

Computer Graphics

CSE 167 [Win 23], Lecture 18: Texture Mapping

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<http://viscomp.ucsd.edu/classes/cse167/wi23>

Many slides from Greg Humphreys, formerly UVA and
Rosalee Wolfe, DePaul tutorial teaching texture mapping visually
Chapter 11 in text book covers some portions

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To Do

- Submit HW4 milestone by tomorrow
- Prepare for final push on HW 4
- Written assignment due Mar 15, 11:59pm
 - Individually, no collaboration, piazza posts
 - Open notes, online. But understand what you turn in, and try to use your own words
 - No final

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Texture Mapping

- Important topic: nearly all objects textured
 - Wood grain, faces, bricks and so on
 - Adds visual detail to scenes
- Meant as a fun and practically useful lecture



Polygonal model

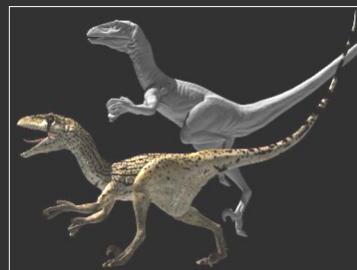


With surface texture

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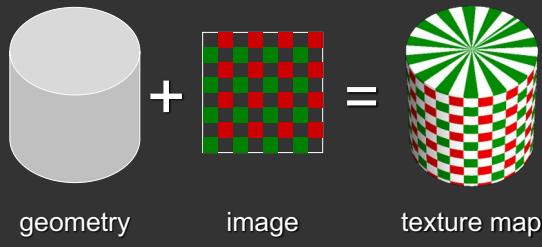
Adding Visual Detail

- Basic idea: use images instead of more polygons to represent fine scale color variation



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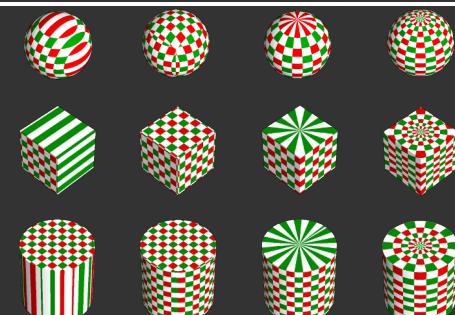
Parameterization



- Q: How do we decide *where* on the geometry each color from the image should go?

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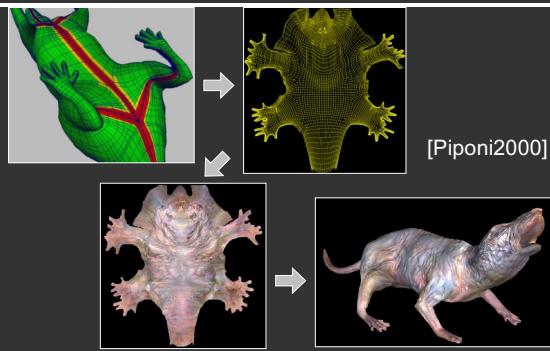
Option: Varieties of projections



[Paul Bourke]

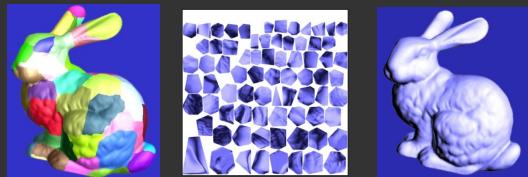
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Option: unfold the surface



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Option: make an atlas



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Option: it's the artist's problem



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CAPE Evaluations

- Fill out now, can be done on phone
- Enthusiasm important to future offerings
- Comments useful to future years
- Some key innovations: modern OpenGL, GLSL; feedback servers (including code), UCSD Online, ...
- Separately, please also evaluate the TAs

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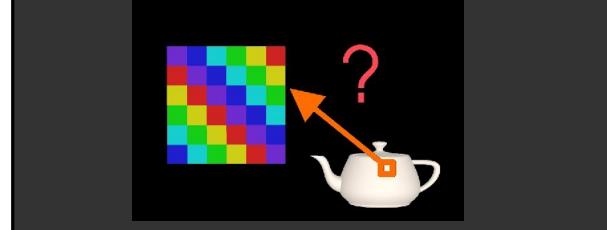
Outline

- *Types of projections*
- Interpolating texture coordinates
- Broader use of textures

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How to map object to texture?

- To each vertex (x,y,z in object coordinates), must associate 2D texture coordinates (s,t)
- So texture fits “nicely” over object



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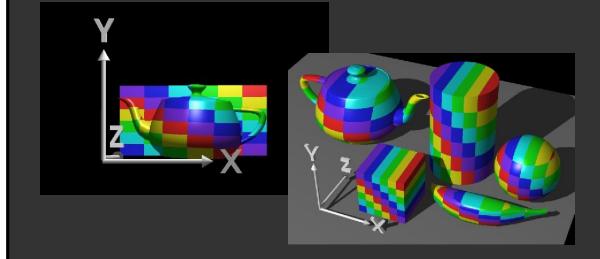
Idea: Use Map Shape

- Map shapes correspond to various projections
 - Planar, Cylindrical, Spherical
- First, map (square) texture to basic map shape
- Then, map basic map shape to object
 - Or vice versa: Object to map shape, map shape to square
- Usually, this is straightforward
 - Maps from square to cylinder, plane, sphere well defined
 - Maps from object to these are simply spherical, cylindrical, cartesian coordinate systems

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Planar mapping

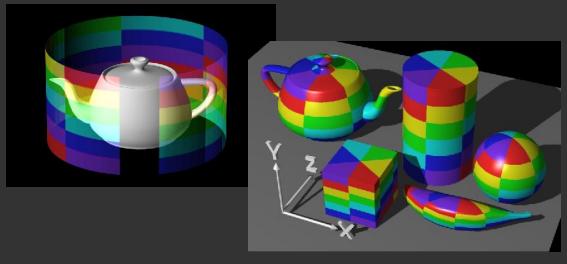
- Like projections, drop z coord $(s,t) = (x,y)$
- Problems: what happens near $z = 0$?



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Cylindrical Mapping

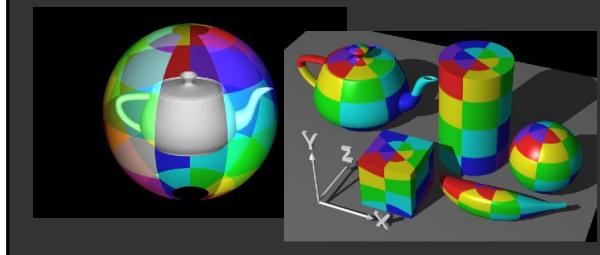
- Cylinder: r, θ, z with $(s,t) = (\theta/(2\pi), z)$
 - Note seams when wrapping around ($\theta = 0$ or 2π)



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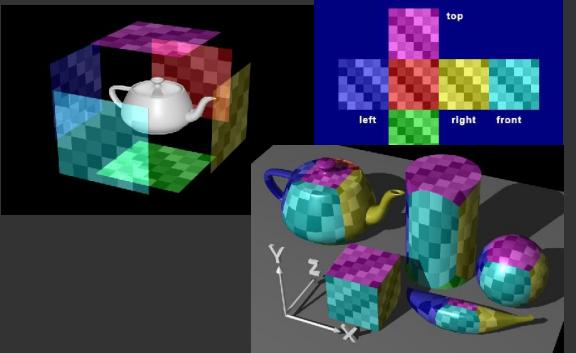
Spherical Mapping

- Convert to spherical coordinates: use latitude/long.
 - Singularities at north and south poles



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Cube Mapping



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Cube Mapping



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Gouraud Shading – Details

$$I_a = \frac{I_1(y_s - y_2) + I_2(y_1 - y_s)}{y_1 - y_2}$$
$$I_b = \frac{I_1(y_s - y_3) + I_3(y_1 - y_s)}{y_1 - y_3}$$
$$I_p = \frac{I_a(x_b - x_p) + I_b(x_p - x_a)}{x_b - x_a}$$

Scan line

Actual implementation efficient: difference equations while scan converting

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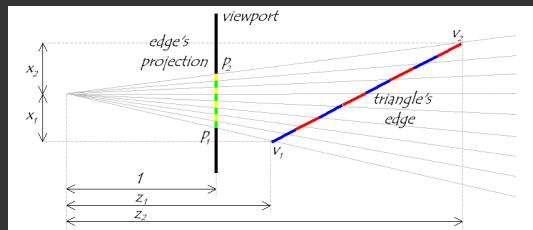
Artifacts

- [Wikipedia page](https://en.wikipedia.org/wiki/File:Perspective_correct_texture_mapping.jpg)
https://en.wikipedia.org/wiki/File:Perspective_correct_texture_mapping.jpg
- What artifacts do you see?
- Why?
- Why not in standard Gouraud shading?
- Hint: problem is in interpolating parameters

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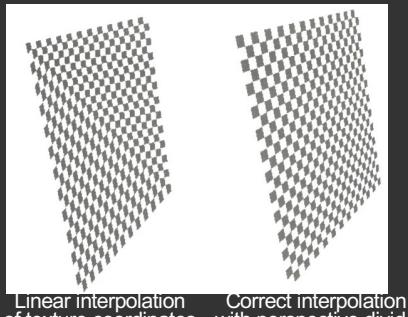
Interpolating Parameters

- The problem turns out to be fundamental to interpolating parameters in screen-space
 - Uniform steps in screen space \neq uniform steps in world space



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Texture Mapping



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Interpolating Parameters

- Perspective foreshortening is not getting applied to our interpolated parameters
 - Parameters should be compressed with distance
 - Linearly interpolating them in screen-space doesn't do this

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Perspective-Correct Interpolation

- Skipping a bit of math to make a long story short...
 - Rather than interpolating u and v directly, interpolate u/z and v/z
 - These do interpolate correctly in screen space
 - Also need to interpolate Z and multiply per-pixel
 - Problem: we don't know z anymore
 - Solution: we do know $w \sim 1/z$
 - So...interpolate uw and vw and w , and compute $u = uw/w$ and $v = vw/w$ for each pixel
 - This unfortunately involves a divide per pixel
- [Wikipedia page](#)

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Texture Map Filtering

- Naive texture mapping aliases badly
- Look familiar?

```
int uval = (int) (u * denom + 0.5f);
int vval = (int) (v * denom + 0.5f);
int pix = texture.getPixel(uval, vval);
```
- Actually, each pixel maps to a region in texture
 - $|PIX| < |TEX|$
 - Easy: interpolate (bilinear) between texel values
 - $|PIX| > |TEX|$
 - Hard: average the contribution from multiple texels
 - $|PIX| \sim |TEX|$
 - Still need interpolation!

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Mip Maps

- Keep textures prefiltered at multiple resolutions
 - For each pixel, linearly interpolate between two closest levels (e.g., trilinear filtering)
 - Fast, easy for hardware
- Why "Mip" maps?

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MIP-map Example

- No filtering:



- MIP-map texturing:



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Texture Mapping Applications

- Modulation, light maps
- Bump mapping
- Displacement mapping
- Illumination or Environment Mapping
- Procedural texturing
- And many more

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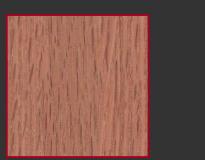
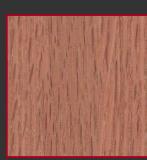
Modulation textures

Map texture values to scale factor



Texture value

$$I = T(s, t)(I_E + K_A I_A + \sum_L (K_D(N \bullet L) + K_S(V \bullet R)^a) S_L I_L + K_T I_T + K_S I_S)$$



Bump Mapping

- Texture = change in surface normal!



Sphere w/ diffuse texture

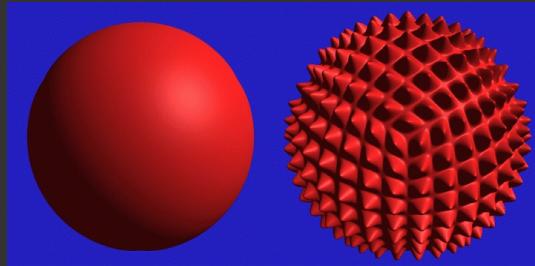
Swirly bump map

Sphere w/ diffuse texture and swirly bump map

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Displacement Mapping



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Illumination Maps

- Quake introduced *illumination maps* or *light maps* to capture lighting effects in video games

Texture map:



Light map



Texture map + light map:



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Environment Maps



Images from *Illumination and Reflection Maps: Simulated Objects in Simulated and Real Environments*
Gene Miller and C. Robert Hoffman
SIGGRAPH 1984 "Advanced Computer Graphics Animation" Course Notes

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Solid textures

Texture values indexed by 3D location (x,y,z)

- Expensive storage, or
- Compute on the fly, e.g. Perlin noise →



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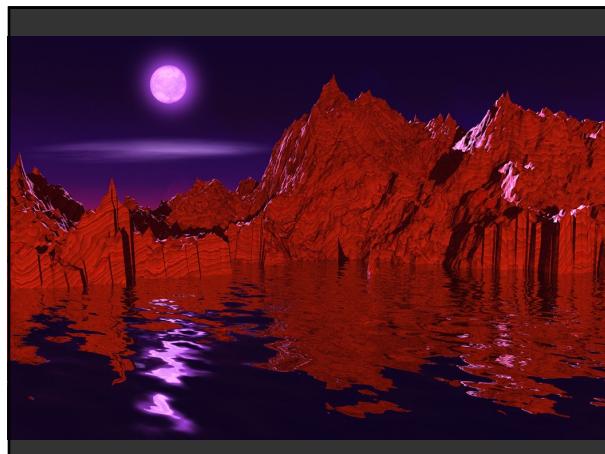
Procedural Texture Gallery



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