Texture Mapping

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CSE 457
Winter 2021

Reading

Optional

- Angel and Shreiner: 7.4-7.10
- Marschner and Shirley: 11.1-11.2.3, 11.2.5, 11.4-11.5

Further reading

- Paul S. Heckbert. Survey of texture mapping. **IEEE Computer Graphics and Applications** 6(11): 56--67, November 1986.
- Woo, Neider, & Davis, Chapter 9
- James F. Blinn and Martin E. Newell. Texture and reflection in computer generated images. **Communications of the ACM** 19(10): 542--547, October 1976.

Texture mapping

Texture mapping (Woo et al., fig. 9-1)

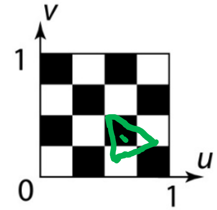
Texture mapping allows you to take a simple polygon and give it the appearance of something much more complex.

- Due to Ed Catmull, PhD thesis, 1974
- Refined by Blinn & Newell, 1976

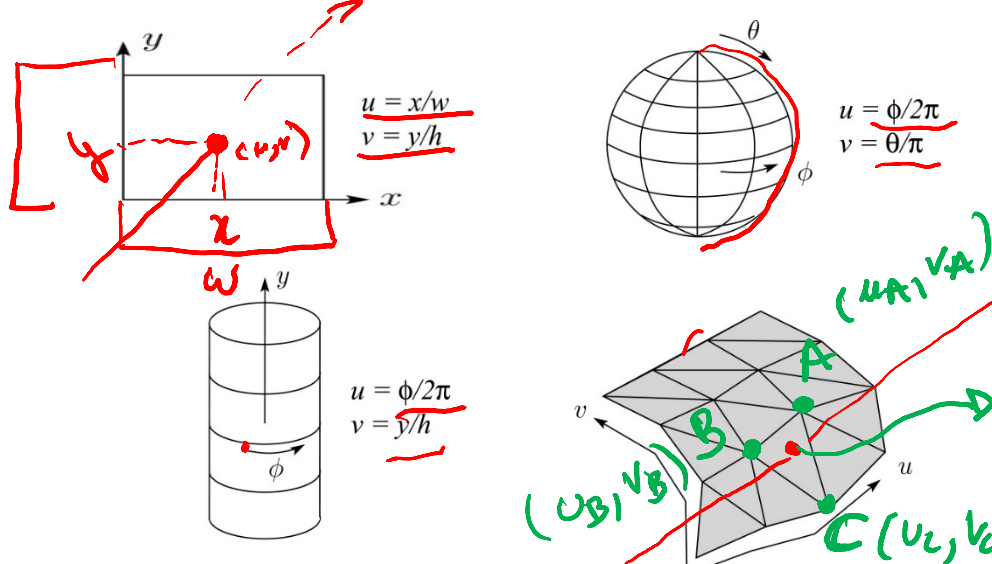
A texture can modulate just about any parameter – diffuse color, specular color, specular exponent, …

Implementing texture mapping

A texture lives in it own abstract image coordinates paramaterized by (u, v) in the range $([0..1], [0..1])$:



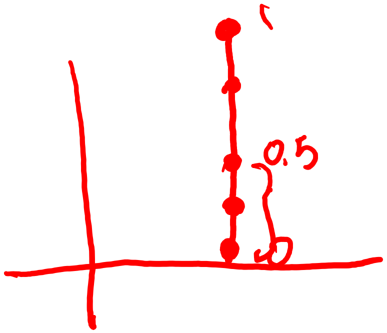
It can be wrapped around many different surfaces:

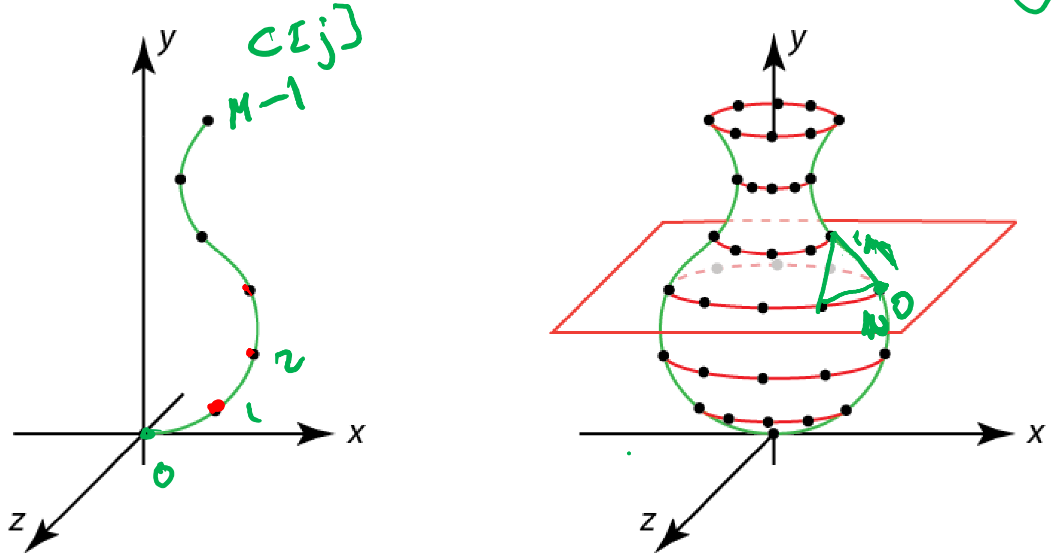


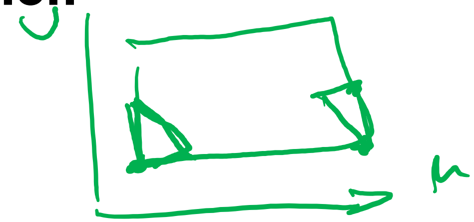
With a ray caster, we can do the sphere and cylinder mappings directly (as we will see later). For graphics hardware, everything gets converted to a triangle mesh with associated (u, v) coordinates.

Note: if the surface moves/deforms, the texture goes with it.

Texture coordinates on a surface of revolution







Recall that for a surface of revolution, we have:

Profile curve: $C[j]$ where $j \in [0..M\text{-}1]$

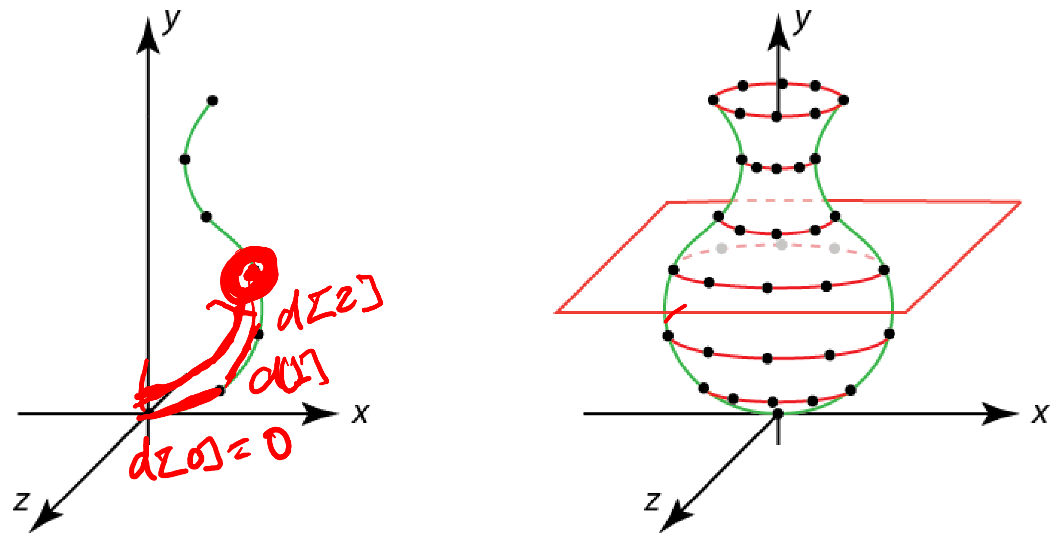
Rotation angles: $\theta[i] = 2\pi i / N$ where $i \in [0..N]$

The simplest assignment of texture coordinates would be:

$u = \frac{i}{N}$ $\quad$ $v = \frac{j}{M-1}$

Note that you should include the rotation angles for $i = 0$ and $i = N$, even though they produce the same points (after rotating by 0 and 2π). Why do this??

Texture coordinates on a surface of revolution



If we wrap an image around this surface of revolution, what artifacts would we expect to see?

We can reduce distortion in v. Define:

$$d[j] = \begin{cases} \left\| C[j] - C[j-1] \right\|, & \text{if } j \neq 0 \\ 0, & \text{if } j = 0 \end{cases}$$

and set v to fractional distance along the curve:

$$V = \sum_{k=0}^{j} d[k] \Big/ \sum_{k=0}^{M-1} d[k]$$

DO THIS!

You must do this for v for the programming assignment!

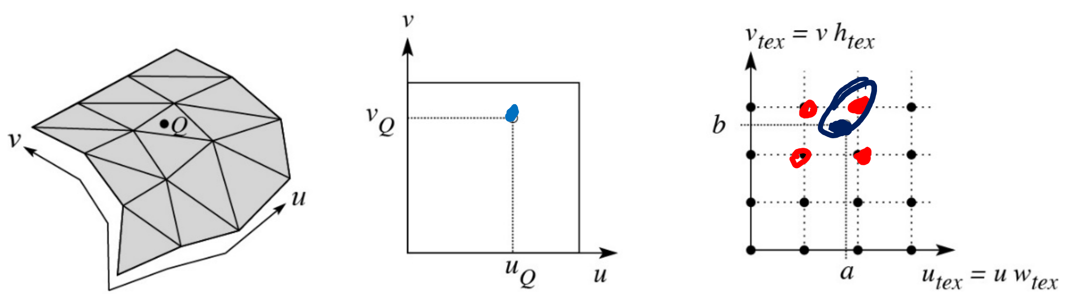
Mapping to texture image coords

The texture is usually stored as an image. Thus, we need to convert from abstract texture coordinate:

(u, v) in the range $([0..1], [0..1])$

to texture image coordinates:

(u_{tex}, v_{tex}) in the range $([0..\, w_{tex}\,], [0..\, h_{tex}\,])$



Point on triangle mesh

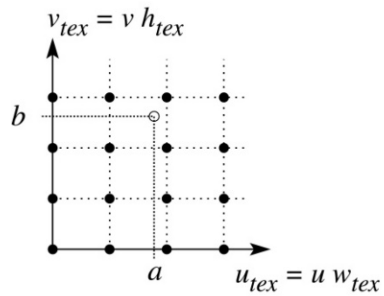
Mapping to abstract texture coords

Mapping to texture pixel coords

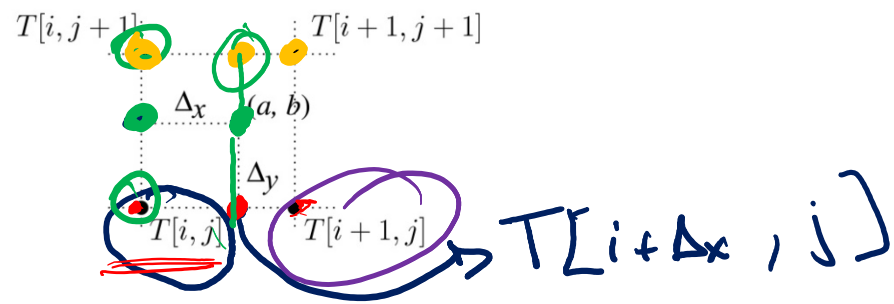
Q: What do you do when the texture sample you need lands between texture pixels?

Texture resampling

We need to resample the texture:



Mapping to
texture pixel coords



Close-up

Thus, we seek to solve for: $\mathbf{T}(a,b) = \mathbf{T}\left(i+\Delta_x, j+\Delta_y\right)$

A common choice is **bilinear interpolation**:

$$\mathrm{T}\left(i+\Delta_x, j\right) = \underline{(1-\Delta x)}\,\mathrm{T}[i,j] + \underline{\Delta x}\,\mathrm{T}[i+1,j]$$

$$\mathrm{T}\left(i+\Delta_x, j+1\right) = \underline{(1-\Delta x)}\,\mathrm{T}[i,j+1] + \underline{\Delta x}\,\mathrm{T}[i+1,j+1]$$

$$\mathrm{T}\left(i+\Delta_x, j+\Delta_y\right) = \underline{(1-\Delta y)}\,\mathrm{T}\left(i+\Delta_x, j\right) + \underline{\Delta y}\,\mathrm{T}\left(i+\Delta_x, j+1\right)$$

$$= \underline{(1-\Delta x)(1-\Delta y)}\,\mathrm{T}[i,j] + \underline{\Delta x\,(1-\Delta y)}\,\mathrm{T}[i+1,j] +$$

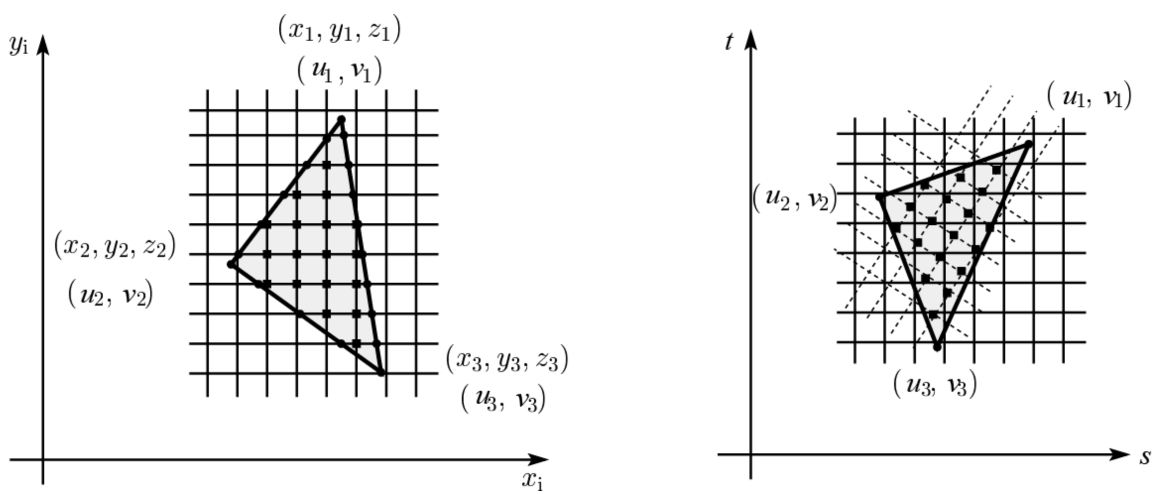
$$\underline{(1-\Delta x)\Delta y}\,\mathrm{T}[i,j+1] + \underline{\Delta x\,\Delta y}\,\mathrm{T}[i+1,j+1]$$

Texture mapping and rasterization

Texture-mapping can also be handled in rasterization algorithms.

<u>Method</u>:

- Scan conversion is done in screen space, as usual
- Each pixel is colored according to the texture
- Texture coordinates are found by Gouraud-style interpolation

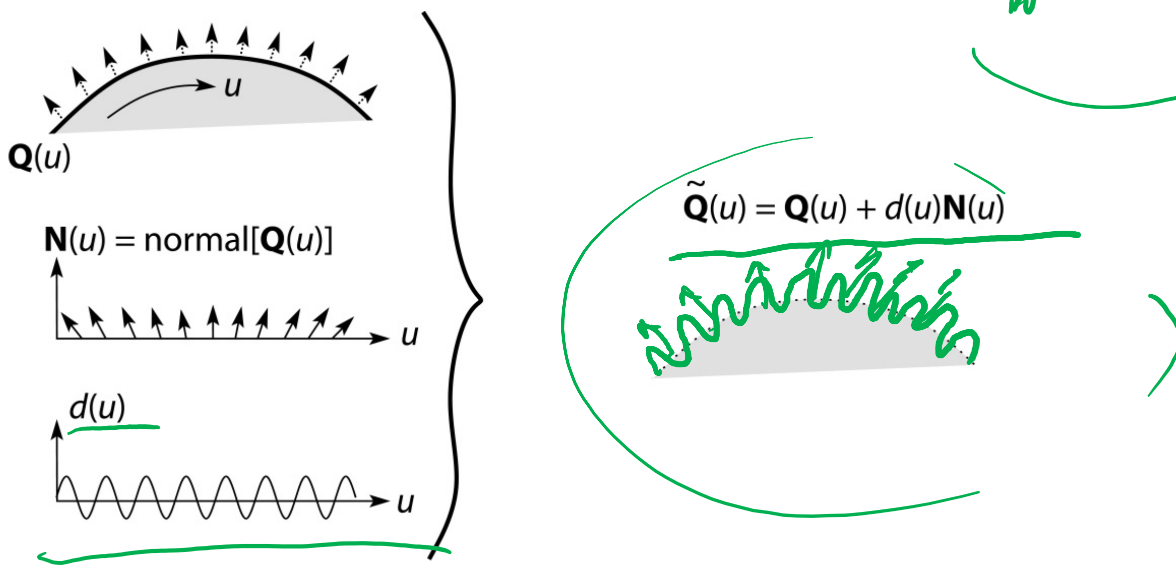


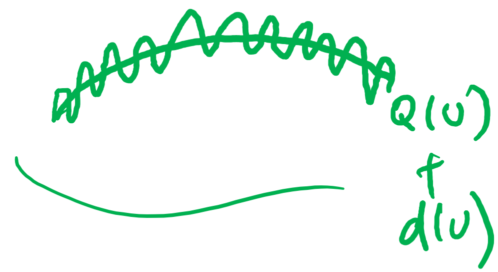
<u>Note</u>: Mapping is more complicated to handle perspective correctly.

Displacement mapping

Textures can be used for more than just color.

In **displacement mapping**, a texture is used to perturb the surface geometry itself. Here's the idea in 2D:





- These displacements "animate" with the surface
- In 3D, you would of course have (u, v) parameters instead of just u.

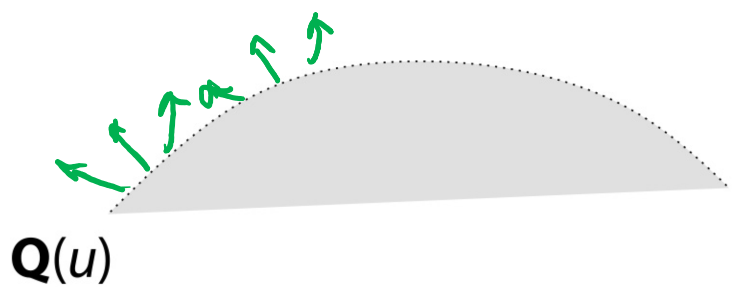
Suppose $\mathbf{Q}$ is a simple surface, like a cube. Will it take more work to render the modified surface $\tilde{\mathbf{Q}}$?

Bump and normal mapping

In **bump mapping**, a texture is used to perturb the normal:

- Use the original, simpler geometry, $\mathbf{Q}(u)$, for hidden surfaces
- Use the normal from the displacement map for shading:

$$\tilde{\mathbf{N}} = \text{normal}[\tilde{\mathbf{Q}}(u)]$$

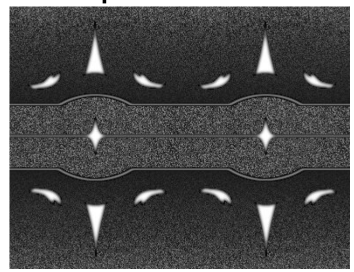


An alternative is to compute the normals from the original bump map height field and map them over the smooth surface. This is called **normal mapping**.

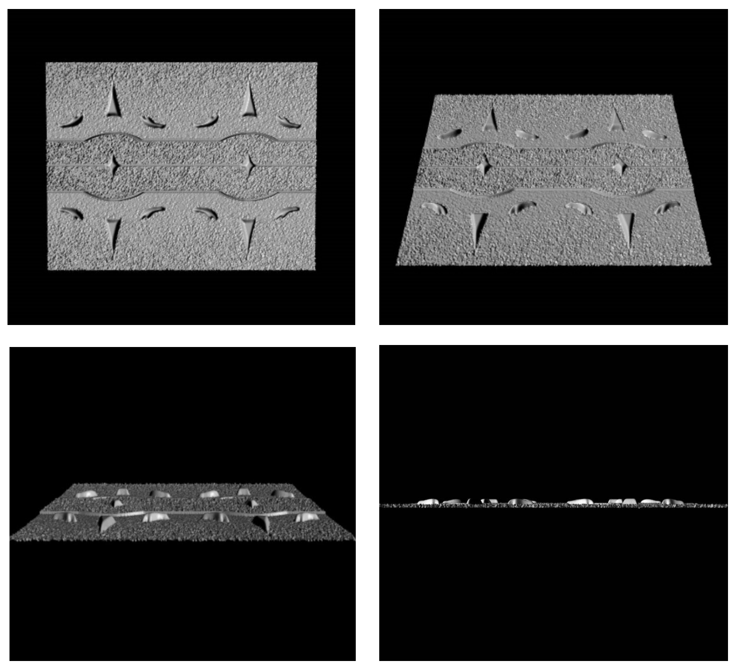
What artifacts in the images would reveal that bump (or normal) mapping is fake?

Displacement vs. bump mapping

Input texture



Rendered as displacement map over a rectangular surface



Displacement vs. bump mapping (cont'd)

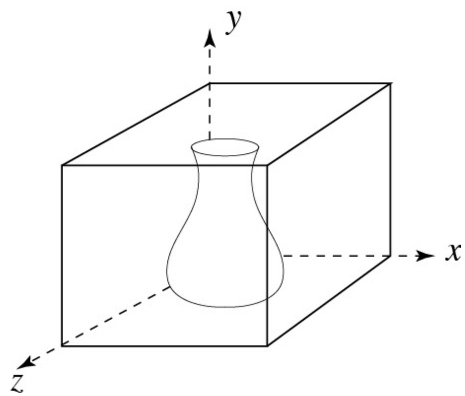
Original rendering

Rendering with bump map wrapped around a cylinder

Bump map and rendering by Wyvern Aldinger

Solid textures

Q: What kinds of artifacts might you see from using a marble veneer instead of real marble?



One solution is to use **solid textures**:

- Use model-space coordinates to index into a 3D texture
- Like "carving" the object from the material

One difficulty of solid texturing is coming up with the textures.

Solid textures (cont'd)

Here's an example for a vase cut from a solid marble texture:

Solid marble texture by Ken Perlin, (Foley, IV-21)

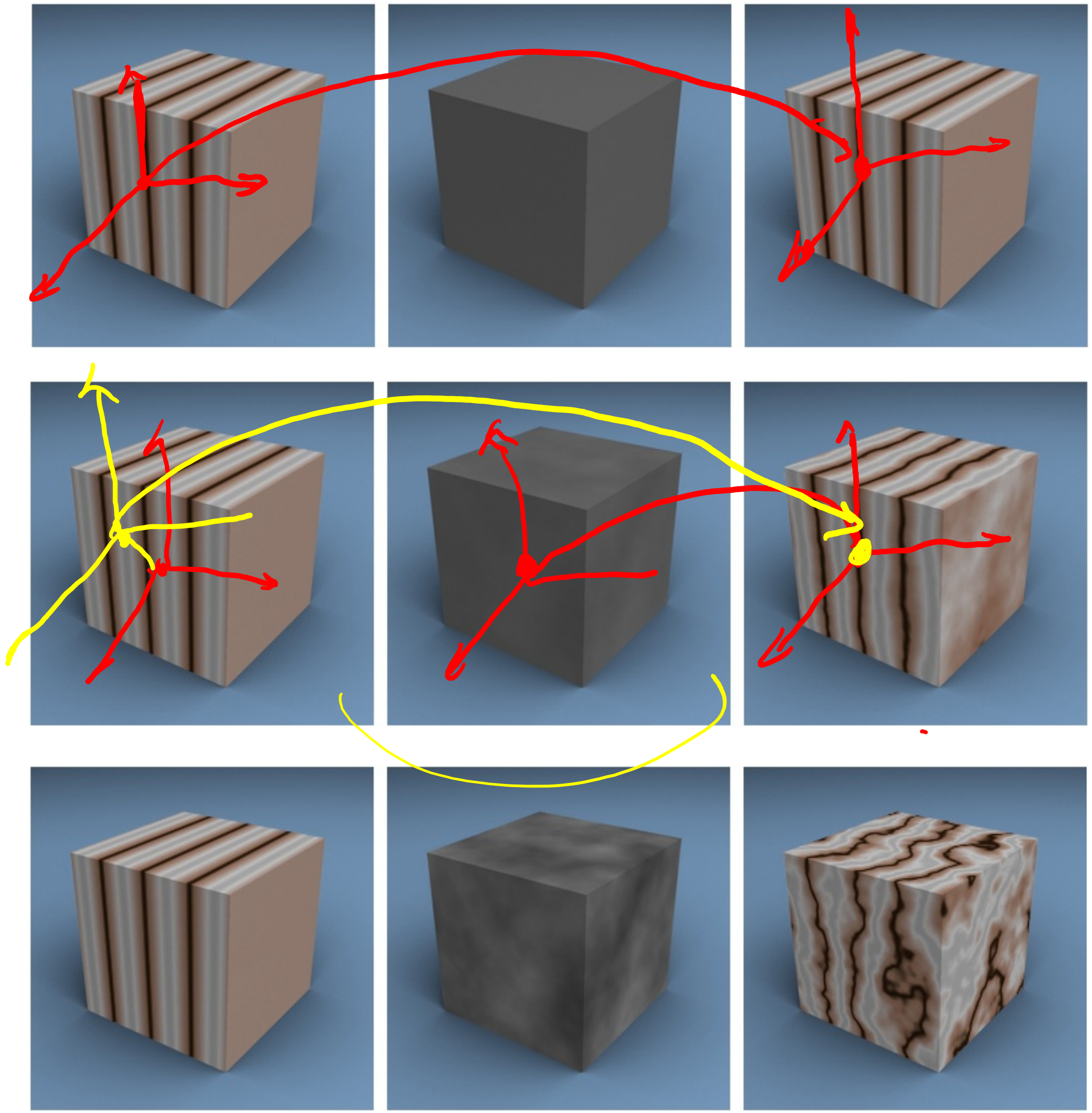
Solid textures (cont'd)

$\text{in}(x, y, z) = \text{stripes}(x)$

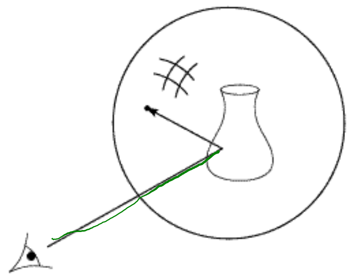
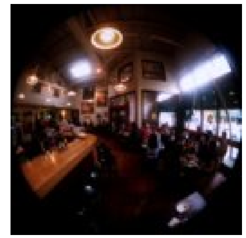
$\text{shift}(x, y, z) = K \bullet \text{noise}(x, y, z)$

$\text{out}(x, y, z) = \text{stripes}(x + \text{shift}(x, y, z))$

Increasing K



Environment mapping

In **environment mapping** (also known as **reflection mapping**), a texture is used to model an object's environment:

- Rays are bounced off objects into environment
- Color of the environment used to determine color of the illumination
- Environment mapping works well when there is just a single object – or in conjunction with ray tracing

This can be readily implemented (without interreflection) in graphics hardware using a fragment shader, where the texture is stored in a "cube map" instead of a sphere.

With a ray tracer, the concept is easily extended to handle refraction as well as reflection (and interreflection).

Summary

What to take home from this lecture:

1. The meaning of the boldfaced terms.

2. Familiarity with the various kinds of texture mapping, including their strengths and limitations.