VGP351 – Week 9

- Agenda:
  - Quiz #4
  - Last day of texture mapping
    - Reflection mapping
    - Projective texturing
    - Texture atlases
    - Texture compression

Reflection Mapping

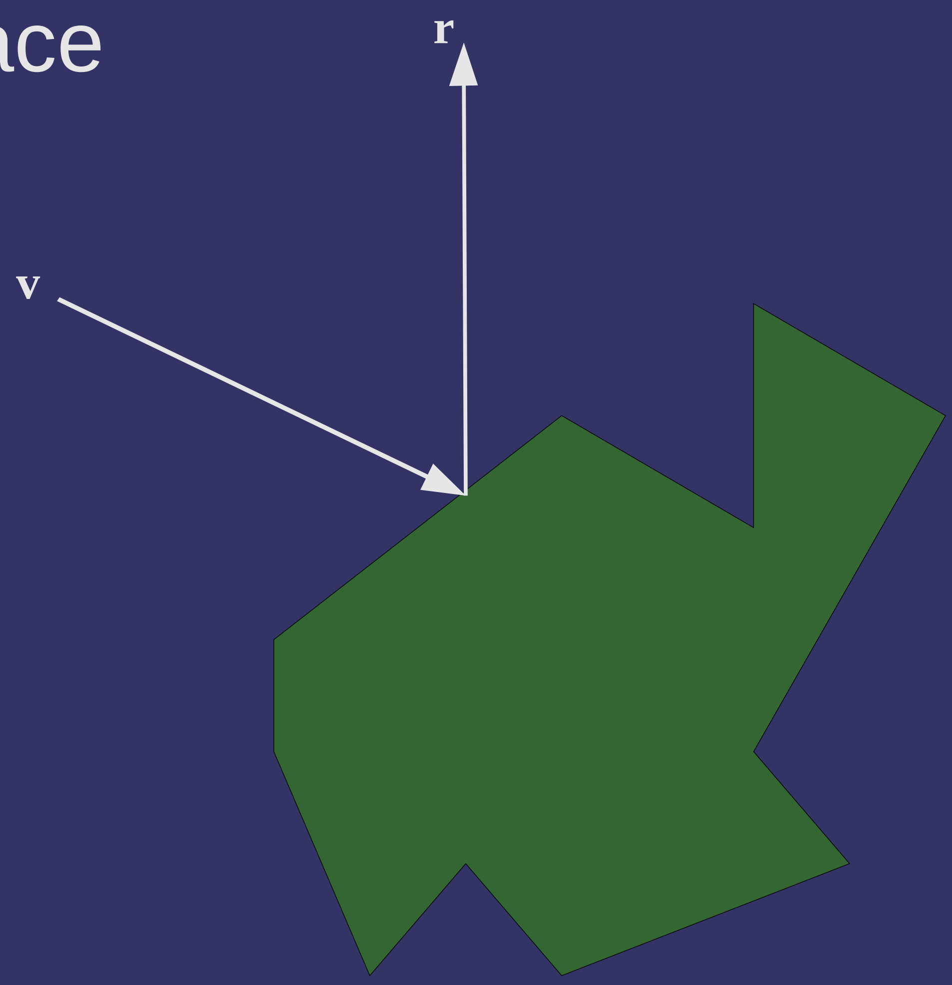
- Simulate reflections of the environment using a texture and texture coordinate calculations
  - Can either be called “environment mapping” or “reflection mapping”

Reflection Mapping

- Forms of reflection mapping are classified by the shape used to simulate the environment
  - Cylindrical
  - Hemispherical
  - Spherical
  - Cube
  - Dual-paraboloid

Reflection Mapping

- Calculate the reflection vector and map to texture space



Reflection Mapping

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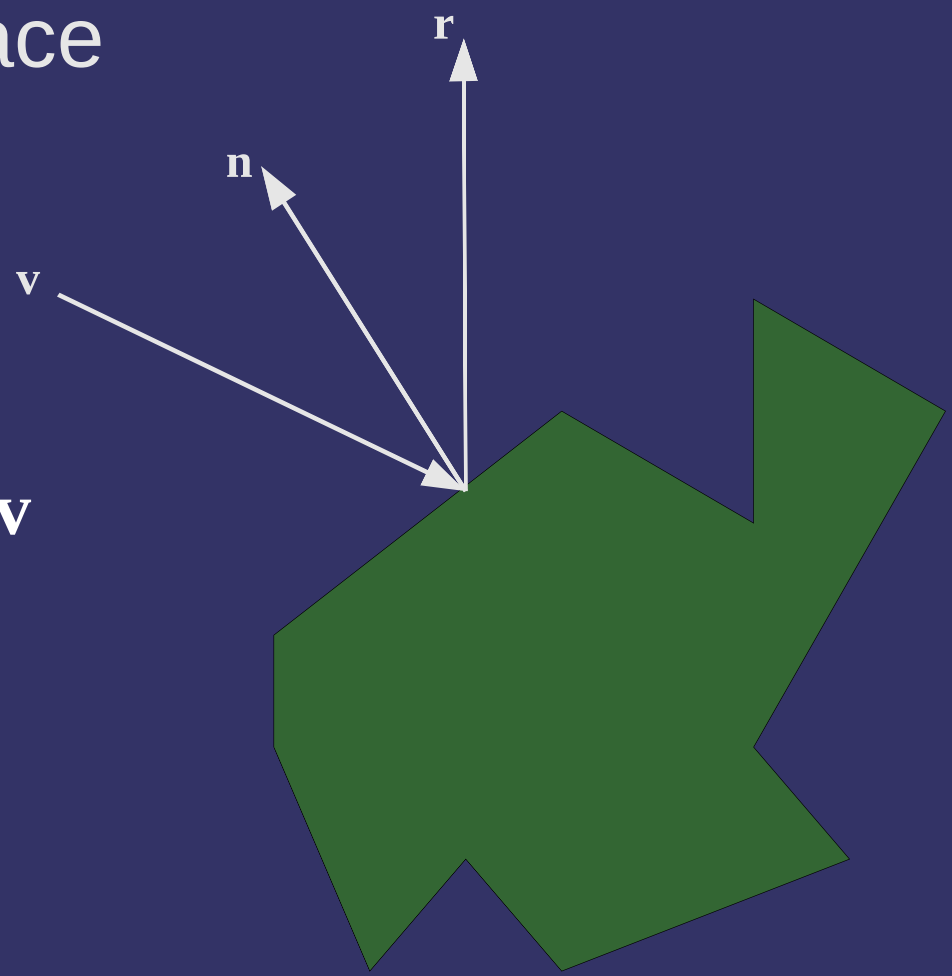


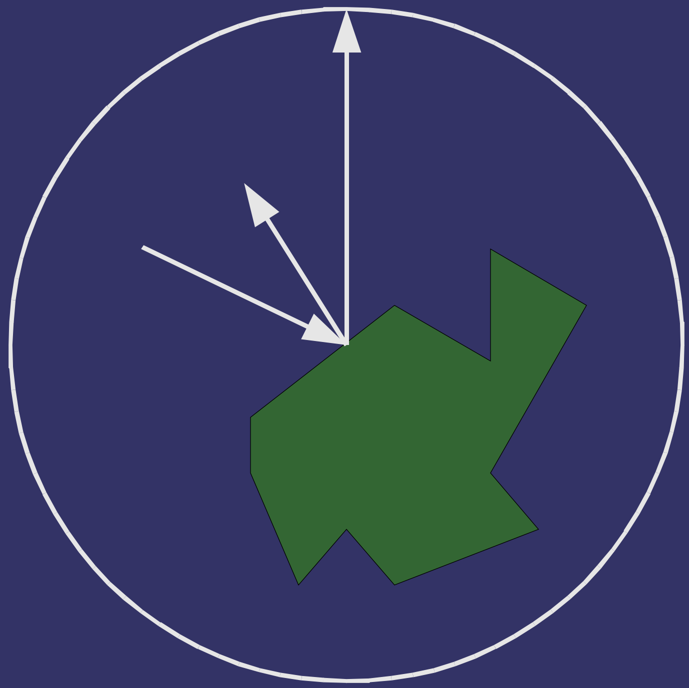
$$\mathbf{r} = \frac{2(\mathbf{n} \cdot -\mathbf{v})}{|\mathbf{n}||\mathbf{v}|}\mathbf{n} + \mathbf{v}$$

Reflection Mapping – Cylindrical

- *Exactly* like cylindrical projection
  - Use the reflection vector instead of the position

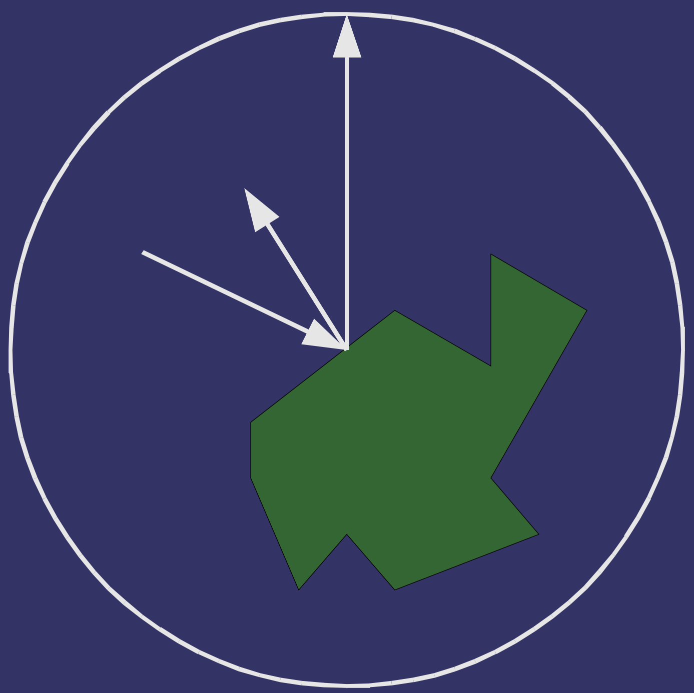
$$s = \frac{\operatorname{atan}(\mathbf{r}_x / \mathbf{r}_z)}{2\pi}$$

$$t = \mathbf{r}_y$$



Reflection Mapping – Cylindrical

- Pros:
  - Easy to implement
  - Easy to get source images
  - Only one texture image
- Cons:
  - Distortion increases away from horizon
  - Can't reflect sky or ground (i.e., $\mathbf{r} = (0, \pm 1, 0)$)



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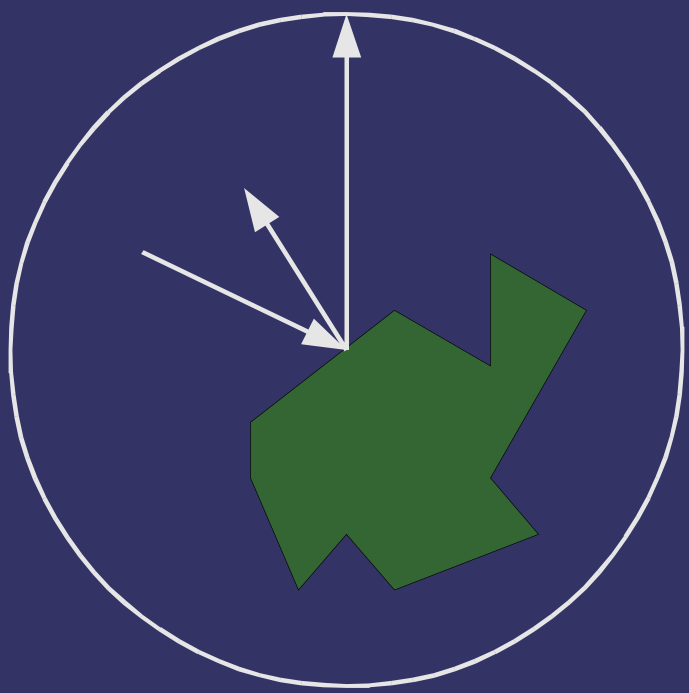

Caused by arctangent!

$$\lim_{z \to 0} \arctan(x/z) = \pm\infty$$

and has a discontinuity when $z = 0$.

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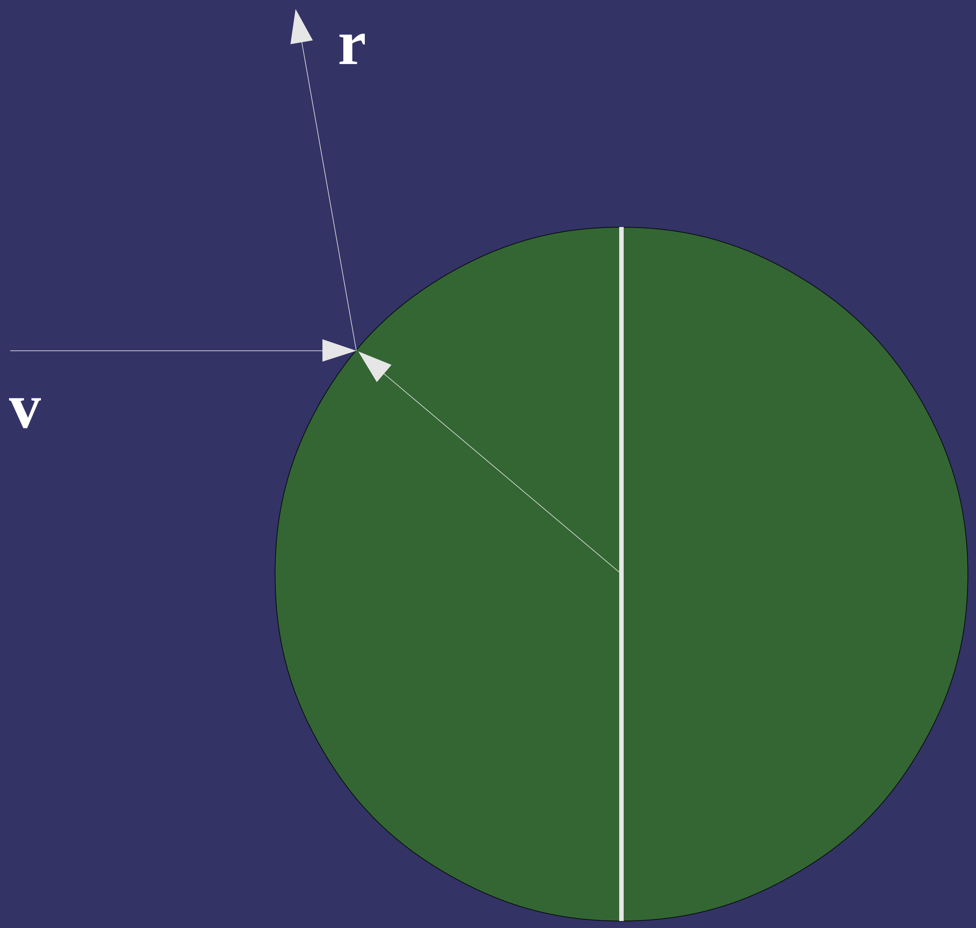
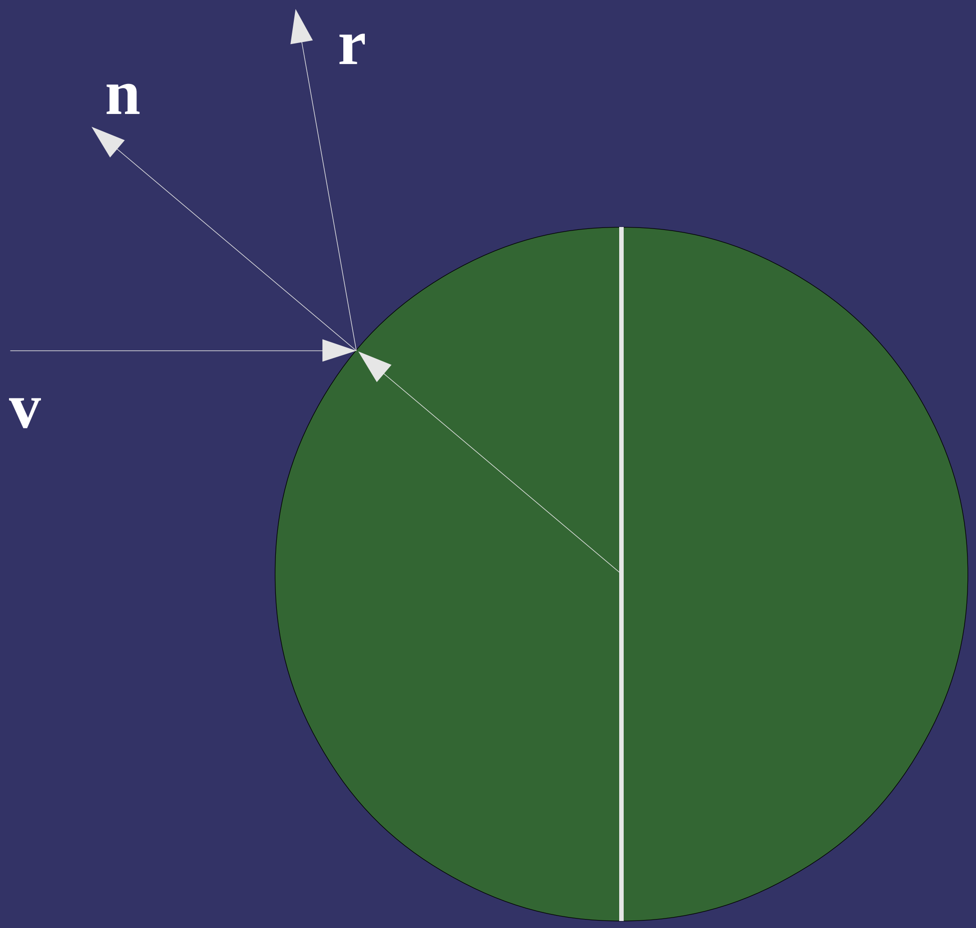
Reflection Mapping – Hemispherical



- Find location with matching infinite view vector and **r**

Reflection Mapping – Hemispherical



- Find location with matching infinite view vector and **r**
  - This is the normal of the sphere at that location

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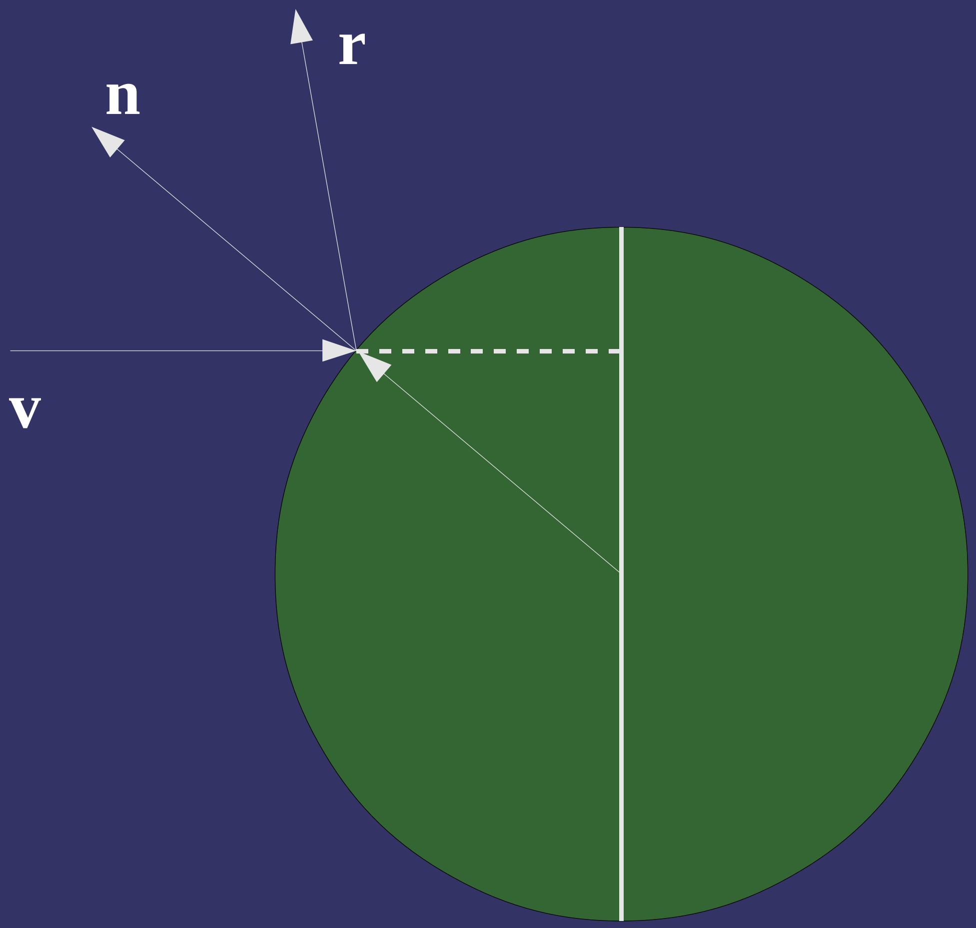
Reflection Mapping – Hemispherical

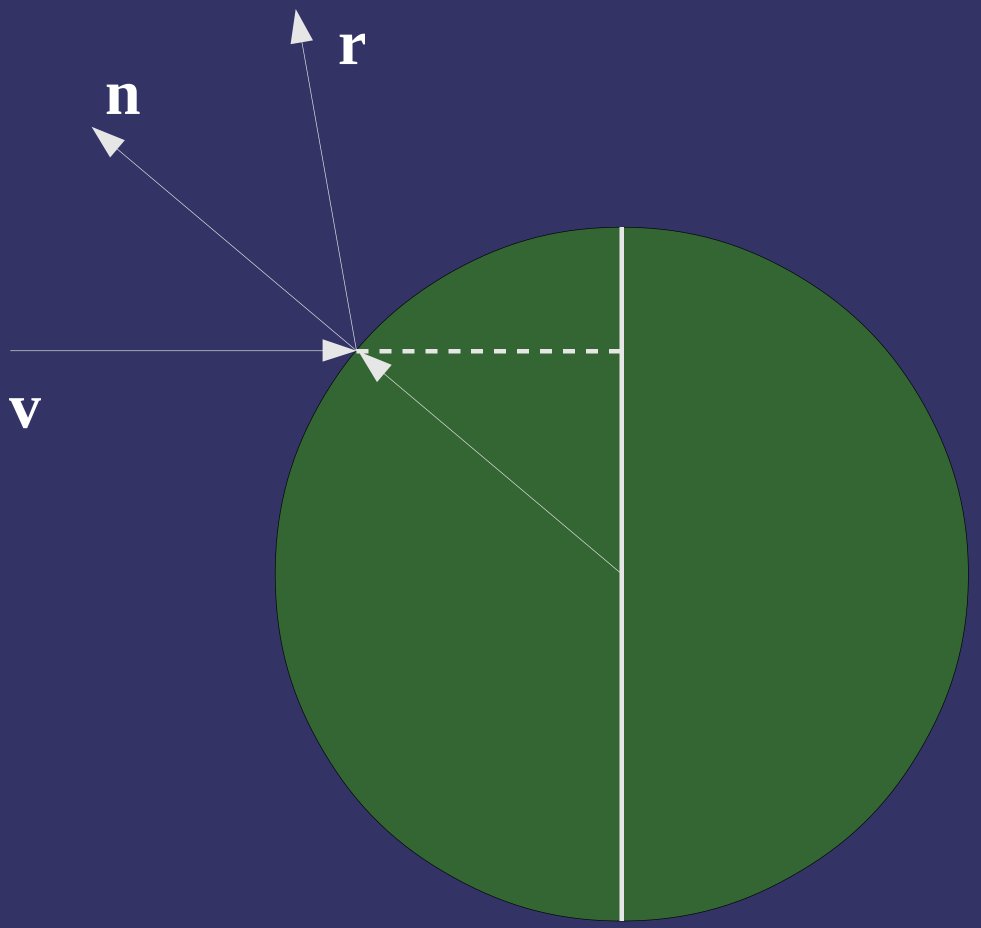


- Find location with matching infinite view vector and $\mathbf{r}$
  - This is the normal of the sphere at that location
  - Texture coordinate is the projection of this vector onto the image

$$s = \frac{\mathbf{r}_x}{\sqrt{2(\mathbf{r}_z + 1)}}$$

$$t = \frac{\mathbf{r}_y}{\sqrt{2(\mathbf{r}_z + 1)}}$$

Reflection Mapping – Hemispherical



- Find location with matching infinite view vector and $\mathbf{r}$
  - This is the normal of the sphere at that location
  - Texture coordinate is the projection of this vector onto the image

Range [-1, 1]

$$s = \frac{\mathbf{r}_x}{\sqrt{2(\mathbf{r}_z + 1)}}$$

$$t = \frac{\mathbf{r}_y}{\sqrt{2(\mathbf{r}_z + 1)}}$$

Reflection Mapping – Hemispherical

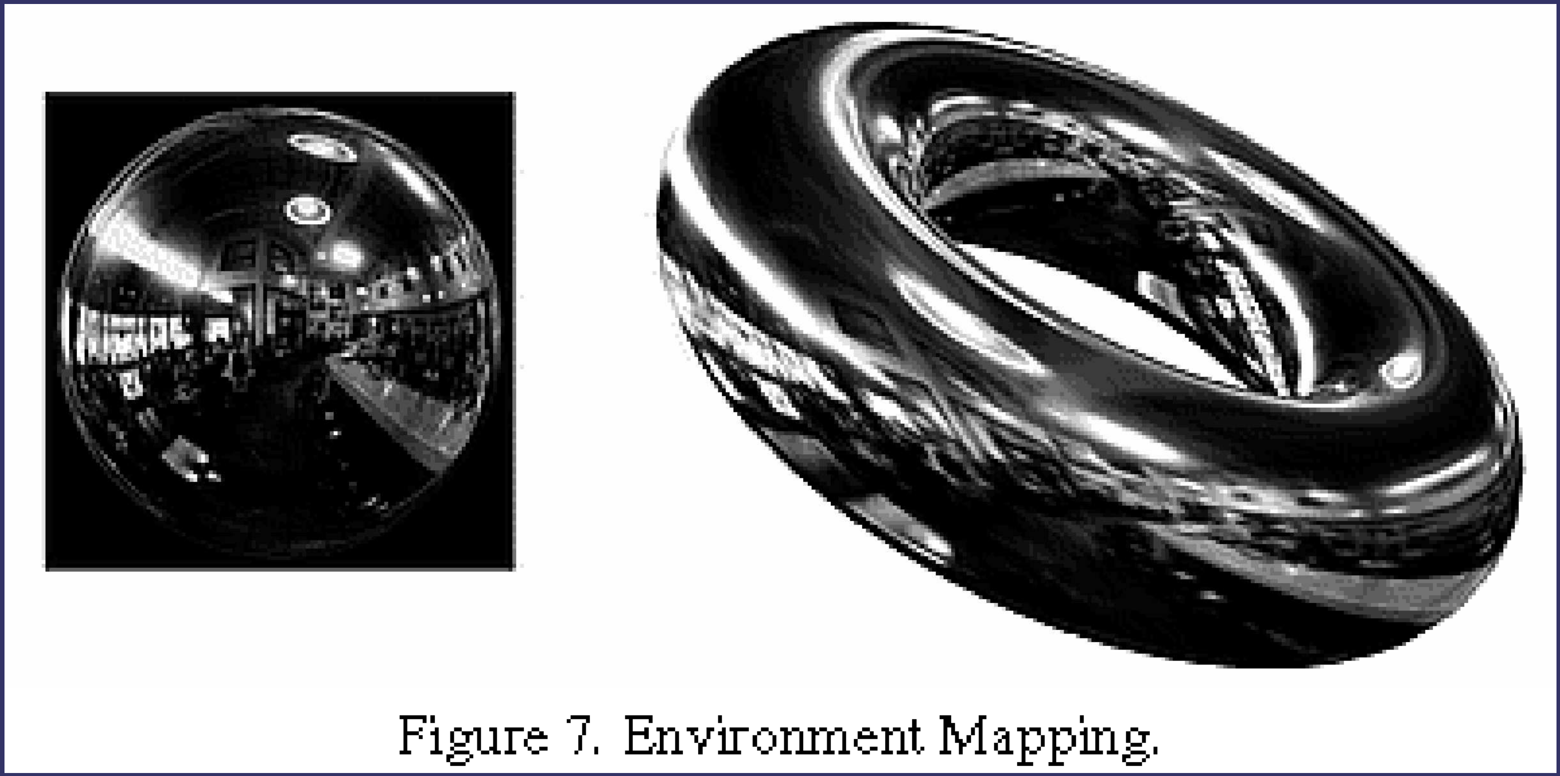
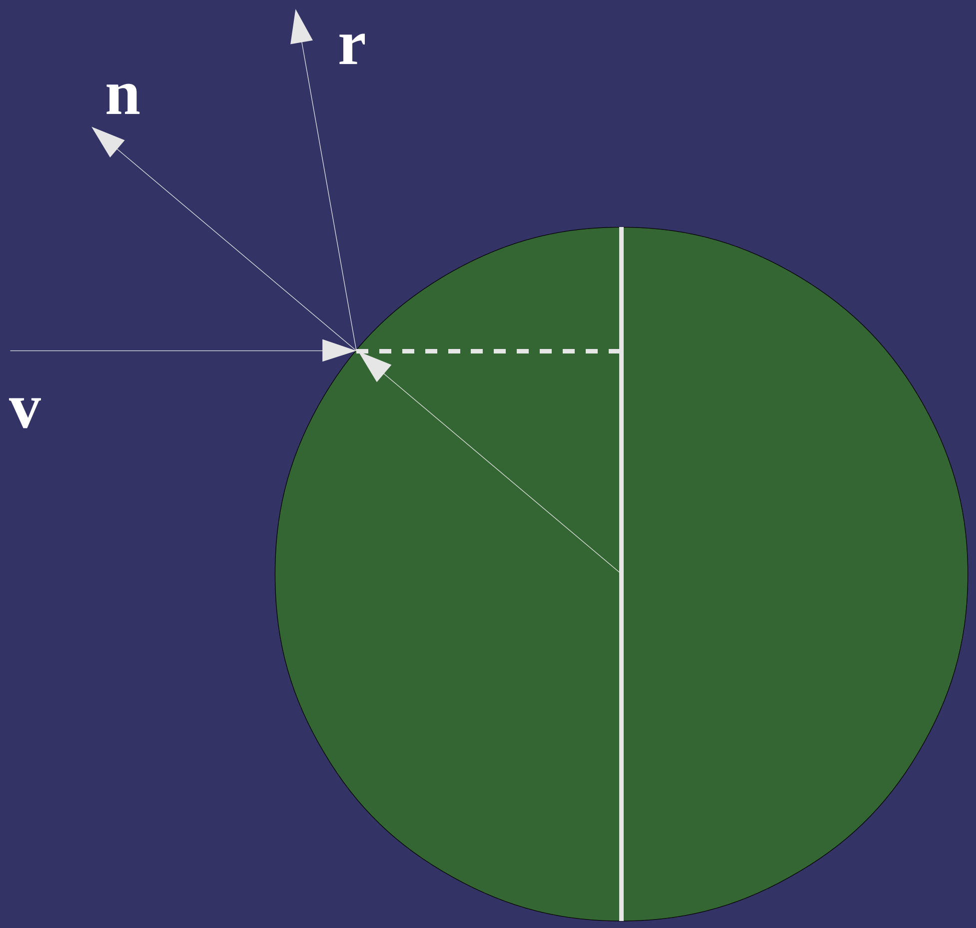


Image from http://www.graficaobscura.com/texmap/index.html

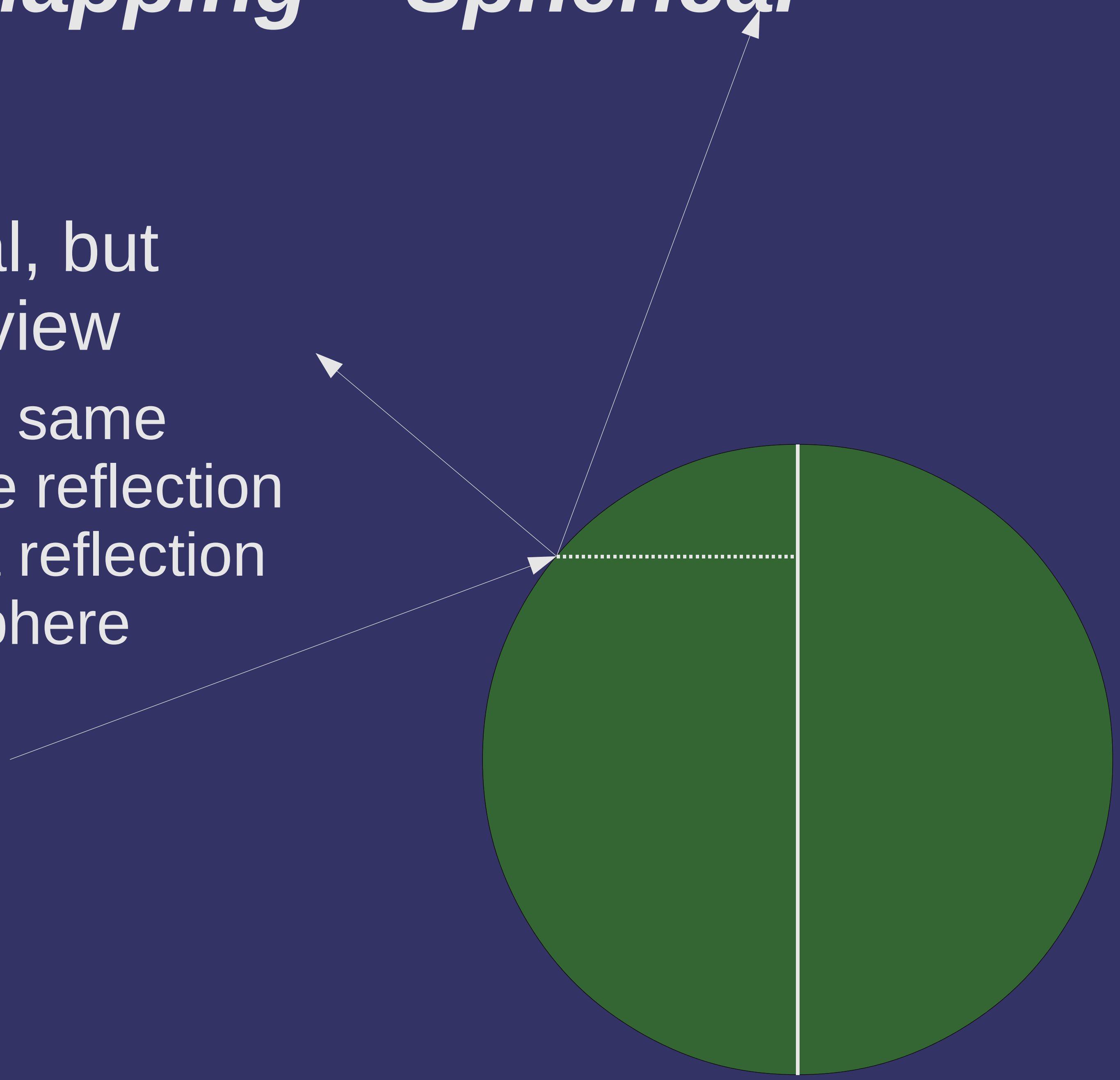
Reflection Mapping – Hemispherical



- Pros:
  - Easy to implement
  - Easy to get source images
  - Only one texture image
- Cons:
  - Reflection map is viewpoint dependent
  - Difficult to render to reflection map

Reflection Mapping – Spherical

- Similar to hemispherical, but uses a local view
  - Note how the same position in the reflection map is now a reflection *behind* the sphere



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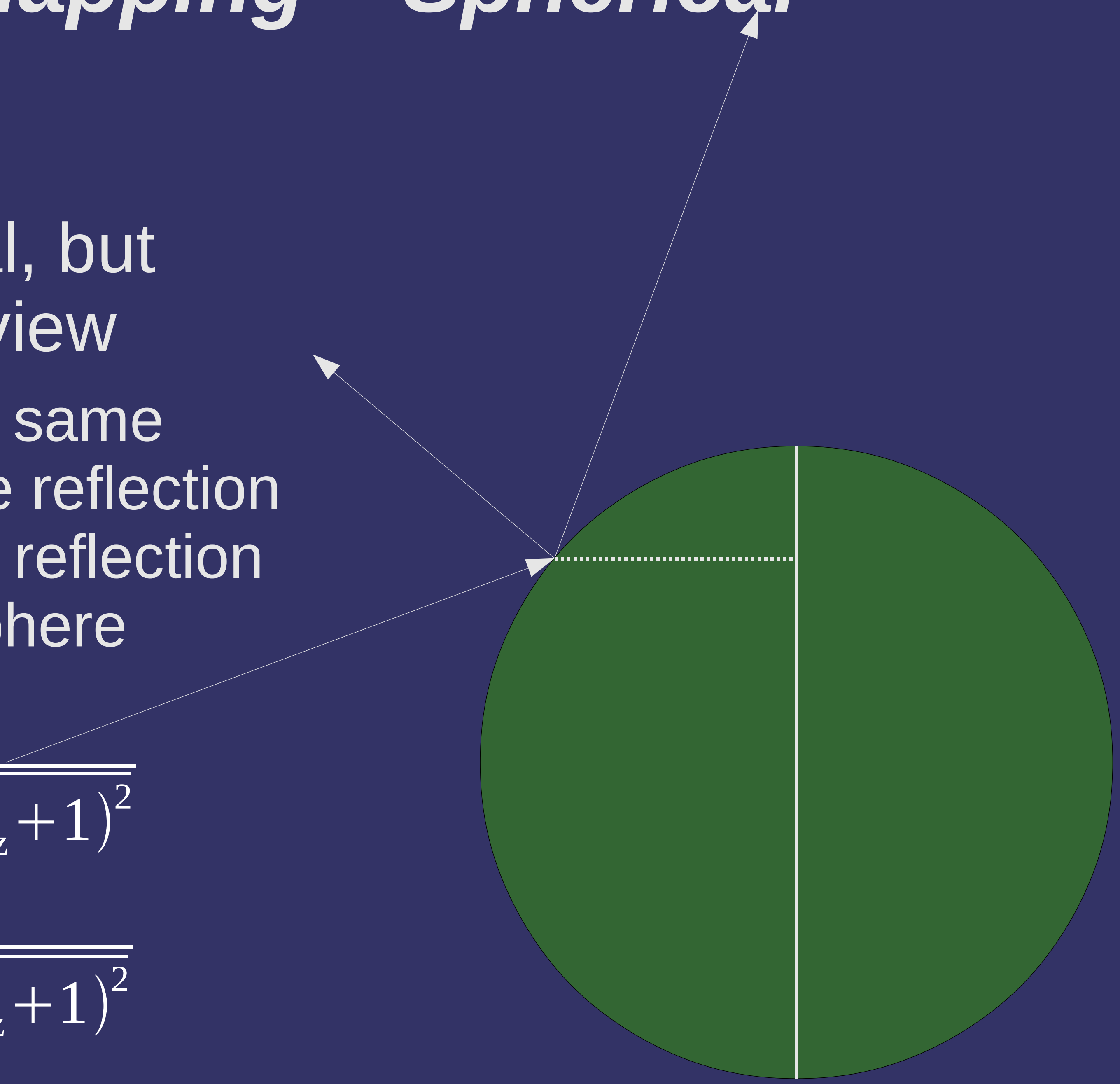
Reflection Mapping – Spherical

- Similar to hemispherical, but uses a local view
  - Note how the same position in the reflection map is now a reflection *behind* the sphere

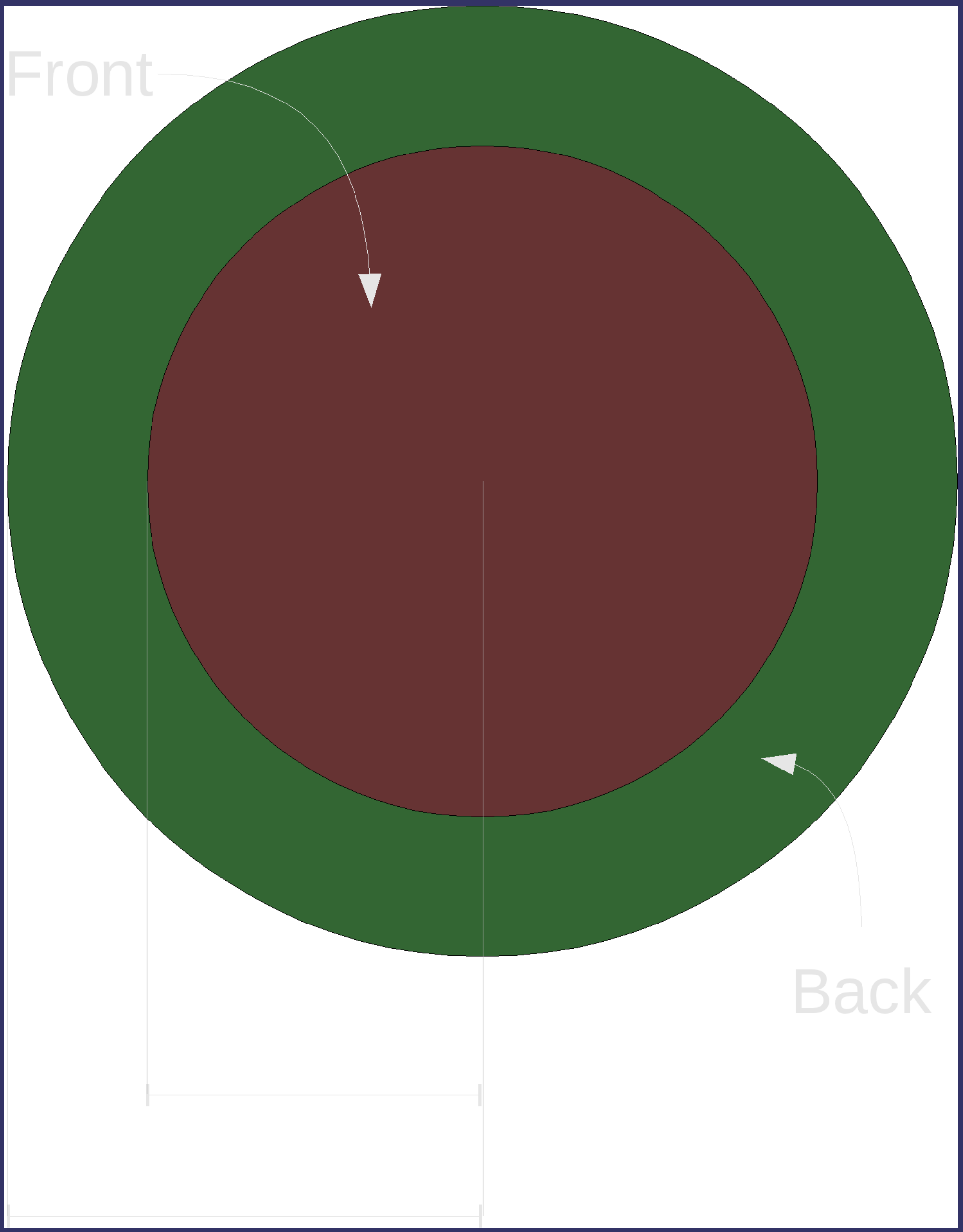
$$s = \frac{\mathbf{r}_x}{\sqrt{\mathbf{r}_x^2 + \mathbf{r}_y^2 + (\mathbf{r}_z + 1)^2}}$$

$$t = \frac{\mathbf{r}_y}{\sqrt{\mathbf{r}_x^2 + \mathbf{r}_y^2 + (\mathbf{r}_z + 1)^2}}$$



Reflection Mapping – Spherical

- Single image for full 360° view



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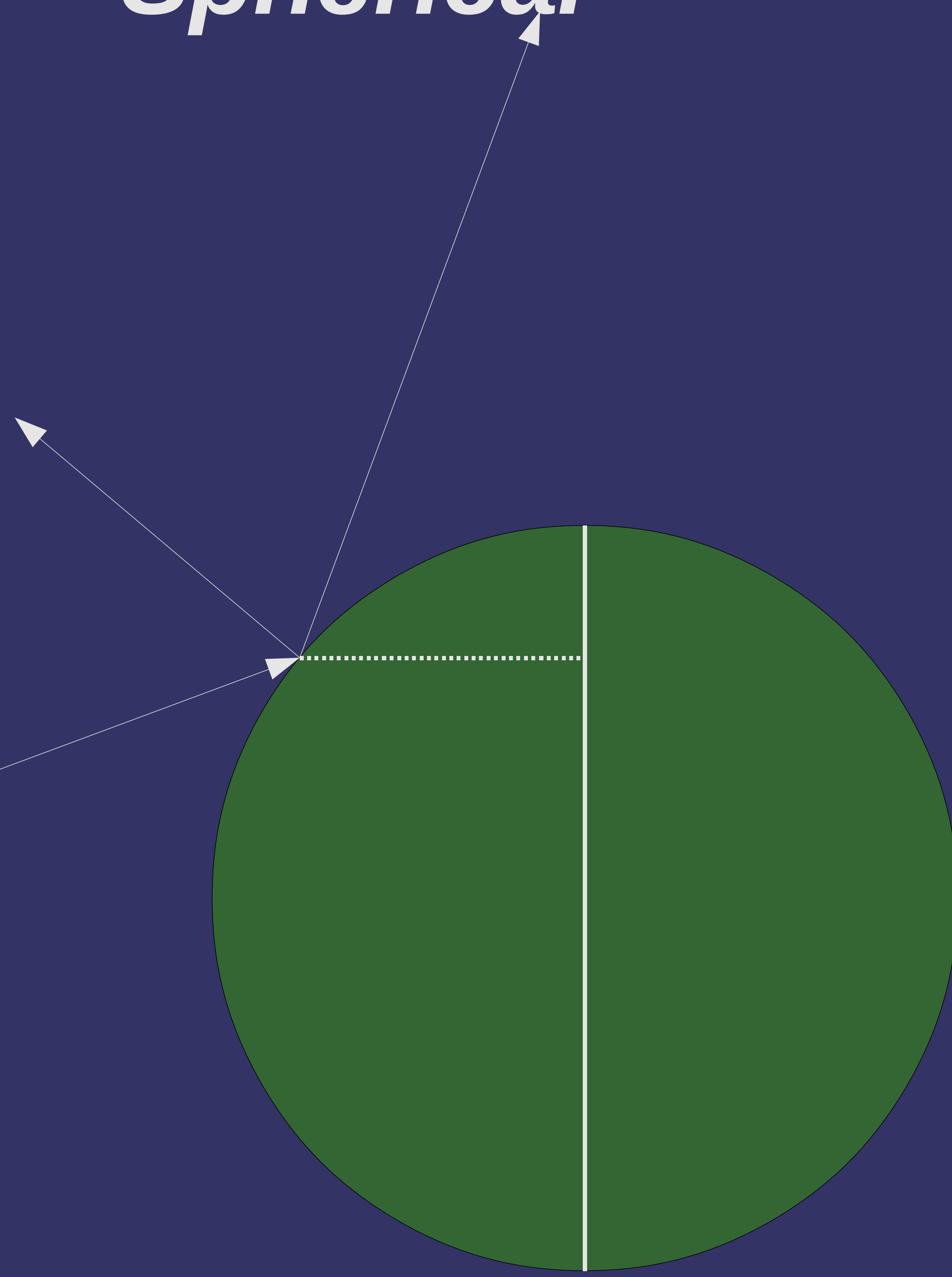
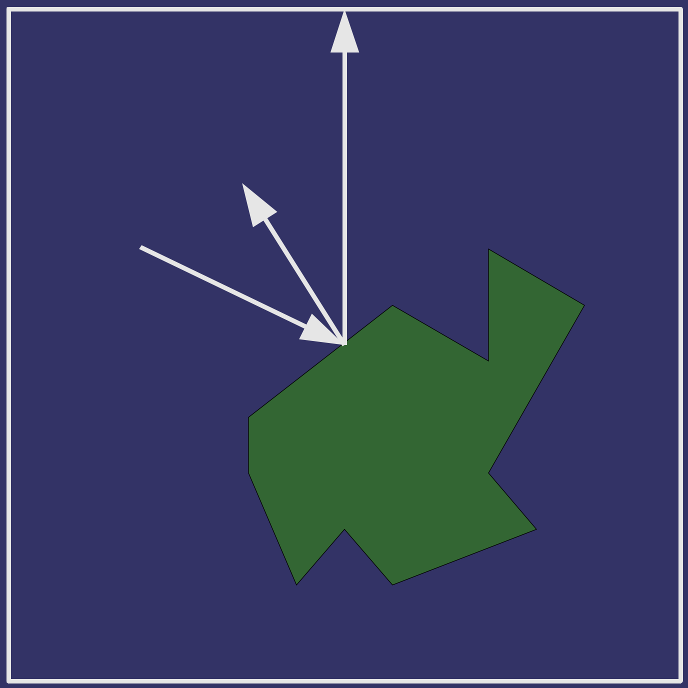
Reflection Mapping – Spherical

- Pros:
  - Easy to implement
  - Only one texture
  - Local viewer and view independent
- Cons:
  - Distortion increases as $\mathbf{r}$ diverges from $\mathbf{v}$
  - Difficult to get source images
  - Difficult to render to reflection map

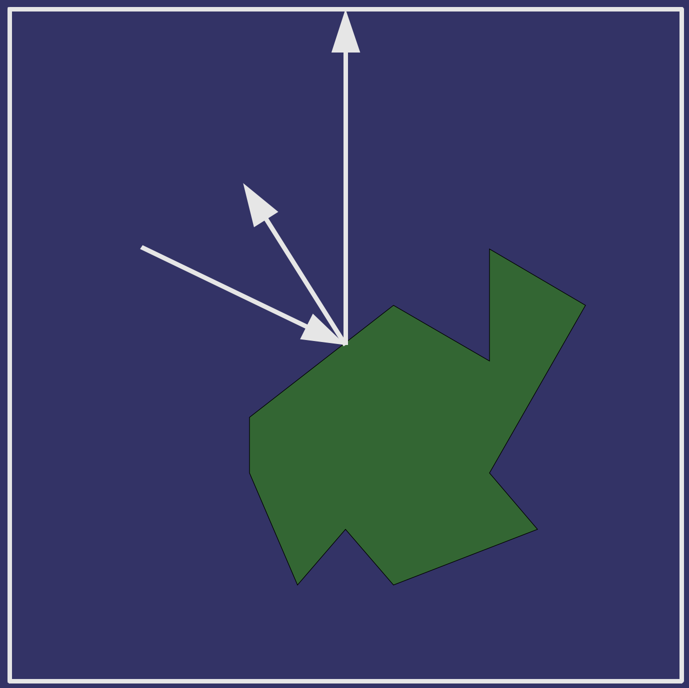


Reflection Mapping – Cube



- Extend $\mathbf{r}$ to intersect unit cube surrounding point

Reflection Mapping – Cube



- Pros:
  - Trivial to implement
  - Easy to render to reflection map
- Cons:
  - More difficult to get source images
  - Discontinuities at cube-face boundaries
  - Have to load multiple images

Reflection Mapping – Cube

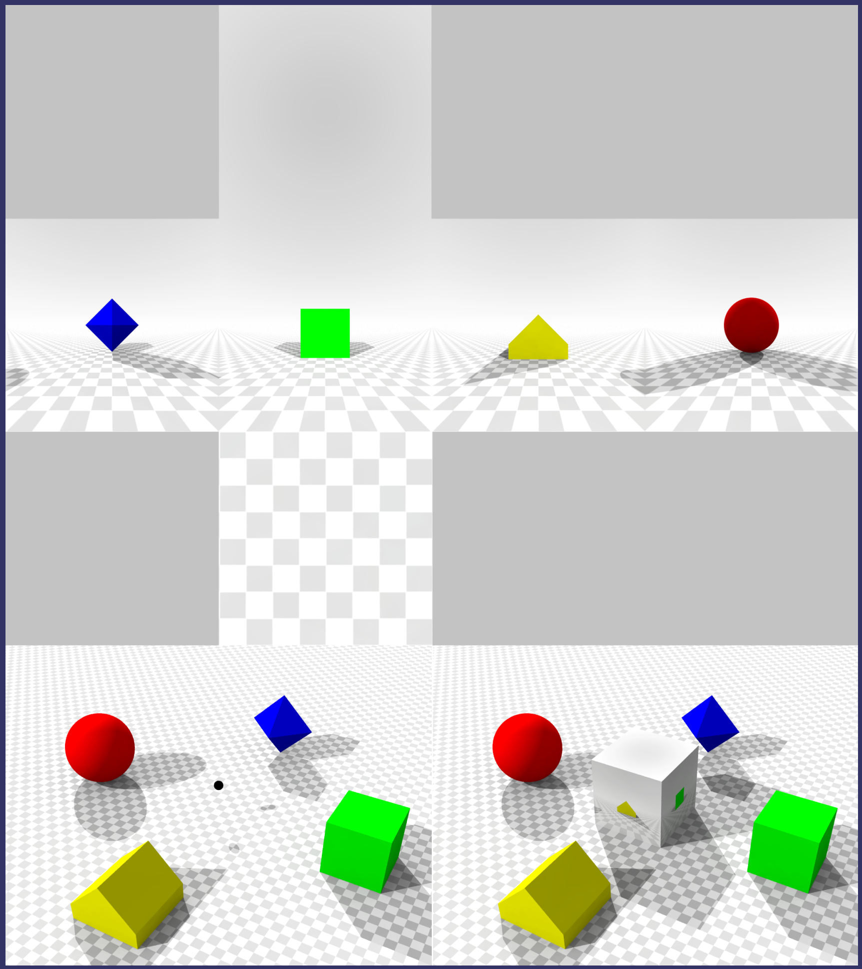


Image from http://en.wikipedia.org/wiki/File:Panorama_cube_map.png

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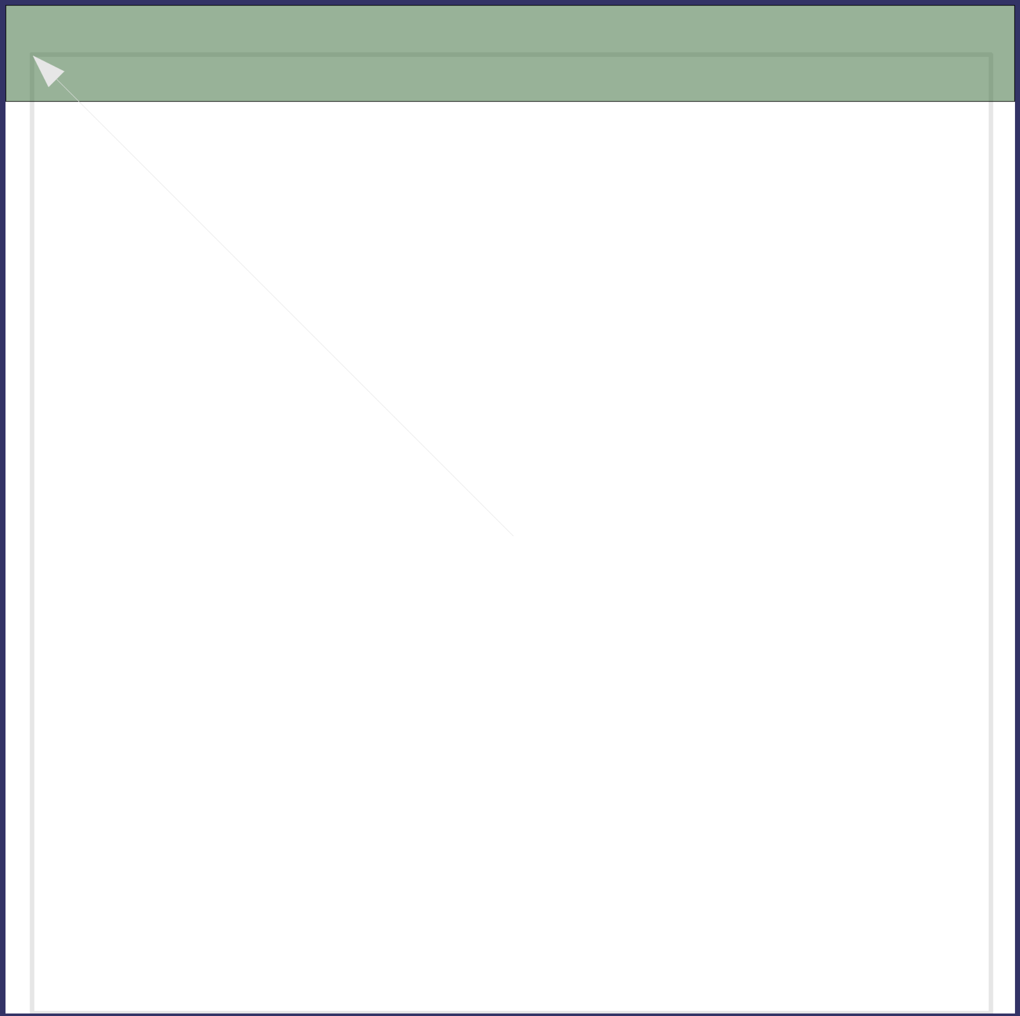
Cube Maps

- Consist of 6 equal sized, square textures
- Accessed using a 3-component texture coordinate
  - Hardware uses largest magnitude component to select cube face
  - Intersection of vector with face determines 2D texture coordinate within that face

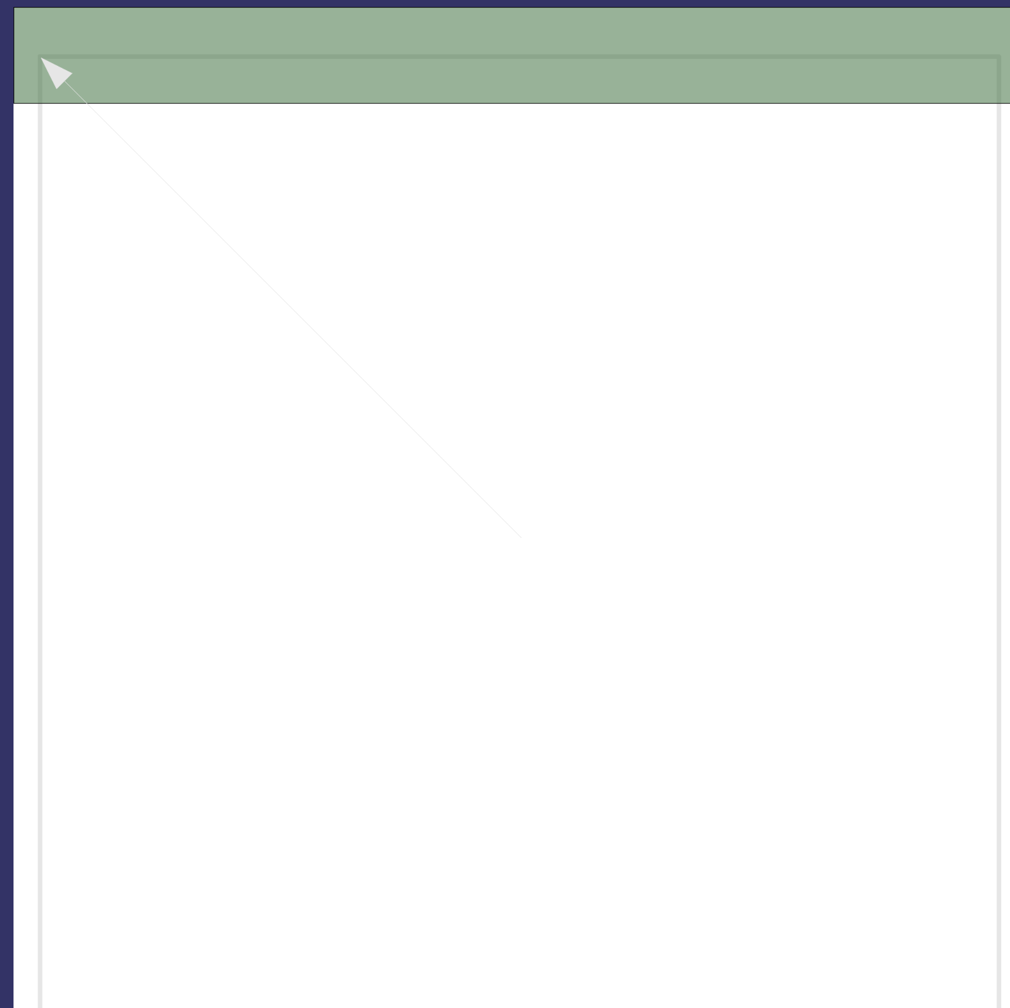
Cube Maps

- Most hardware samples from *one* cube map face
  - What happens when the texture coordinate hits the edge texel of one face?



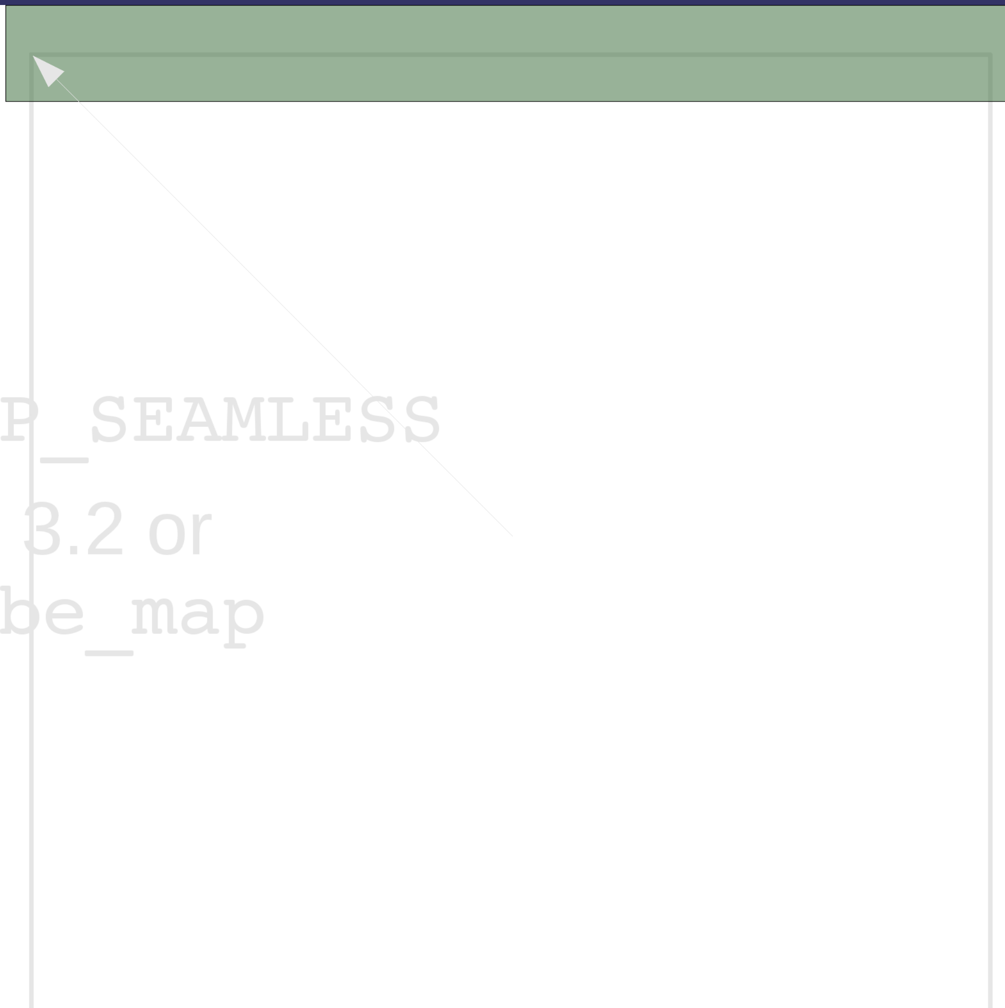
Cube Maps

- Most hardware samples from *one* cube map face
  - Texel wrap modes are applied *within* the face
    - Use clamp-to-edge
  - Discontinuity at the boundaries
  - Can be fixed by using a texture border
    - Most hardware doesn't support this!



Cube Maps

- Newer hardware can sample from two cube map faces
  - Global enable `GL_TEXTURE_CUBE_MAP_SEAMLESS`
  - Requires either OpenGL 3.2 or `GL_ARB_seamless_cube_map`



Cube Maps

- Bind texture to `GL_TEXTURE_CUBE_MAP`
- Set texture data for specific cube faces using per-face targets:
  - `GL_TEXTURE_CUBE_MAP_POSITIVE_X`
  - `GL_TEXTURE_CUBE_MAP_NEGATIVE_X`
  - `GL_TEXTURE_CUBE_MAP_POSITIVE_Y`
  - `GL_TEXTURE_CUBE_MAP_NEGATIVE_Y`
  - `GL_TEXTURE_CUBE_MAP_POSITIVE_Z`
  - `GL_TEXTURE_CUBE_MAP_NEGATIVE_Z`

Cube Maps

- Cube map textures must be *cube map complete*
  - If a mipmap filter mode is used, each face must be mipmap complete
  - Data must be available for all six faces
  - Level 0 of all six faces must be the same size
  - All faces must be square

References

http://www.debevec.org/ReflectionMapping/

- Historical overview of reflection mapping. Includes references to many seminal papers and some good images.

http://www.graficaobscura.com/texmap/index.html

- The section on “Environment Mapping” provides additional background on the hemispherical technique.

http://www.reindelsoftware.com/Documents/Mapping/Mapping.html

- Good survey of most of the techniques discussed tonight.

http://local.wasp.uwa.edu.au/~pbourke/miscellaneous/cube2cyl/

- Description of a program to convert cubic environment maps to cylindrical environment maps or Blinn / Newell spherical environment maps. The pictures are worth well more than 1,000 words.

Projective Texturing

- Applying a texture to a scene as though it were "projected" from a slide projector
  - Useful for various lighting effects
    - Complex shaped spot lights (i.e., flash light)
  - The basis of several shadow techniques
    - You'll have to wait until VGP353

Projective Texturing

- Fundamental problem: given a projector in world space and a point in world space, determine where the point is in texture space
- What does this sound like?

Projective Texturing

- Fundamental problem: given a projector in world space and a point in world space, determine where the point is in texture space
- What does this sound like?
  - Projecting from world space (through camera space) to screen space
  - So we need a projector position, projection direction, a reference up direction, and the usual assortment of projection frustum parameters

Projective Texturing

- Process is similar to viewing transformations:
  - Construct a transformation from world-space to projector-space
  - Construct a projection transformation for the projector's frustum
  - Transform each vertex by these matrices
  - Divide by Z
  - Result is the texture coordinate...almost

Projective Texturing

- View coordinates have a range [-1, 1], but texture coordinates have range [0, 1]

Projective Texturing

- View coordinates have a range [-1, 1], but texture coordinates have range [0, 1]

$$s = (x/2.0) + 0.5$$
$$t = (y/2.0) + 0.5$$

Projective Texturing

- View coordinates have a range [-1, 1], but texture coordinates have range [0, 1]

$$s = (x / 2.0) + 0.5$$
$$t = (y / 2.0) + 0.5$$

Scale (2.0) — Translation (0.5)

Projective Texturing

- View coordinates have a range [-1, 1], but texture coordinates have range [0, 1]

$$M_{\text{bias}} = \begin{bmatrix} \frac{1}{2} & 0 & 0 & \frac{1}{2} \\ 0 & \frac{1}{2} & 0 & \frac{1}{2} \\ 0 & 0 & \frac{1}{2} & \frac{1}{2} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Projective Texturing

- What happens if a point *behind* the projection point is projected?

Projective Texturing

- What happens if a point *behind* the projection point is projected?
  - It gets *inverted* in X and Y onto the image plane
  - This is called an *anti-projection*

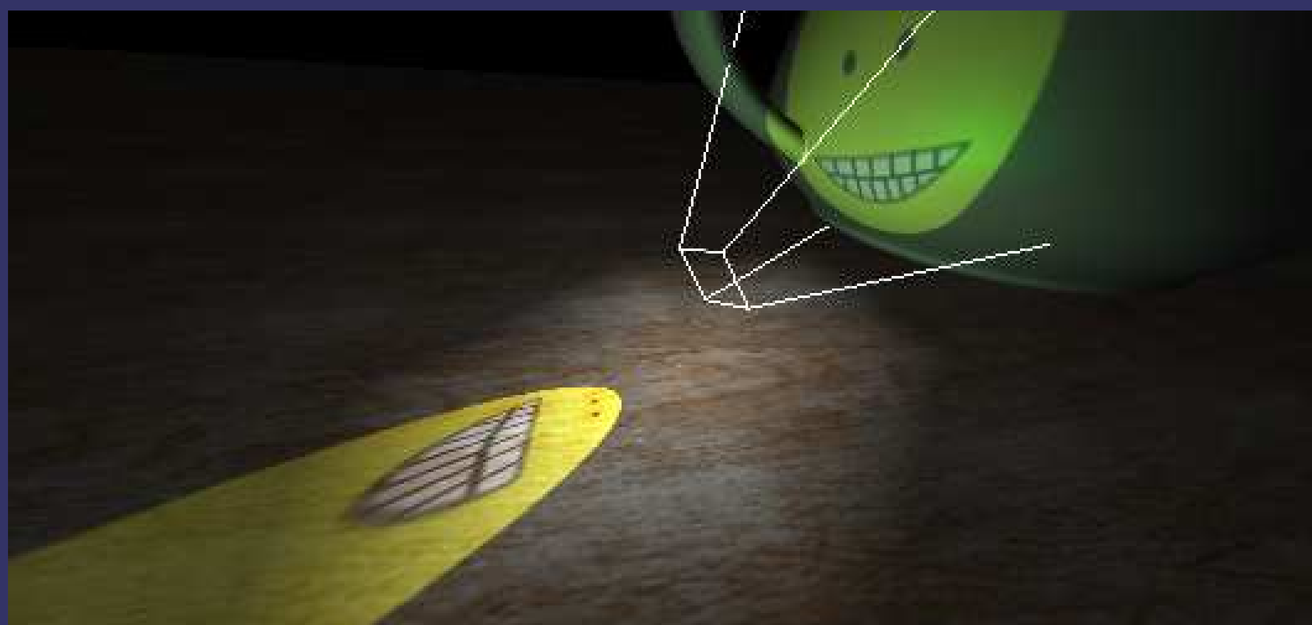


Figure 4. Projective texture mapping produces a reverse projection as well.

Image from [Everitt 01]

Projective Texturing

- How can anti-projections be eliminated?

Projective Texturing

- How can anti-projections be eliminated?
  - Detect the -z case and don't use the texture

```
color = (tc.z < 0.0)
    ? vec4(0.0) : texture2DProj(tex, tc);
```

  - Clamp z at 0 or ϵ

```
tc.z = max(tc.z, 0.0);
color = texture2DProj(tex, tc);
```

References

http://en.wikipedia.org/wiki/Projective_texture_mapping

Everitt, Cass. 2001. "Projective Texture Mapping." NVIDIA Corporation. http://developer.nvidia.com/object/Projective_Texture_Mapping.html

http://www.ozone3d.net/tutorials/glsl_texturing_p08.php

Cost of State Changes

- Changing state can be expensive
  - At the very least, most hardware will have to flush internal data cache
  - One of the more expensive pieces of state to change is a texture binding

Cost of State Changes

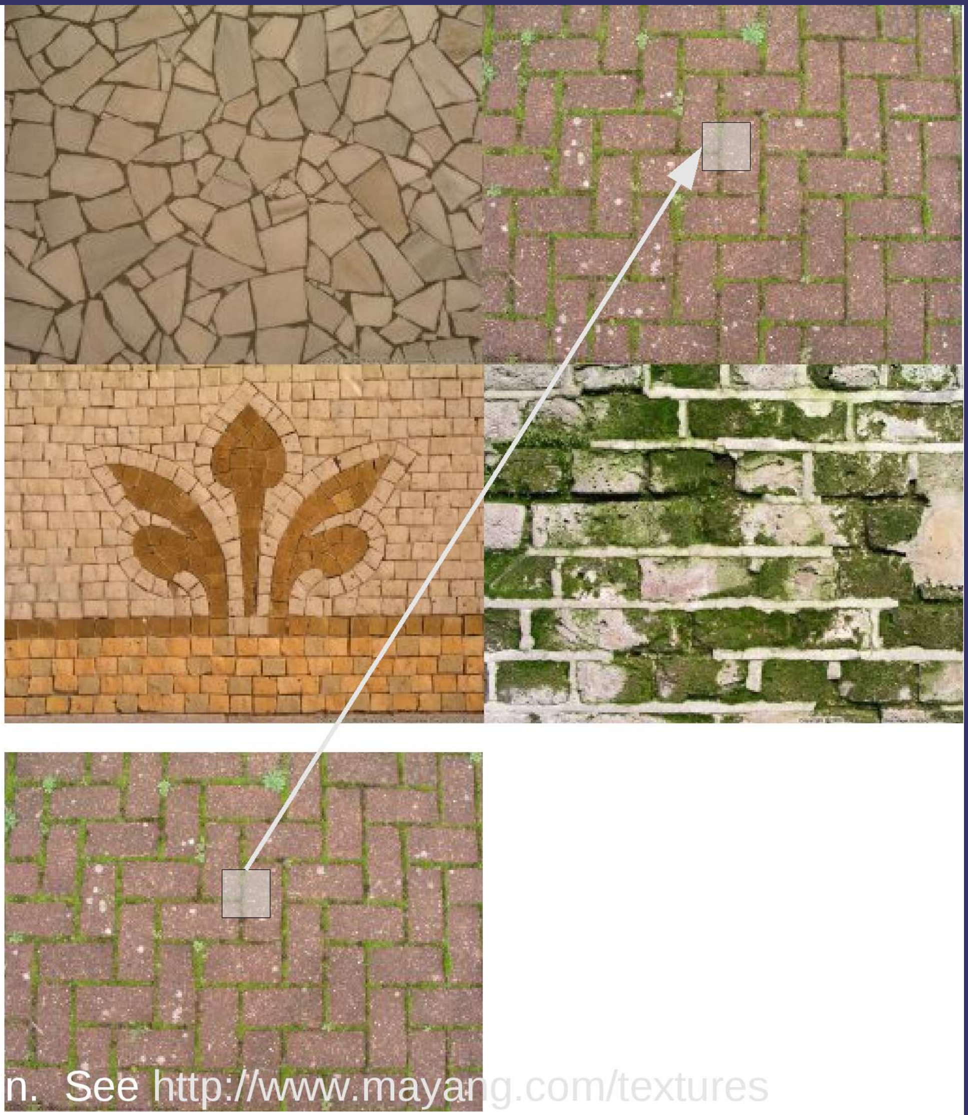
- Most common strategy to reduce state changes is sorting
  - Objects are sorted by common state and rendered in batches
  - This is a hassle and may not always be possible

Texture Atlases

- The number of texture binding changes can be reduced by packing multiple images into a single texture
  - When multiple texture maps are combined into a single, larger texture, it is called a *texture atlas*

Texture Atlases

- Texture coordinates must be updated for use with an atlas
  - Scale to the relative size within the atlas
  - Bias to the base position within the atlas



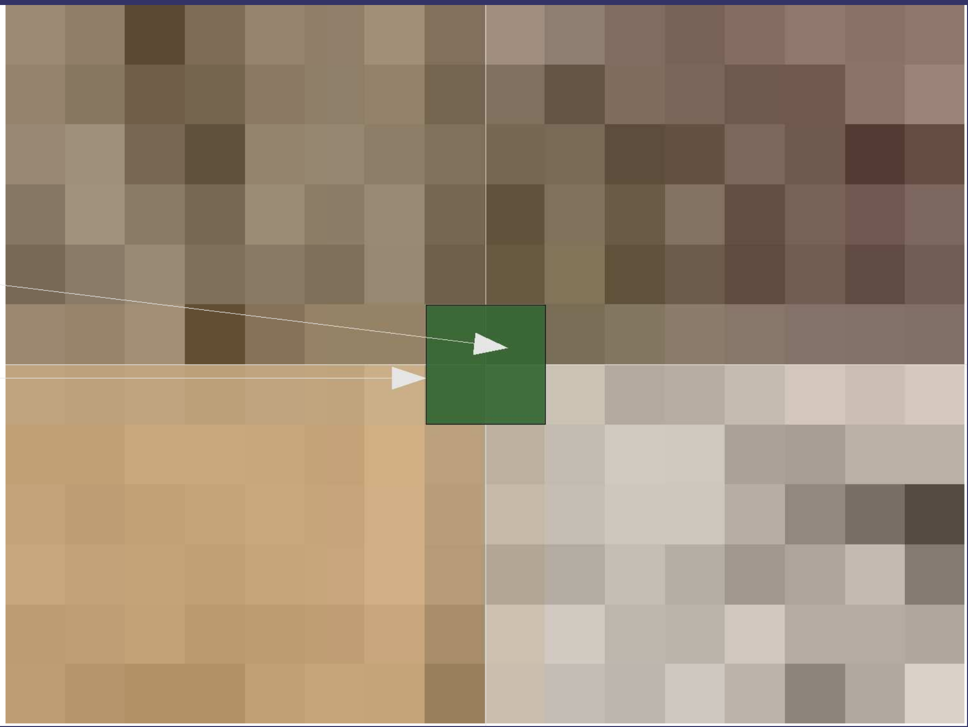
n. See http://www.mayang.com/textures

Texture Atlases

- Care must be taken around borders!
  - Sampling this point

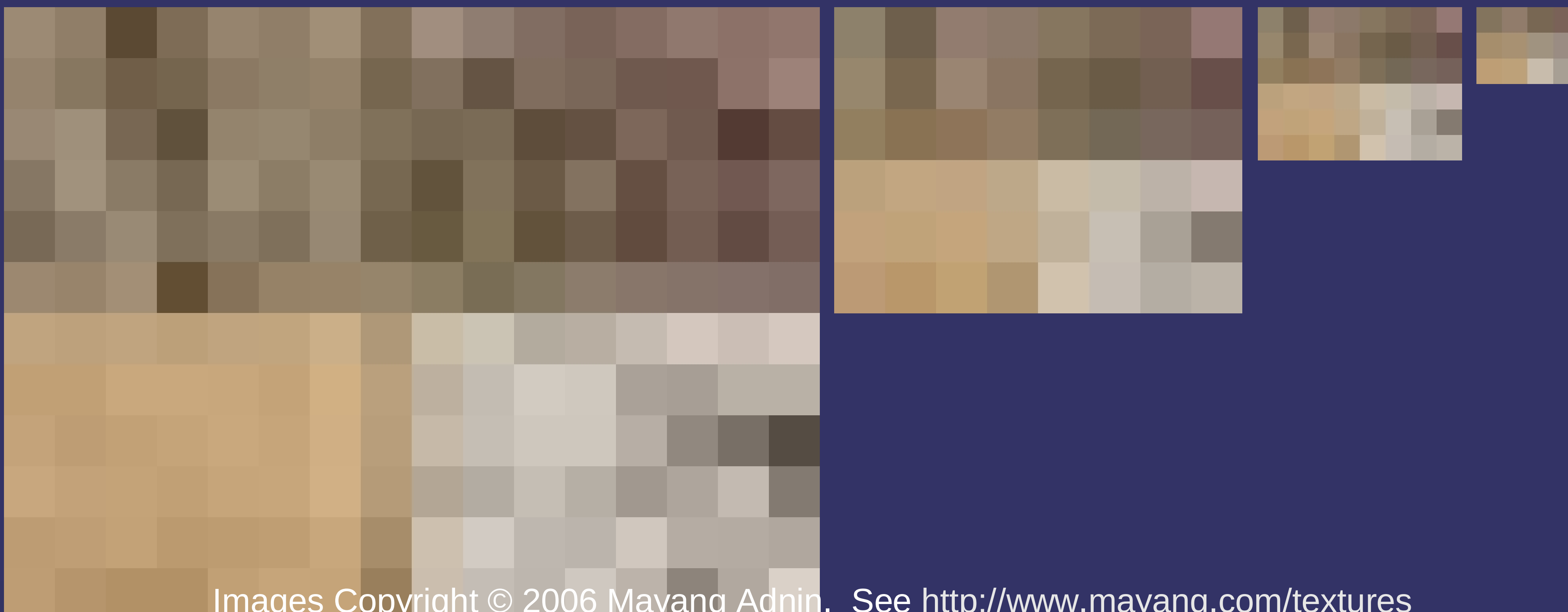
Texture Atlases

- Care must be taken around borders!
  - Sampling this point
  - Will use this filter area



Texture Atlases

- Care must also be taken with mipmapping



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Texture Atlases

- Care must also be taken with mipmapping
  - Clamping the LOD can fix this

References

http://www.gamasutra.com/features/20060126/ivanov_01.shtml

The Balancing Act...

- Want to have numerous, highly detailed textures
  - Reduce aliasing
  - Prevent repetitive use of identical textures
- Want to have high performance rendering
  - Want to keep all textures in fast, on-card memory
  - Want to minimize bandwidth required to access textures

Compression

- Two usual ways to reduce storage requirements:
  - Have less data to store
  - Compress data

Compression

- Compression is used all the time!
  - Zip
  - Rar
  - JPEG
  - MPEG
  - MP3
  - etc.

Compression

- General data compression techniques have rely on a common principle:

  Reduce data size by storing redundancies in a compact manner

  - Each data set has a different amount of redundancy:

```
-rw-rw-r-- 1 idr idr 20005 2009-02-25 18:41 crazy_paving_4142298.JPG
-rw-rw-r-- 1 idr idr 23246 2009-02-25 18:42 diagonal_pattern_brick_flooring_9181152.JPG
-rw-rw-r-- 1 idr idr 22886 2009-02-25 18:42 tiles_golden_feathers_motif_4142310.JPG
-rw-rw-r-- 1 idr idr 29135 2009-02-25 18:42 wet_lichen_brick_5132630.JPG
```

  - All four images are the same resolution and color depth

Compression

- Variable compression is unsuitable for texture storage
  - Variably compressed data must be *serially* accessed to find a particular data element
  - Textures are accessed randomly
    - Texture-fetch hardware must quickly convert a texture coordinate to a texel address

Texture Compression

- Several fixed-ratio compression techniques exist specifically for textures:
  - S3TC
  - FXT1
  - PVR-TC
  - ETC
- All techniques compress a rectangular block of texels into a fixed size block
  - Blocks are usually either 2×2 or 2×4

Texture Compression

- What's the trade-off?

Texture Compression

- What's the trade-off?
  - Access speed improves
  - Compression ratio decreases
    - JPEG regularly achieves 10:1 or 20:1 where as most texture compression algorithms only achieve 4:1
  - Quality decreases
    - Each block is compressed the same amount (ratio) regardless of how much redundancy is actually available
    - Hand-wavy description: if there isn't 4:1 worth of redundancy, actual data is thrown away

Texture Compression

- Specify that OpenGL compress textures for you
  - Use one of the *generic* compressed formats for the `internalFormat` specified to `glTexImage2D`
    - `GL_COMPRESSED_ALPHA`
    - `GL_COMPRESSED_LUMINANCE`
    - `GL_COMPRESSED_LUMINANCE_ALPHA`
    - `GL_COMPRESSED_INTENSITY`
    - `GL_COMPRESSED_RGB`
    - `GL_COMPRESSED_RGBA`

Texture Compression

- Specify that OpenGL compress textures for you
  - Use one of the *specific* compressed formats for the `internalFormat` specified to `glTexImage2D`
    - `GL_COMPRESSED_RGB_S3TC_DXT1_EXT`
    - `GL_COMPRESSED_RGBA_S3TC_DXT1_EXT`
    - `GL_COMPRESSED_RGBA_S3TC_DXT3_EXT`
    - `GL_COMPRESSED_RGBA_S3TC_DXT5_EXT`
    - etc.

Texture Compression

- Determine which compressed formats are available:
  - Find out how many formats by querying `GL_NUM_COMPRESSED_TEXTURE_FORMATS`
  - Get the list of formats by querying `GL_COMPRESSED_TEXTURE_FORMATS`

Texture Compression

- Specify pre-compressed data:

```
void glCompressedTexImage1D(GLenum target,
    GLint level, GLenum internalformat,
    GLsizei width, GLint border,
    GLsizei imageSize, const GLvoid *data);

void glCompressedTexSubImage1D(GLenum target,
    GLint level, GLint xoffset, GLsizei width,
    GLenum format, GLsizei imageSize,
    const GLvoid *data);
```

Texture Compression

- Read back a compressed texture:

```
void glGetCompressedTexImage(GLenum target,
    GLint level, GLvoid *img);
```

  - Will fail if the internal format is not a compressed format

References

http://www.gamasutra.com/features/20051228/sherrod_01.shtml

Next week...

- Framebuffer blending
  - Alpha blending
  - Multipass rendering
  - Compositing
- Stencil buffer
- Quiz #4

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