# Texture Mapping

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## Reading

Required

- Angel, 7.4-7.10

Recommended

- Paul S. Heckbert. Survey of texture mapping. **IEEE Computer Graphics and Applications** 6(11): 56--67, November 1986.

Optional

- 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.

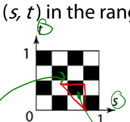
- Due to Ed Catmull, PhD thesis, 1974
- Refined by Blinn & Newell, 1976

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

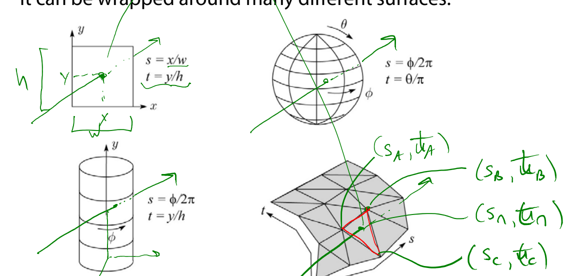


## Implementing texture mapping

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



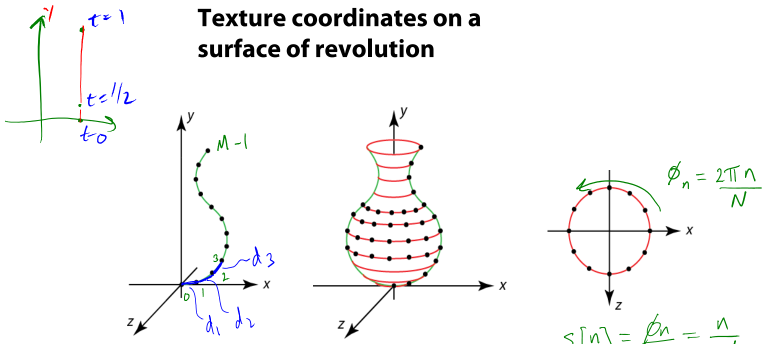

It can be wrapped around many different surfaces:




With a ray caster, we can do the sphere and cylinder mappings directly (as we will see later). For z-buffers, everything gets converted to a triangle mesh with associated ($s$, $t$) coordinates.

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

## Texture coordinates on a surface of revolution




$\phi_n = \frac{2\pi n}{N}$

$s[n] = \frac{\phi_n}{2\pi} = \frac{n}{N}$

~~$t = \frac{m}{M-1}$~~

$t[m] = \frac{\sum_{i=1}^{m} d_i}{\sum_{i=1}^{M-1} d_i}$

$(t[0] = 0)$



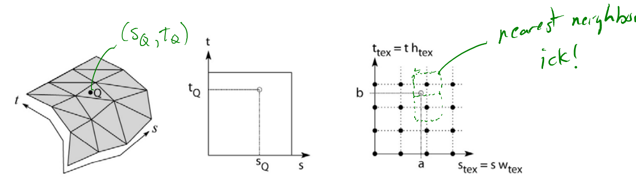
## Mapping to texture image coords

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

$(s, t)$ in the range ([0..1], [0..1])

to texture image coordinates:

$(s_{tex}, t_{tex})$ in the range ([0.. $w_{tex}$], [0.. $h_{tex}$])



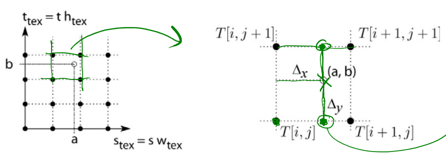

Point on triangle mesh | Mapping to abstract texture coords | Mapping to texture pixel coords

**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

$\Delta_x, \Delta_y \in [0,1]$

$T[i+\Delta_x, j] = T[i,j] + \Delta_x (T[i+1,j] - T[i,j])$

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

A common choice is **bilinear interpolation**:

$T(i+\Delta_x, j) = \underline{(1-\Delta_x)}\, T[i,j] + \underline{\Delta_x}\, T[i+1,j]$

$T(i+\Delta_x, j+1) = \underline{(1-\Delta_x)}\, T[i,j+1] + \underline{\Delta_x}\, T[i+1,j+1]$

$T(i+\Delta_x, j+\Delta_y) = \underline{(1-\Delta_y)}\, T(i+\Delta_x, j) + \underline{\Delta_y}\, T(i+\Delta_x, j+1)$

$= \underline{(1-\Delta_x)(1-\Delta_y)}\, T[i,j] + \underline{\Delta_x(1-\Delta_y)}\, T[i+1,j] +$

$\underline{(1-\Delta_x)\Delta_y}\, T[i,j+1] + \underline{\Delta_x \Delta_y}\, T[i+1,j+1]$

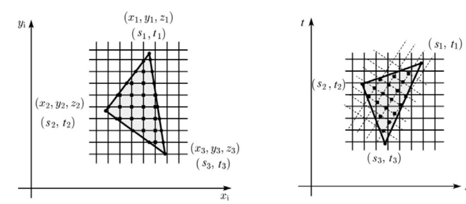


## Texture mapping and the z-buffer

Texture-mapping can also be handled in z-buffer algorithms.

Method:

- 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

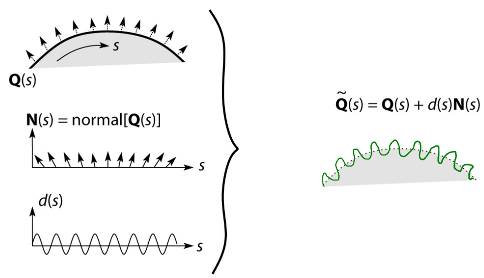



Note: Mapping is more complicated to handle perspective correctly!

## 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 ($s$, $t$) parameters instead of just $s$.

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

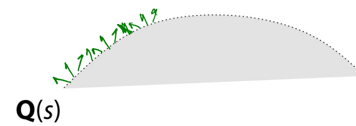


## Bump mapping

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

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

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

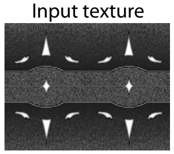



What artifacts in the images would reveal that bump mapping is fake?
silhouettes, perspective, cast shadows

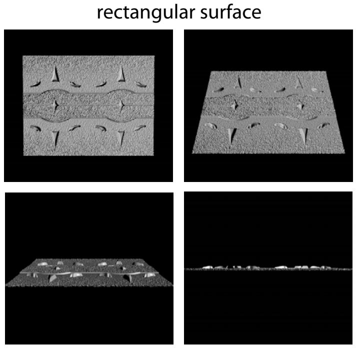


## Displacement vs. bump mapping

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

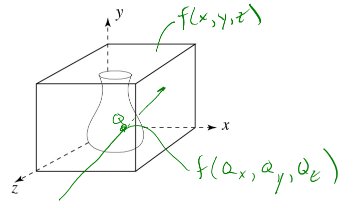
*Bump map and rendering by Wyvern Aldinger*

## Solid textures

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

Edges won't agree where they wrap and meet

Stretch & compression due to different radii




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)*

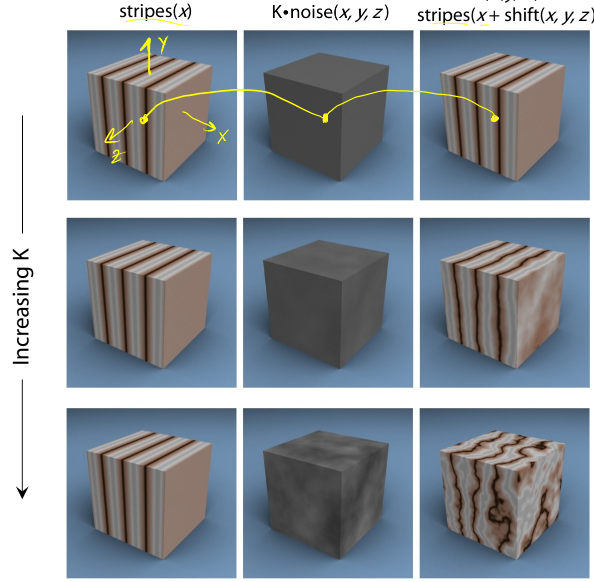


## Solid textures (cont'd)

in($x, y, z$) = stripes($x$)

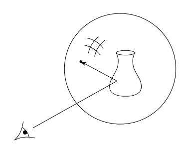
shift($x, y, z$) = K•noise($x, y, z$)

out($x, y, z$) = stripes($x$ + shift($x, y, z$))






## 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) 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.