OpenGL Texture Mapping

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Objectives

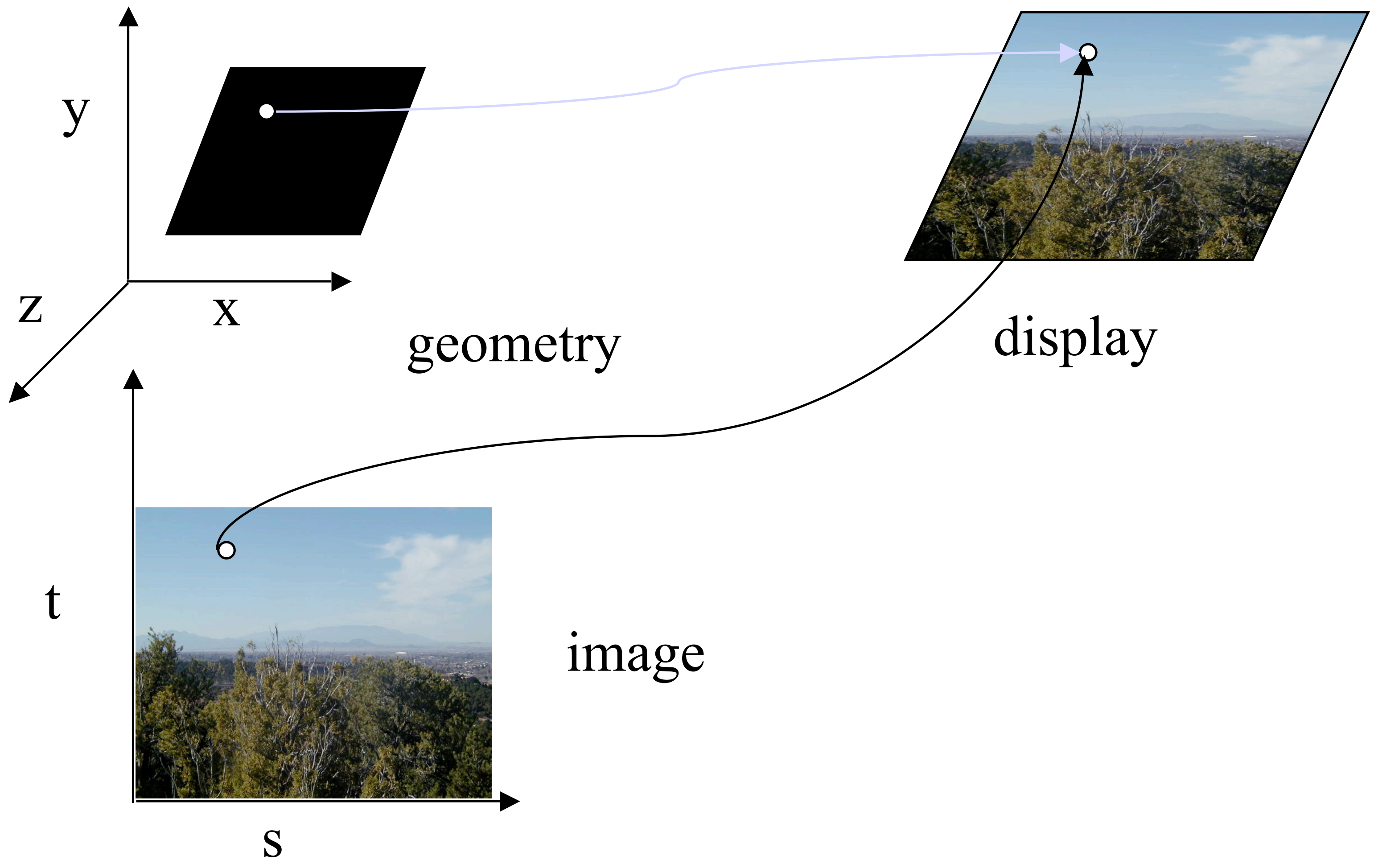
- Introduce the OpenGL texture functions and options

Basic Stragegy

Three steps to applying a texture

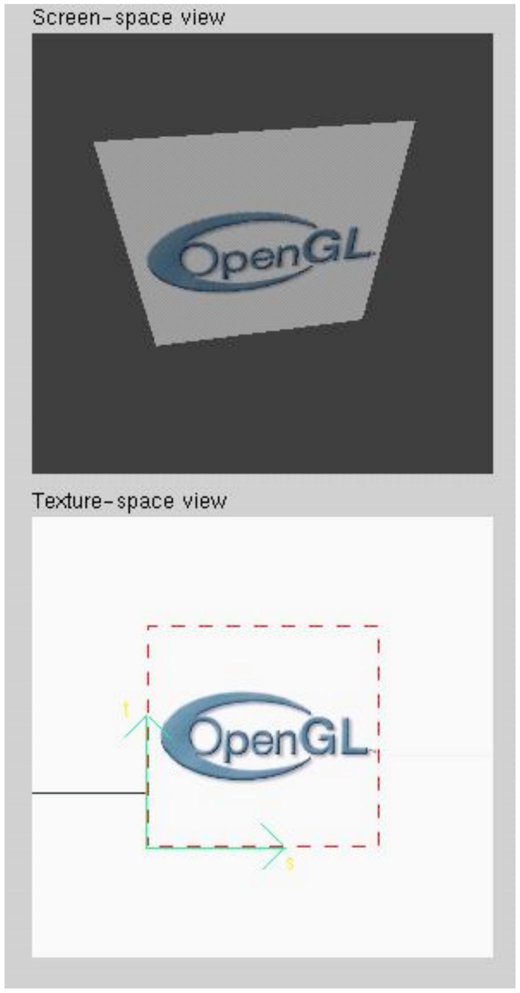
1. specify the texture
   - read or generate image
   - assign to texture
   - enable texturing
2. assign texture coordinates to vertices
   - Proper mapping function is left to application
3. specify texture parameters
   - wrapping, filtering

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 at the rasterizer
  - "complex" textures do not affect geometric complexity

$$\begin{tikzcd}
\text{vertices} \arrow[r] & \boxed{\text{geometry pipeline}} \arrow[dr] & \\
 & & \boxed{\text{rasterizer}} \\
\text{image} \arrow[r] & \boxed{\text{pixel pipeline}} \arrow[ur] &
\end{tikzcd}$$

Specifying a Texture Image

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

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

- 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);
```

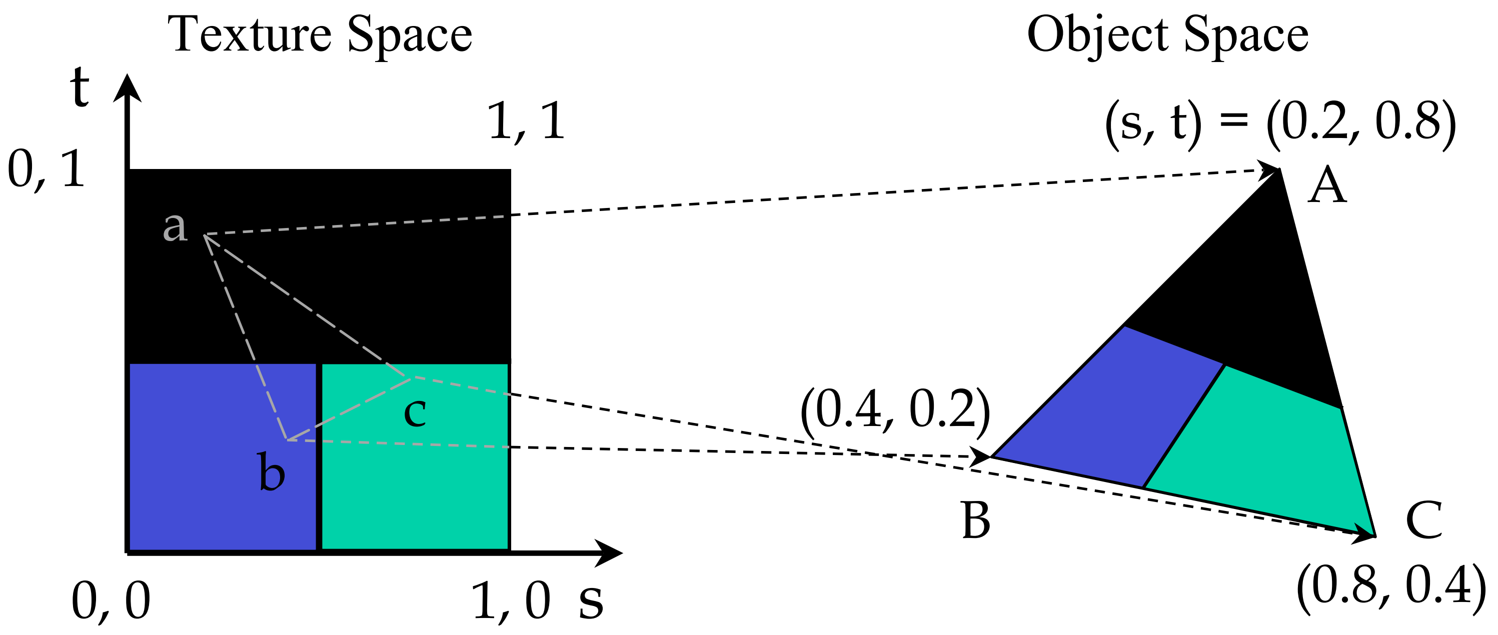
Converting A Texture Image

- 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 );`

    ```
    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



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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();
```

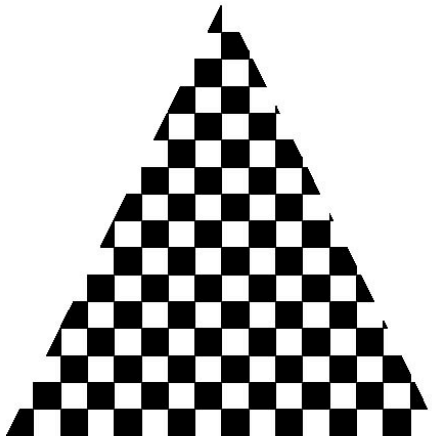
Note that we can use vertex arrays to increase efficiency

Interpolation

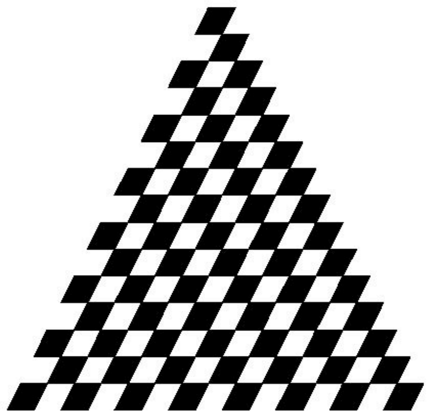
OpenGL uses interpolation to find proper texels from specified texture coordinates

Can be distortions

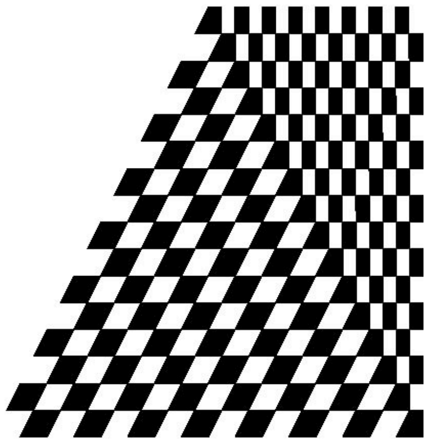
good selection of tex coordinates



poor selection of tex coordinates



texture stretched over trapezoid showing effects of bilinear interpolation



Texture Parameters

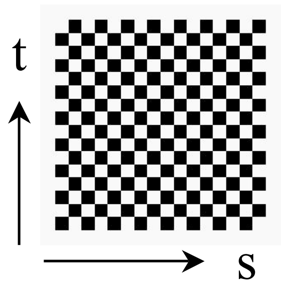
- OpenGL has a variety of parameters that determine how texture is applied
  - Wrapping parameters determine what happens if s and t are outside the (0,1) range
  - Filter modes allow us to use area averaging instead of point samples
  - Mipmapping allows us to use textures at multiple resolutions
 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

Wrapping Mode

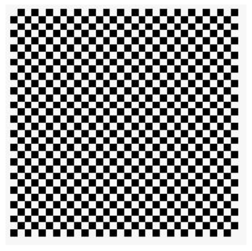
Clamping: if $s,t > 1$ use 1, if $s,t < 0$ use 0

Wrapping: use s,t modulo 1

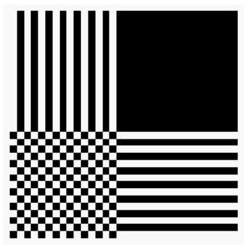
```
glTexParameteri( GL_TEXTURE_2D,
     GL_TEXTURE_WRAP_S, GL_CLAMP )
glTexParameteri( GL_TEXTURE_2D,
     GL_TEXTURE_WRAP_T, GL_REPEAT )
```



texture



GL_REPEAT wrapping

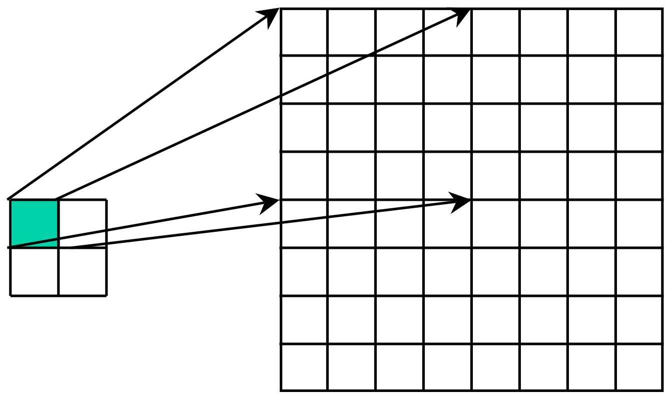


GL_CLAMP wrapping

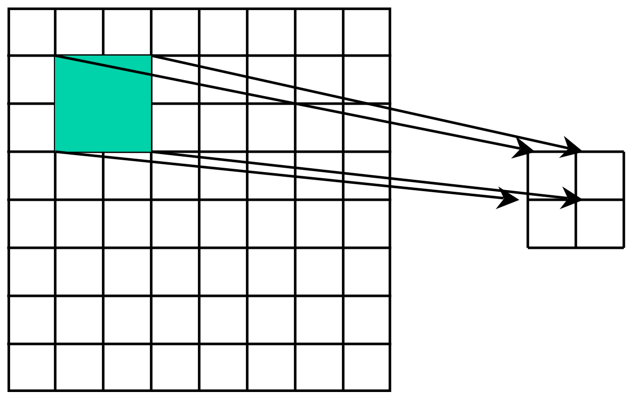
Magnification and Minification

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



Magnification



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)

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Mipmapped Textures

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

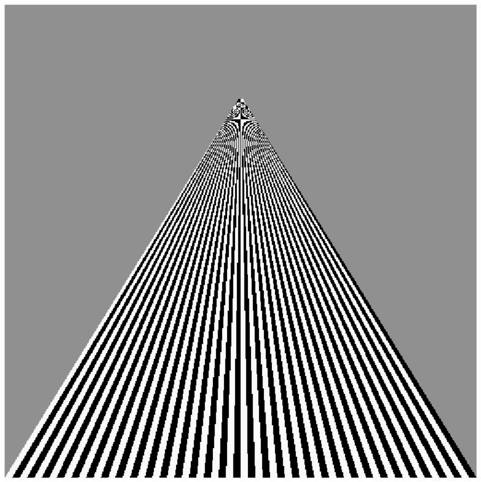
```
glTexImage2D( GL_TEXTURE_*D, level, … )
```

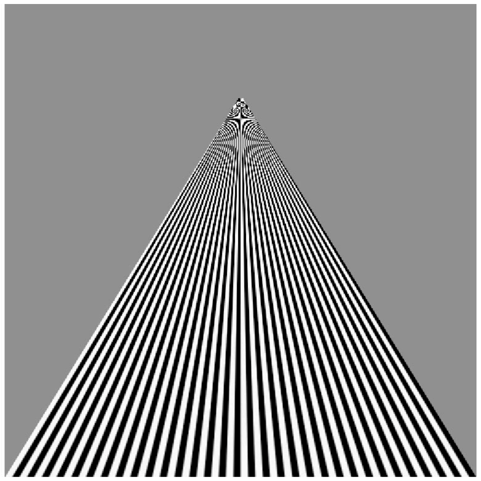
- GLU mipmap builder routines will build all the textures from a given image

```
gluBuild*DMipmaps( … )
```

Example

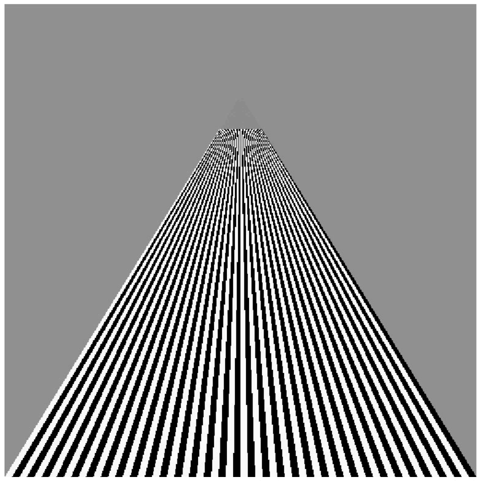
point sampling

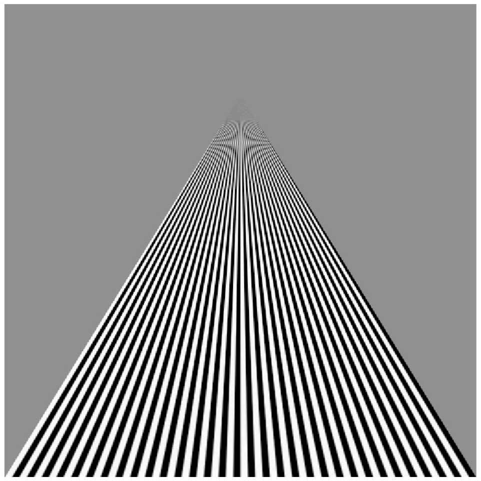




linear filtering

mipmapped point sampling





mipmapped linear filtering

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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 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