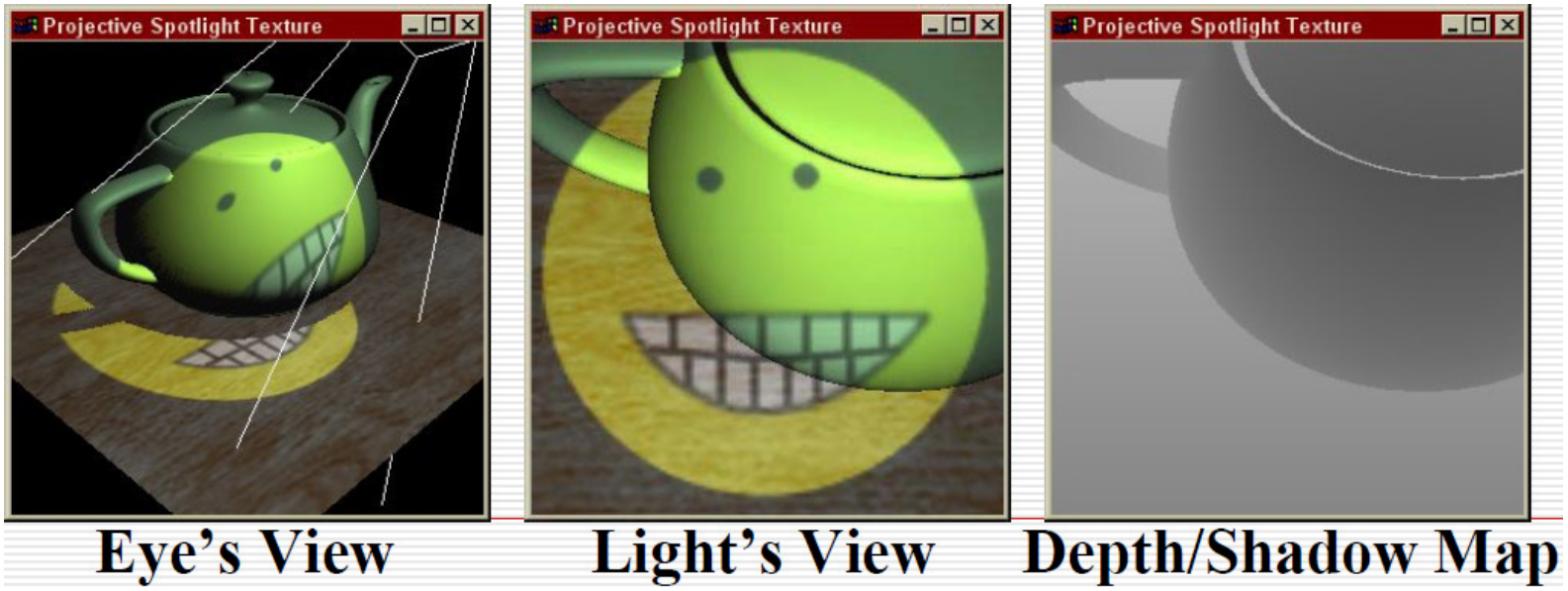
Shadow map



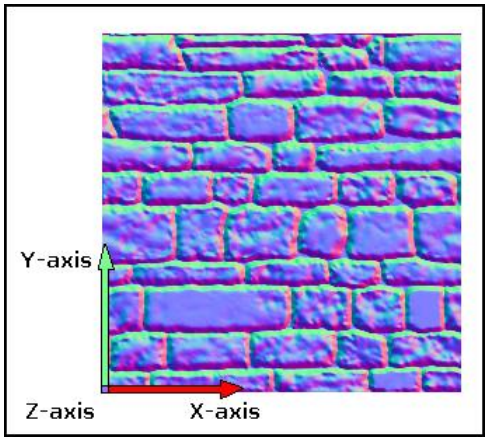


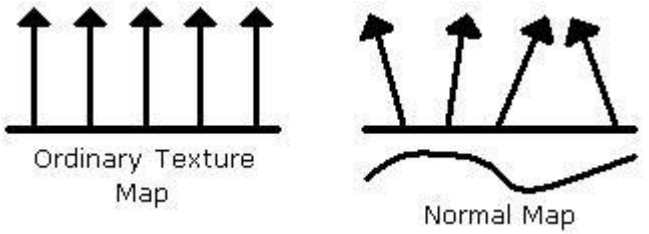
Basic Steps of Shadow Maps

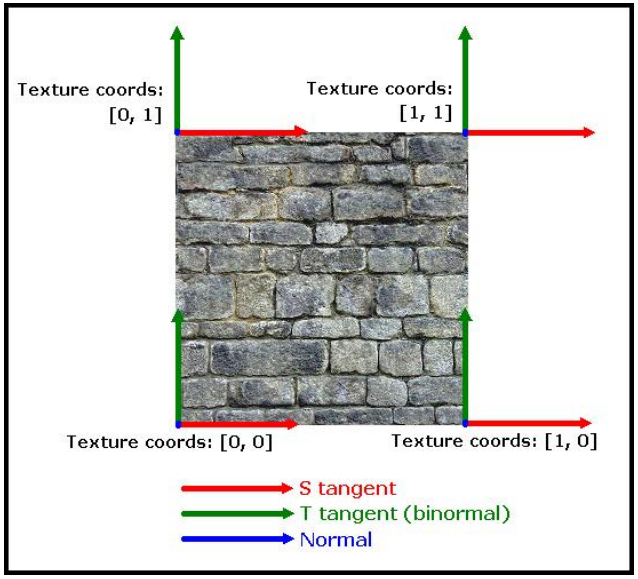
- Render the scene from the light's point of view, Use the light's depth buffer as a texture (shadow map),
- Projectively texture the shadow map onto the scene,
- Use "texture color"(comparison result) in fragment shading.

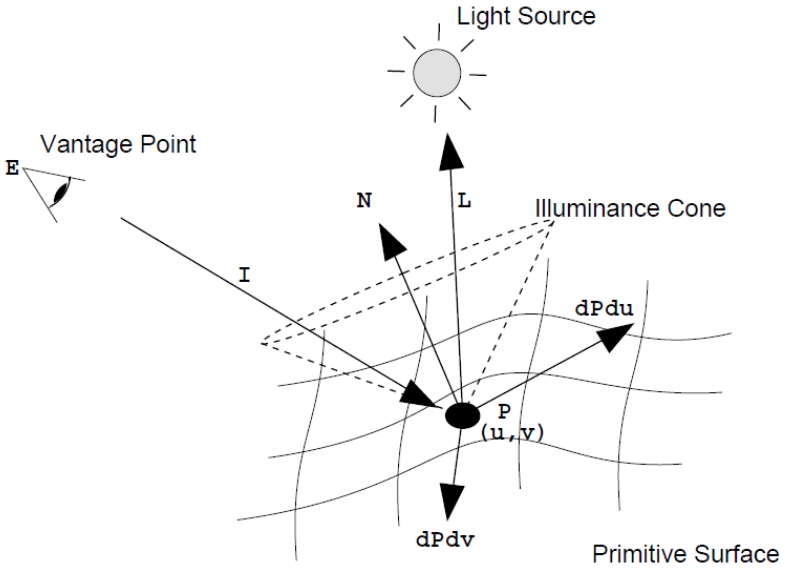


Tangent space







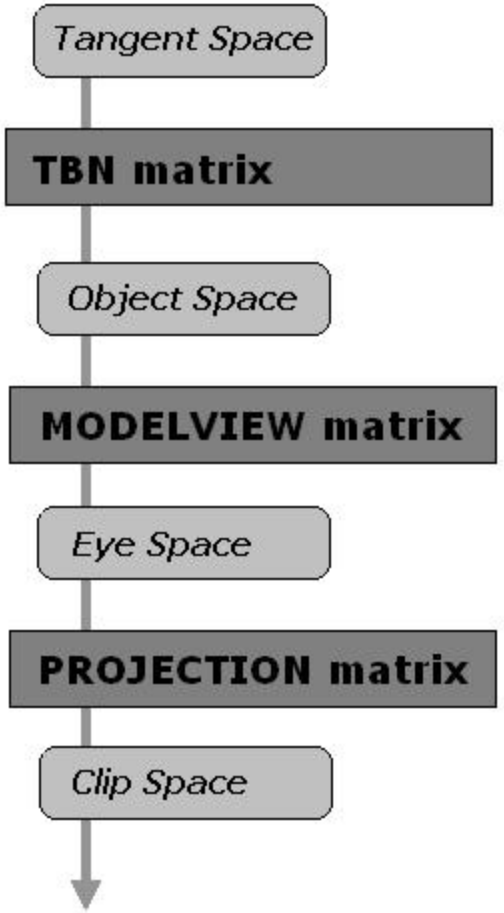


TBN matrix
(**T**angent, **B**inormal, **N**ormal)

T = normalize(dx/du, dy/du, dz/du)

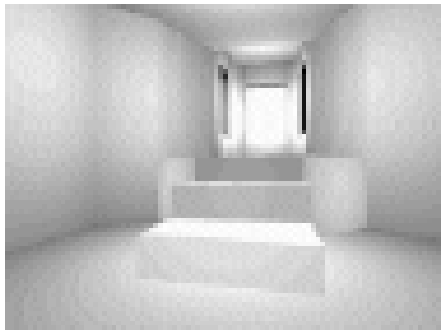
N = T $\times$ normalize(dx/dv, dy/dv, dz/dv)

B = N $\times$ T

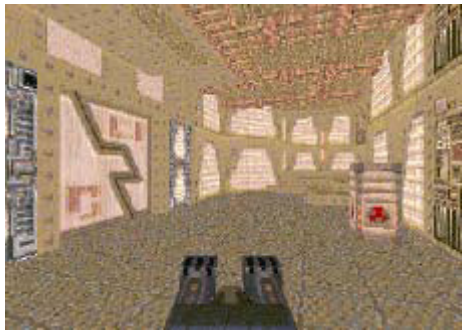


Texture Mapping in Quake

Light Map



Texture Only



Texture & Light Maps

- GI texture using radiosity