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

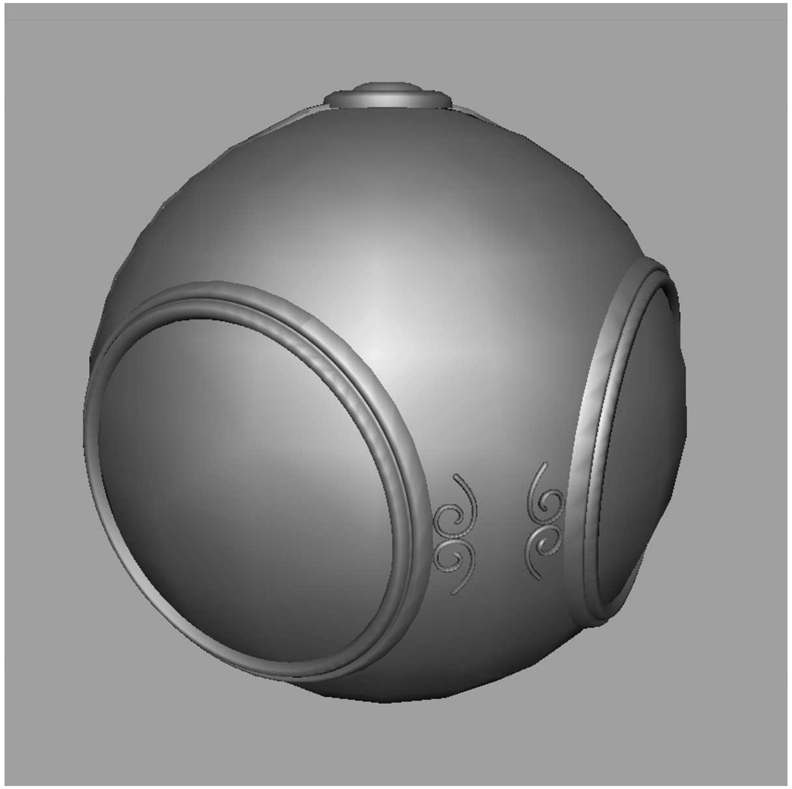
Modeling an Orange

- 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

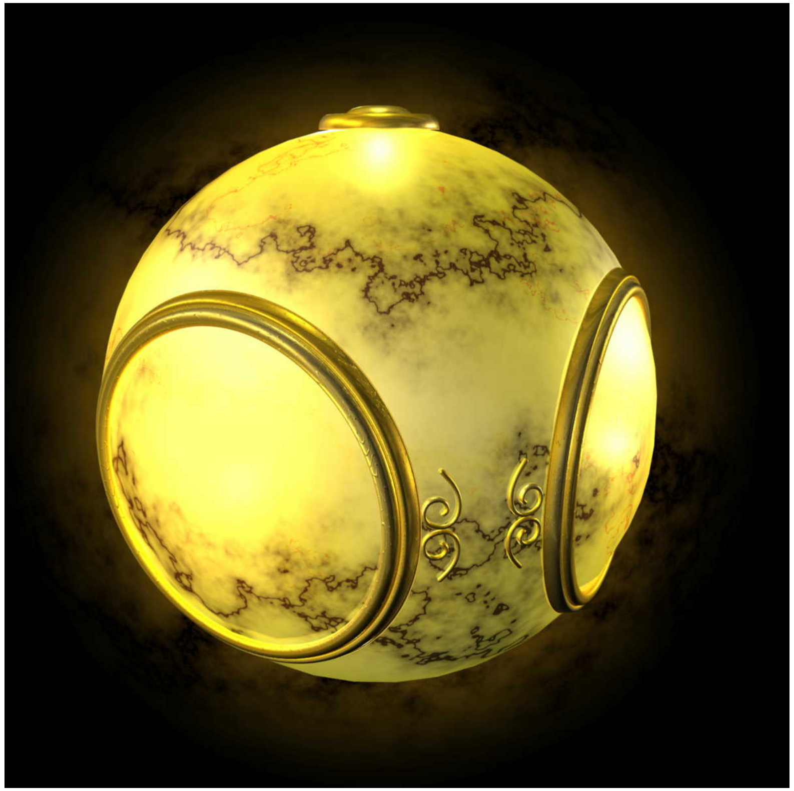
Modeling an Orange (2)

- Take a picture of a real orange, scan it, and “paste” onto 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

Texture Mapping



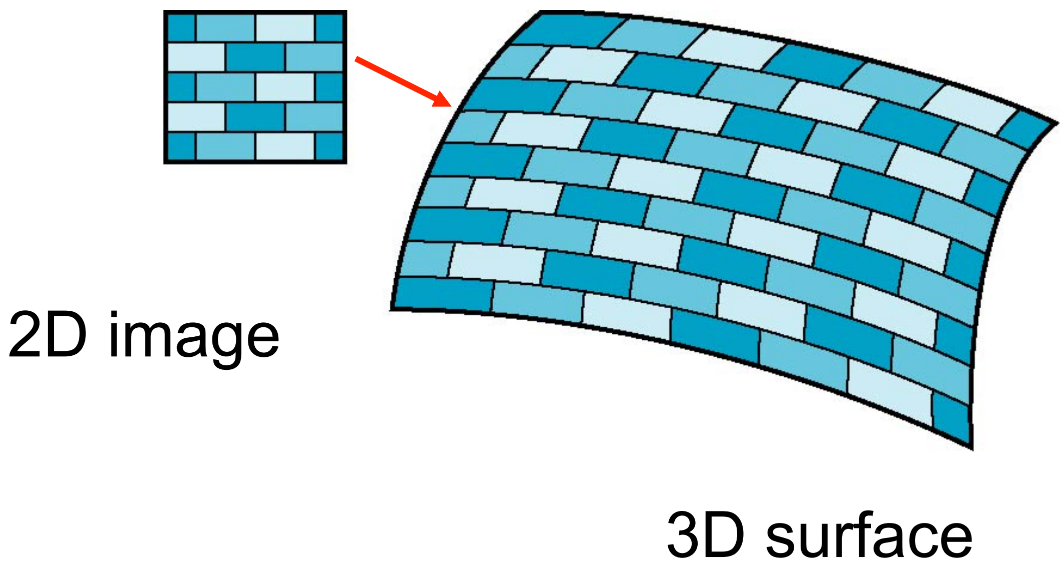
geometric model



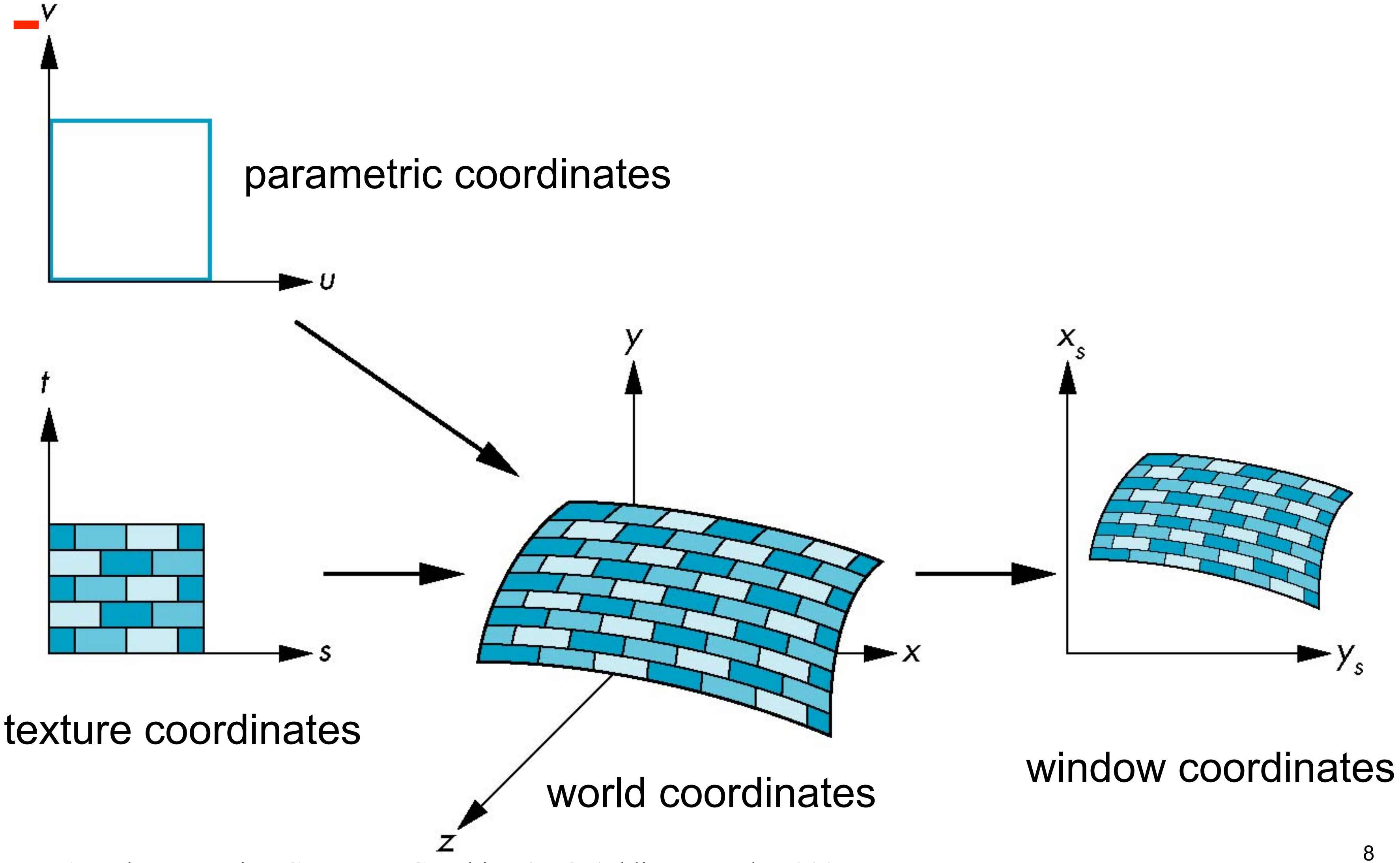
texture mapped

Is it simple?

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

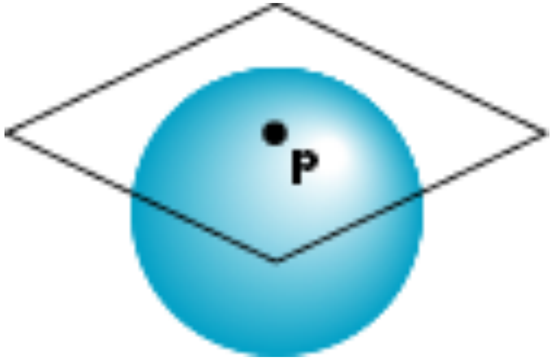


Texture Mapping



Parametric Form

- For sphere



$$x=x(u,v)=\cos u \sin v$$
$$y=y(u,v)=\cos u \cos v$$
$$z= z(u,v)=\sin u$$

- Tangent plane determined by vectors

$$\partial \mathbf{p}/\partial u = [\partial x/\partial u, \partial y/\partial u, \partial z/\partial u]T$$
$$\partial \mathbf{p}/\partial v = [\partial x/\partial v, \partial y/\partial v, \partial z/\partial v]T$$

- Normal given by cross product

$$\mathbf{n} = \partial \mathbf{p}/\partial u \times \partial \mathbf{p}/\partial v$$

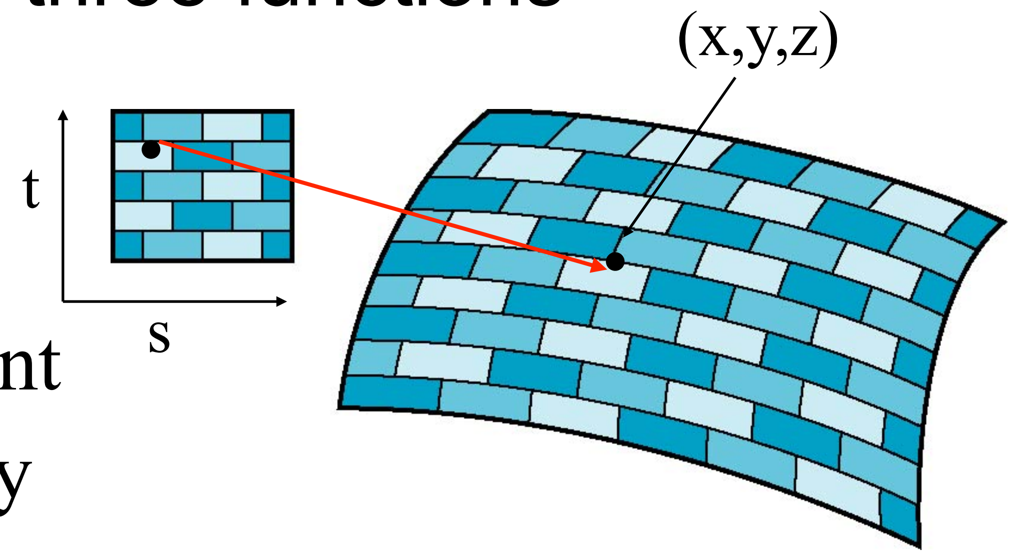
Mapping Functions

- 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

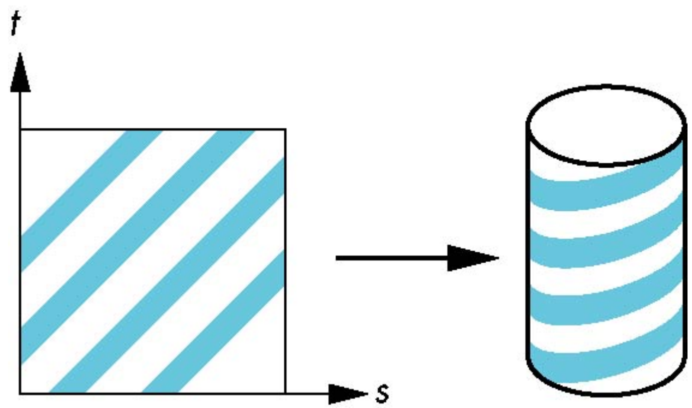
- We really want to go backwards
  - Given a pixel, we want to know to which point on an object it corresponds
  - Given a point on an object, we want to know to which point in the texture it corresponds
- Need a map of the form

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

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

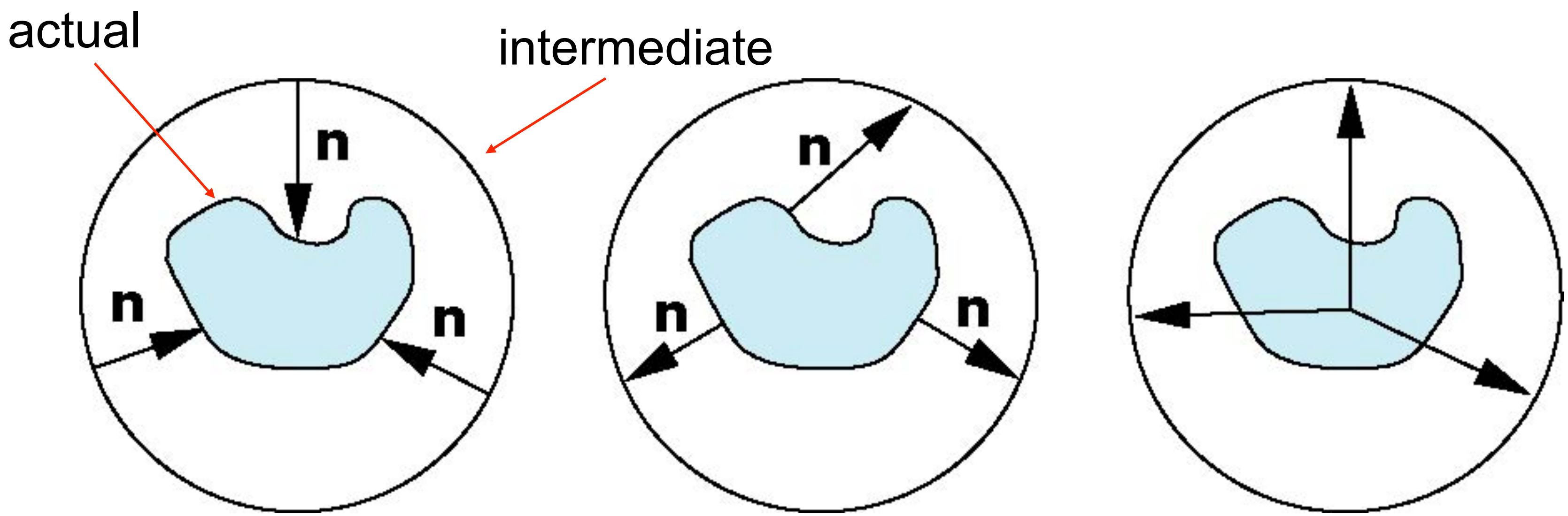
$$x = r \cos 2\pi u$$
$$y = r \sin 2\pi u \cos 2\pi v$$
$$z = r \sin 2\pi u \sin 2\pi v$$

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

Spheres are used in environmental maps

Second Mapping

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



OpenGL Texture Mapping

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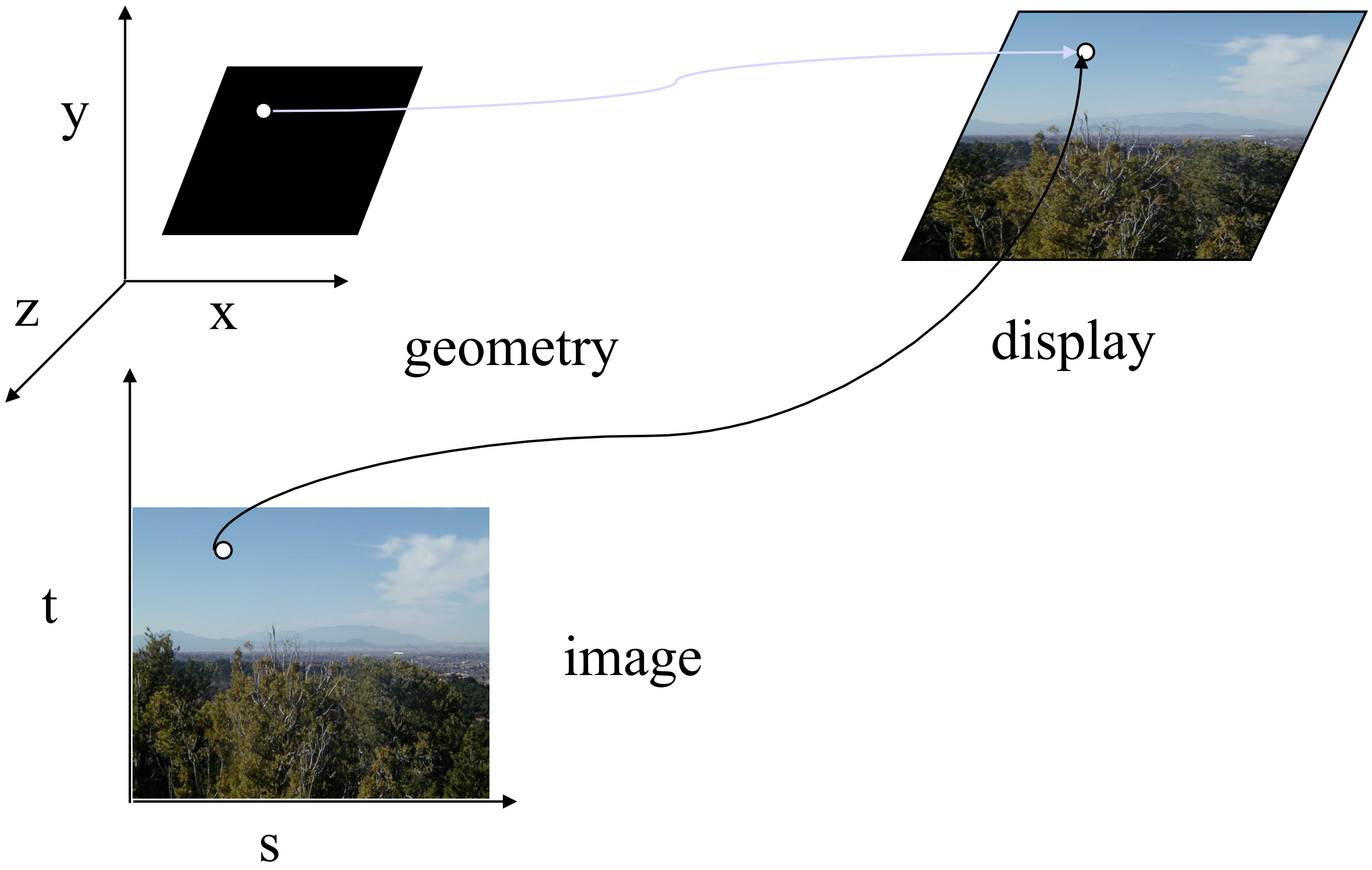
Basic Strategy

Three steps to applying a texture

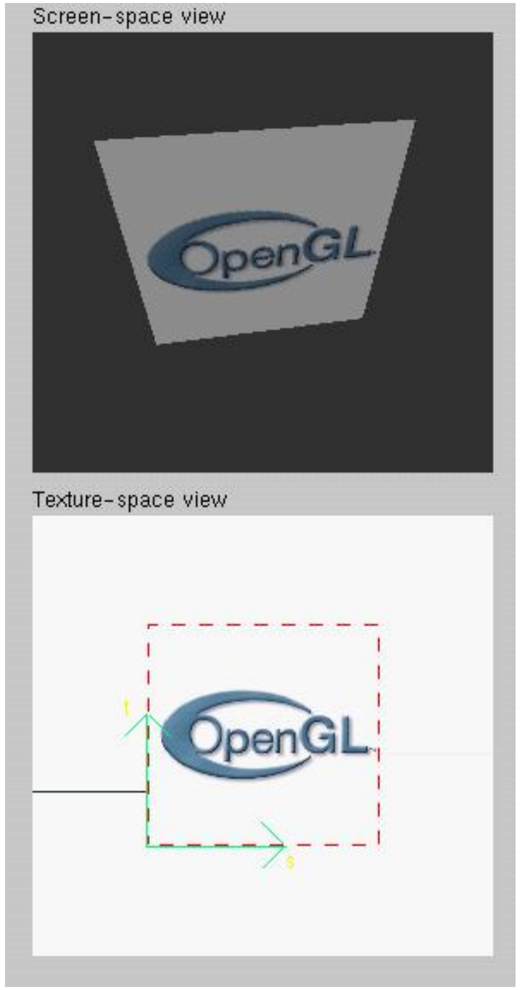
1. specify the texture
   - read or generate image
   - assign to texture
   - enable texturing
2. assign texture coordinates to vertices
   - Proper mapping function is left to application
3. specify texture parameters
   - wrapping, filtering

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



Specifying a Texture Image

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

  `Glubyte my_texels[512][512];`

- 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

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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

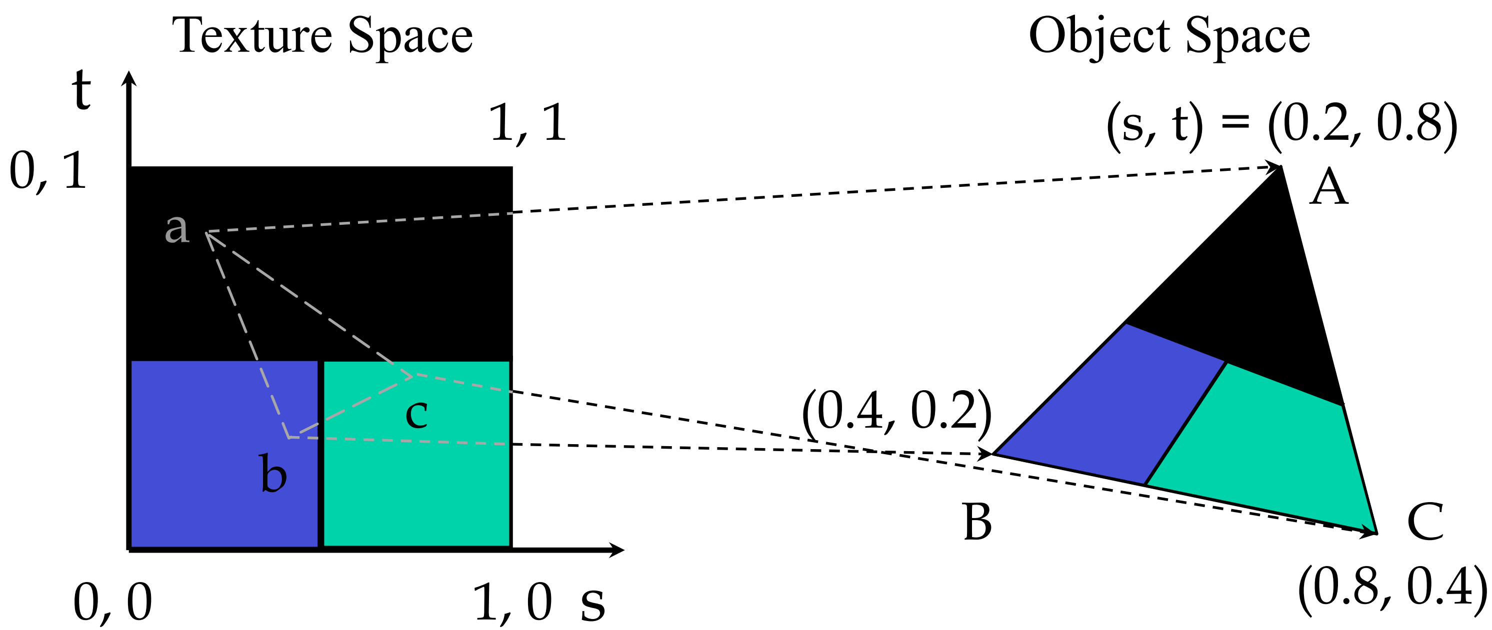
```
glTexImage2D(GL_TEXTURE_2D, 0, 3, 512, 512, 0,
 GL_RGB, GL_UNSIGNED_BYTE, my_texels);
```

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); //if no shading used
 glNormal3f(u0, v0, w0); // if shading used
 glTexCoord2f(s0, t0);
 glVertex3f(x0, y0, z0);
 glColor3f(r1, g1, b1);
 glNormal3f(u1, v1, w1);
 glTexCoord2f(s1, t1);
 glVertex3f(x1, y1, z1);
      .
      .
glEnd();
```

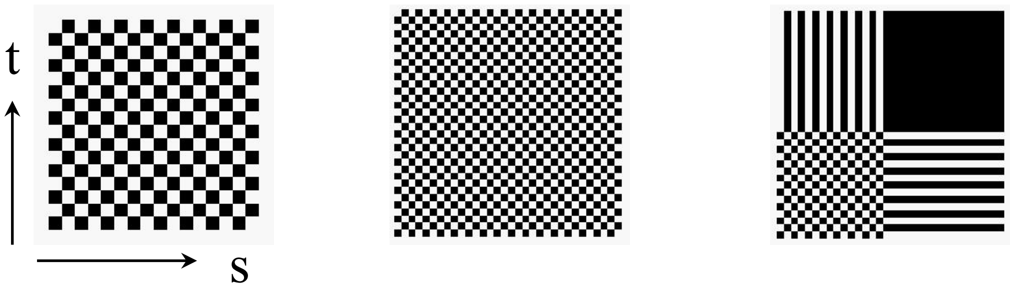
Note that we can use vertex arrays to increase efficiency

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