Texture Mapping (cont.)

Jian Huang

CS 456

OpenGL functions

- *During initialization read in or create the texture image and place it into the OpenGL state.*

  glTexImage2D (GL_TEXTURE_2D, 0, GL_RGB, imageWidth, imageHeight, 0, GL_RGB, GL_UNSIGNED_BYTE, imageData);

- *Before rendering your textured object, enable texture mapping and tell the system to use this particular texture.*

  glBindTexture (GL_TEXTURE_2D, 13);

OpenGL functions

- *During rendering, give the cartesian coordinates and the texture coordinates for each vertex.*

```
glBegin (GL_QUADS);
    glTexCoord2f (0.0, 0.0);
    glVertex3f (0.0, 0.0, 0.0);
    glTexCoord2f (1.0, 0.0);
    glVertex3f (10.0, 0.0, 0.0);
    glTexCoord2f (1.0, 1.0);
    glVertex3f (10.0, 10.0, 0.0);
    glTexCoord2f (0.0, 1.0);
    glVertex3f (0.0, 10.0, 0.0);
glEnd ();
```

OpenGL functions

- Automatic texture coordinate generation
  - *Void glTexGenf(coord, pname, param)*
    - *Coord:*
      - *GL_S, GL_T, GL_R, GL_Q*
    - *Pname*
      - *GL_TEXTURE_GEN_MODE*
      - *GL_OBJECT_PLANE*
      - *GL_EYE_PLANE*
    - *Param*
      - *GL_OBJECT_LINEAR*
      - *GL_EYE_LINEAR*
      - *GL_SPHERE_MAP*

What happens when outside the 0-1 range?

- (u,v) should be in the range of 0~1
- What happens when you request (1.5 2.3)?
  - Tile: repeat (OGL); the integer part of the value is dropped, and the image repeats itself across the surface
  - Mirror: the image repeats itself but is mirrored (flipped) on every other repetition
  - Clamp to edge – value outside of the range are clamped to this range
  - Clamp to border – all those outside are rendered with a separately defined color of the border

Methods for modifying surface

- After a texture value is retrieved (may be further transformed), the resulting values are used to modify one or more surface attributes
- Called *combine functions* or *texture blending operations*
  - Replace: replace surface color with texture color
  - Decal: replace surface color with texture color, blend the color with underlying color with an alpha texture value, but the alpha component in the framebuffer is not modified
  - Modulate: multiply the surface color by the texture color (shaded + textured surface)

Multi-Pass Rendering

- The final color of a pixel in the framebuffer is dependent on:
  - The shading/illumination applied on it
  - How those fragments are combined/blended together
- Given the set graphics hardware, how can we get more control (programmability)?
  - Example: color plate V in the book
- Want a range of special effects to be available but tailor based on the variety of hardware?

Multi-pass Rendering

- Each pass renders every pixel once
- Each pass computes a piece of the lighting equation and the framebuffer is used to store intermediate results

Quake III Engine

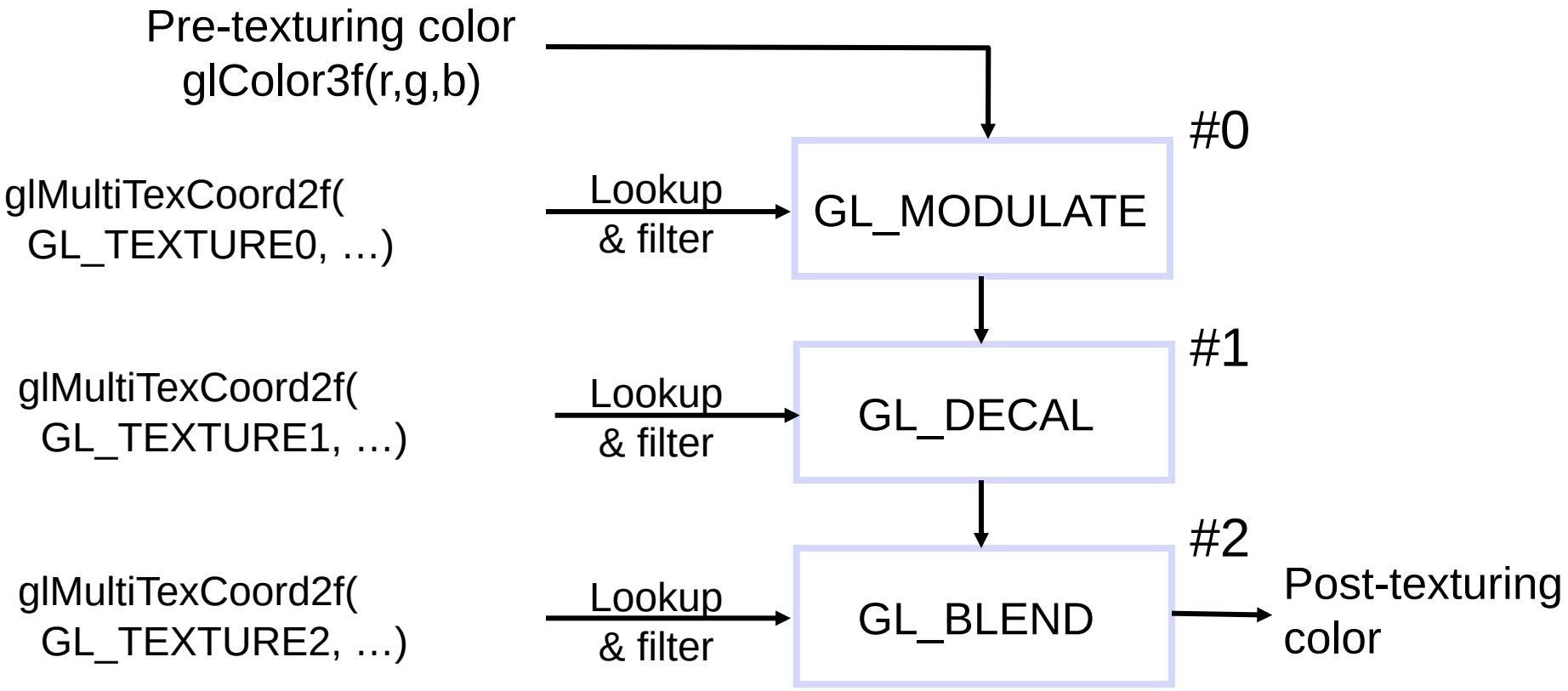
- Ten passes
  - (1-4: accumulate bump map)
  - 5: diffuse lighting)
  - 6: base texture (with specular component)
  - (7: specular lighting)
  - (8: emissive lighting)
  - (9: volumetric/atmospheric effects)
  - (10: screen flashes)

AB+CD?

- Using framebuffer as the intermediate storage, can multi-pass rendering implement AB+ CD ?
  - Suppose A, B, C, D are each result of a certain pass

Multi-texture Environments

- Chain of Texture Units (Texture Stages)



Multi-Texturing

- Should have at least 2 texture units if multi-texturing is supported
- Each texture unit:
  - Texture image
  - Filtering parameters
  - Environment application
  - Texture matrix stack
  - Automatic texture-coordinate generation (doesn't seem obvious, but very have very creative apps)

Multi-Texturing

- Apply more than one texture to each fragment
  - Alpha
  - Luminance
  - Luminance and alpha
  - Intensity
  - RGB
  - RGBA
- For instance, first put a color texture on a fragment and then put an intensity map on the fragment that modulates the intensity to simulate lighting situation
  - (what could this be?)

Putting Things Together

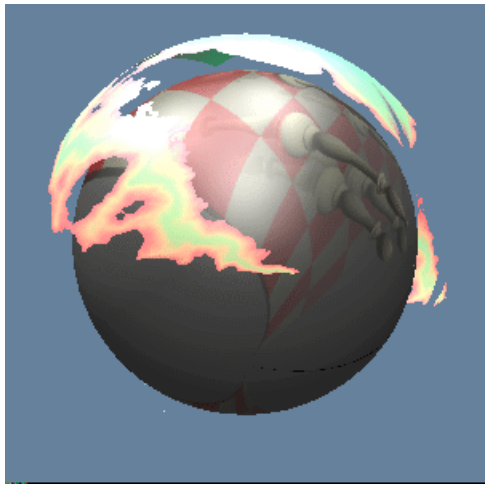
- With multi-pass rendering + multi-texturing, the lighting equation can be very flexibly controlled to render effects that graphics hardware does not do by its default
- Common practice in the industry now
- Next, let’s look at a few established texturing methods

Alpha Mapping

- Given a square texture , what if we only want the interesting part of it?
  - Say, a tree?
- Utilize the alpha channel of the texture, so that only the interesting part becomes non-transparent
- But what about the order?

Alpha Mapping

- A binary mask, really redefines the geometry.



Light Mapping

- Given a complicated lighting condition, how to accelerate and still get real-time frame rates?
- Assuming your environment is diffuse, let’s compute your lighting condition once and then use as texture map

Example

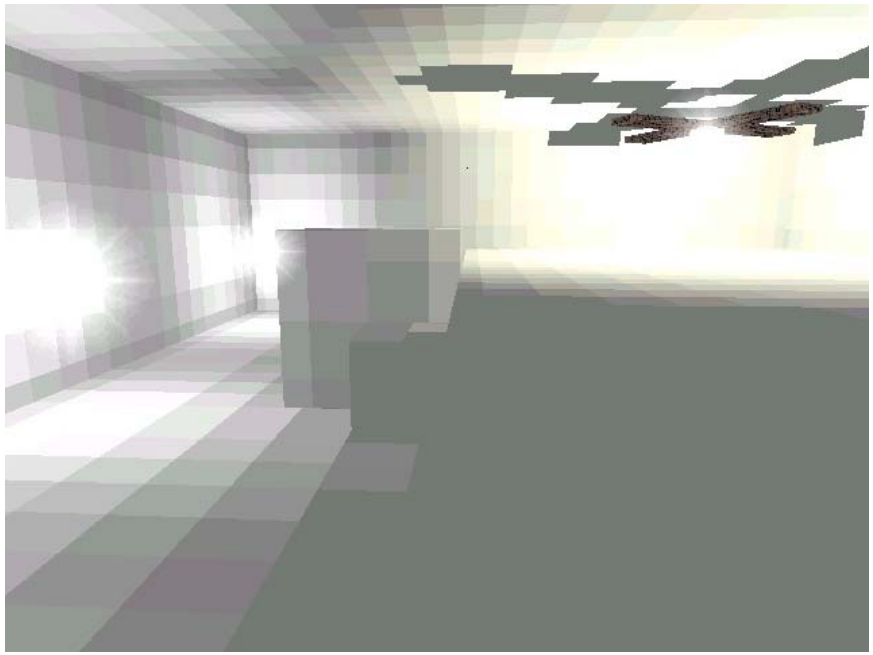
Choosing a Mapping

- Problem: In a preprocessing phase, points on polygons must be associated with points in maps
- One solution:
  - Find groups of polygons that are “near” co-planar and do not overlap when projected onto a plane
    - Result is a mapping from polygons to planes
  - Combine sections of the chosen planes into larger maps
  - Store texture coordinates at polygon vertices
- Lighting tends to change quite slowly (except at hard shadows), so the map resolution can be poor

Generating the Map

- Problem: What value should go in each pixel of the light map?
- Solution:
  - Map texture pixels back into world space (using the inverse of the texture mapping)
  - Take the illumination of the polygon and put it in the pixel
- Advantages of this approach:
  - Choosing “good” planes means that texture pixels map to roughly square pieces of polygon - good sampling
  - Not too many maps are required, and not much memory is wasted

Example



Example

Applying Light Maps

- Use multi-texturing hardware
  - First stage: Apply color texture map
  - Second stage: Modulate with light map
- Pre-lighting textures:
  - Apply the light map to the texture maps as a pre-process
  - When is this less appealing?
- Multi-pass rendering:
  - Same effect as multi-texturing, but modulating in the frame buffer

Gloss Mapping

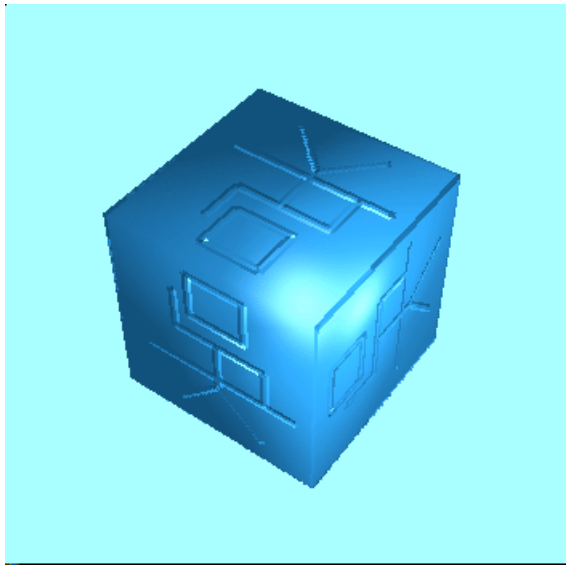
- To rendering a tile floor that is worn in places or a sheet of metal with some rusty spots
- Let’s control the specular component of the lighting equation

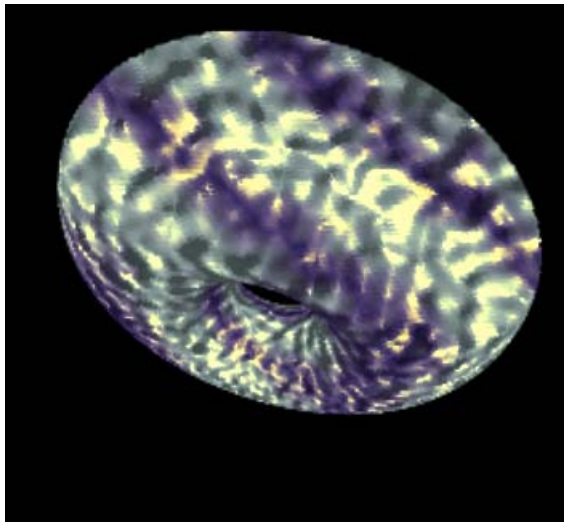
Bump Mapping

- Many textures are the result of small perturbations in the surface geometry
- Modeling these changes would result in an explosion in the number of geometric primitives.
- Bump mapping attempts to alter the lighting across a polygon to provide the illusion of texture.

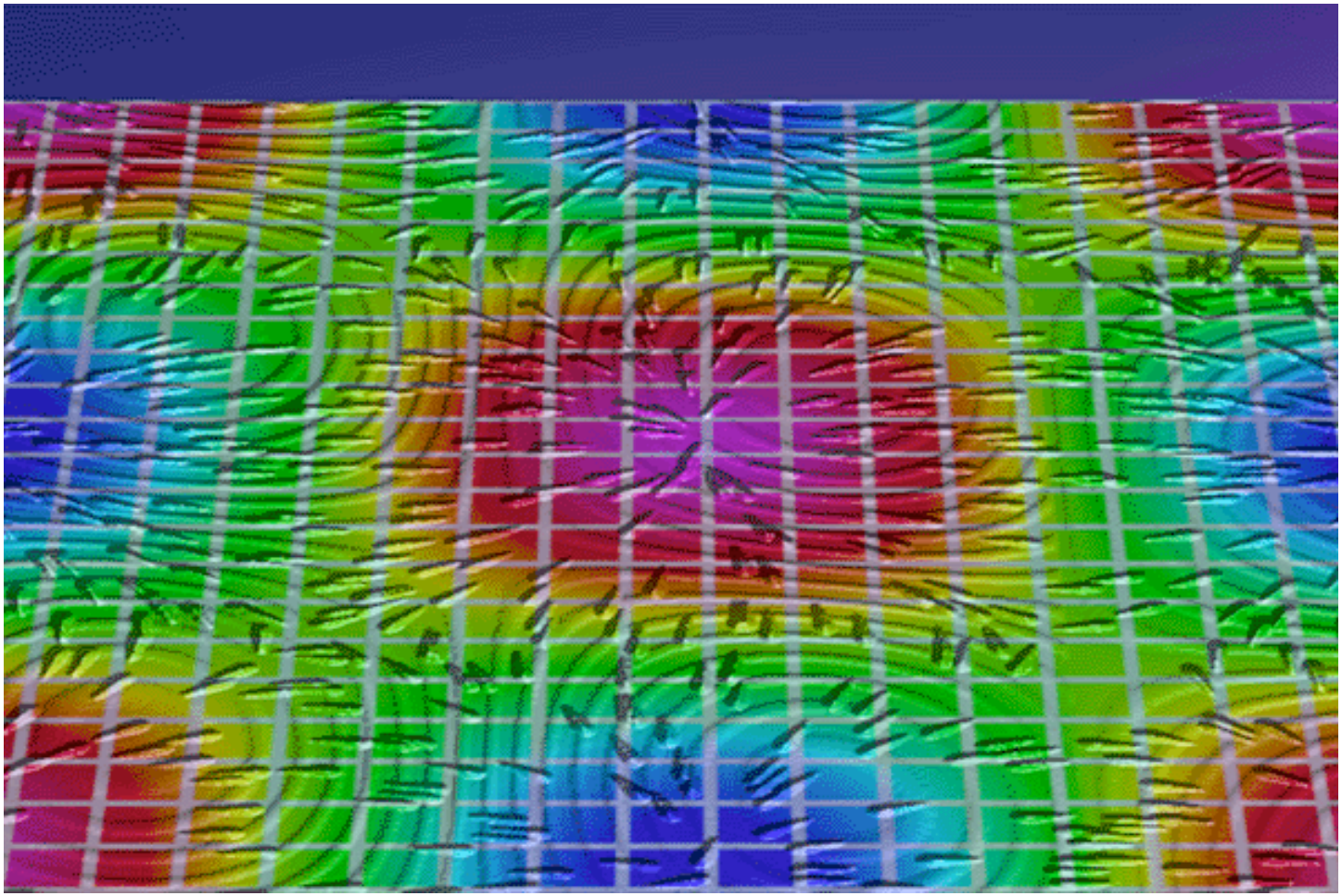
Bump Mapping

- This modifies the surface normals.
- More on this later.

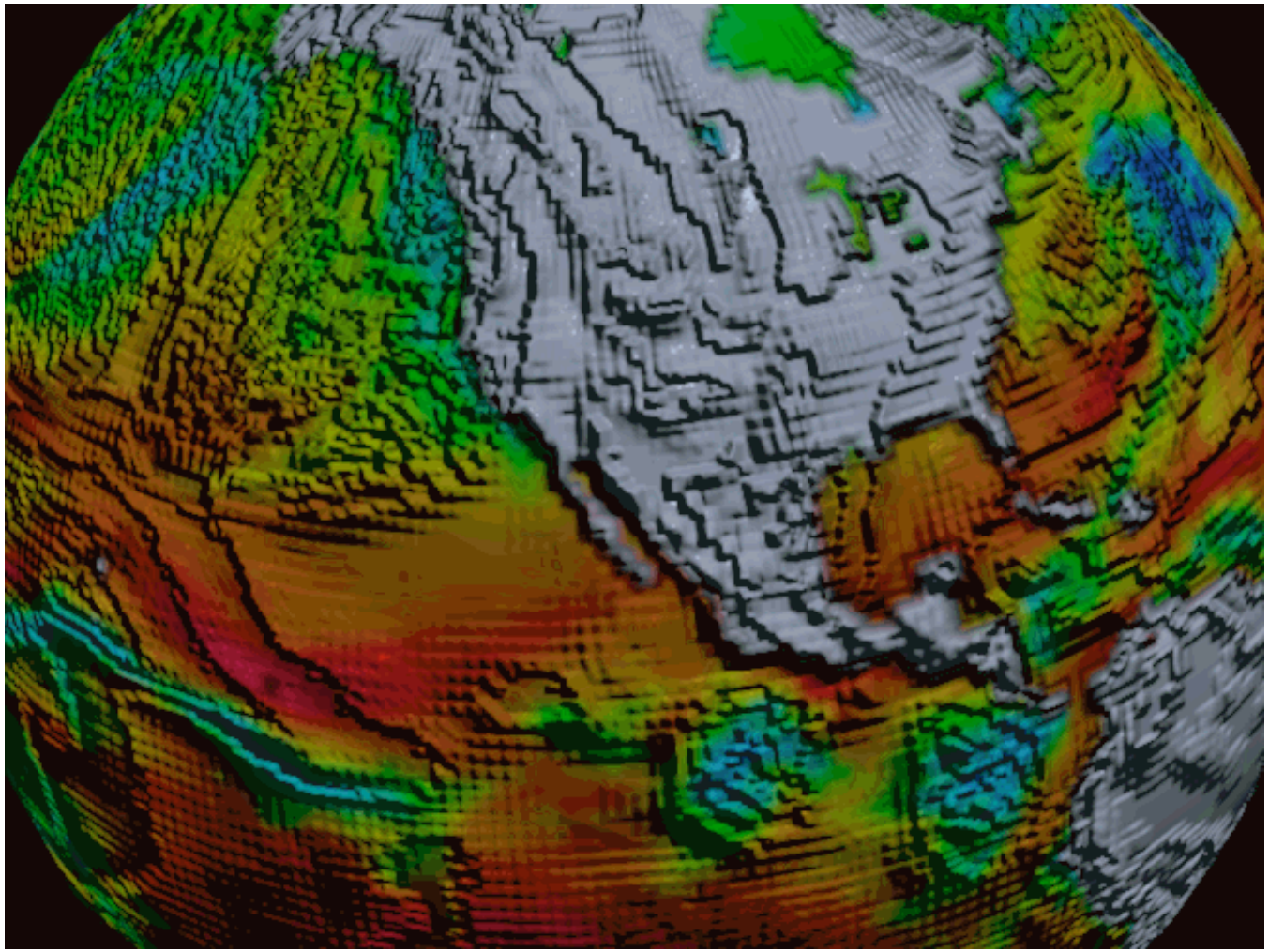




Bump Mapping

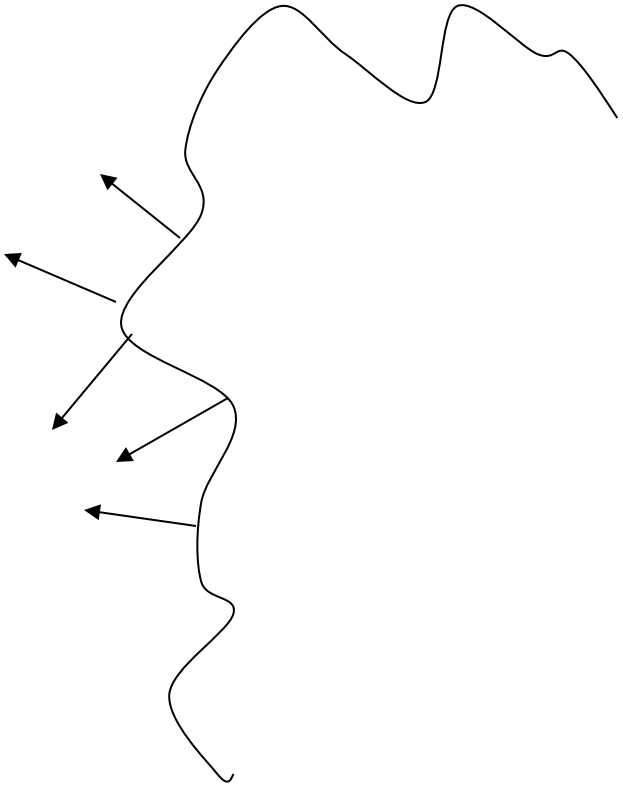


Bump Mapping



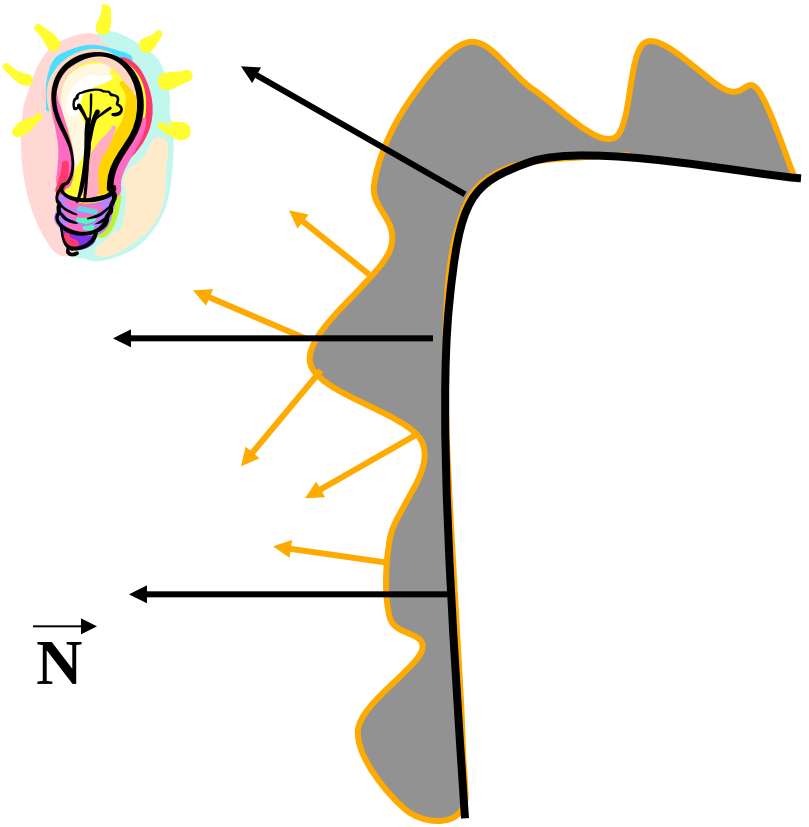
Bump Mapping

- Consider the lighting for a modeled surface.



Bump Mapping

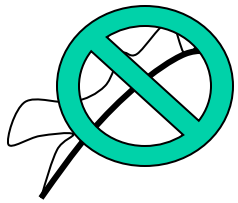
- We can model this as deviations from some base surface.
- The question is then how these deviations change the lighting.



Bump Mapping

- Assumption: small deviations in the normal direction to the surface.

$$\vec{\mathbf{X}} = \vec{\mathbf{X}} + B\,\vec{\mathbf{N}}$$



Where B is defined as a 2D function parameterized over the surface:

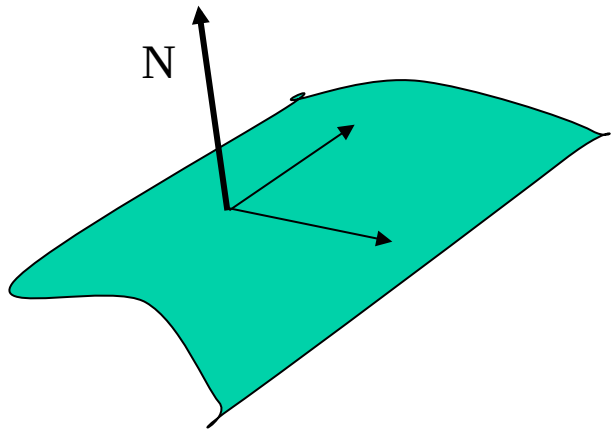
$$B = f(u,v)$$

Bump Mapping

- Step 1: Putting everything into the same coordinate frame as B(u,v).
  - x(u,v), y(u,v), z(u,v) – this is given for parametric surfaces, but easy to derive for other analytical surfaces.
  - Or $\vec{\mathbf{O}}(u,v)$

Bump Mapping

- Define the tangent plane to the surface at a point (u,v) by using the two vectors O_u and O_v.
- The normal is then given by:
  - $\mathbf{N = O_u \times O_v}$



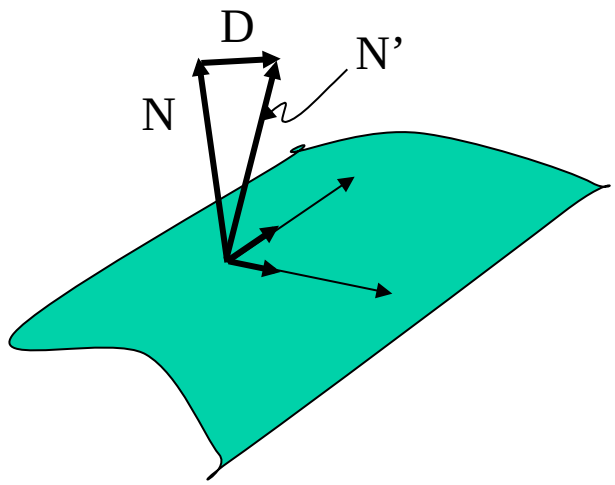
Bump Mapping

- The new surface positions are then given by:
  - $\mathbf{O'}(u,v) = \mathbf{O}(u,v) + B(u,v)\,\mathbf{N}$
  - **Where,** $\mathbf{N} = \mathbf{N} / |\mathbf{N}|$
- Differentiating leads to:
  - $\mathbf{O'_u} = \mathbf{O_u} + B_u\,\mathbf{N} + B\,(\mathbf{N})_u \quad \approx \mathbf{O'_u} = \mathbf{O_u} + B_u\,\mathbf{N}$
  - $\mathbf{O'_v} = \mathbf{O_v} + B_v\,\mathbf{N} + B\,(\mathbf{N})_v \quad \approx \mathbf{O'_v} = \mathbf{O_v} + B_v\,\mathbf{N}$

If B is small.

Bump Mapping

- This leads to a new normal:
  - $\mathbf{N'}(u,v) = \mathbf{O_u \times O_v} - B_u(\mathbf{N \times O_v}) + B_v(\mathbf{N \times O_u}) + B_u B_v(\mathbf{N \times N})$
  - » $= \mathbf{N} - B_u(\mathbf{N \times O_v}) + B_v(\mathbf{N \times O_u})$
  - » $= \mathbf{N + D}$

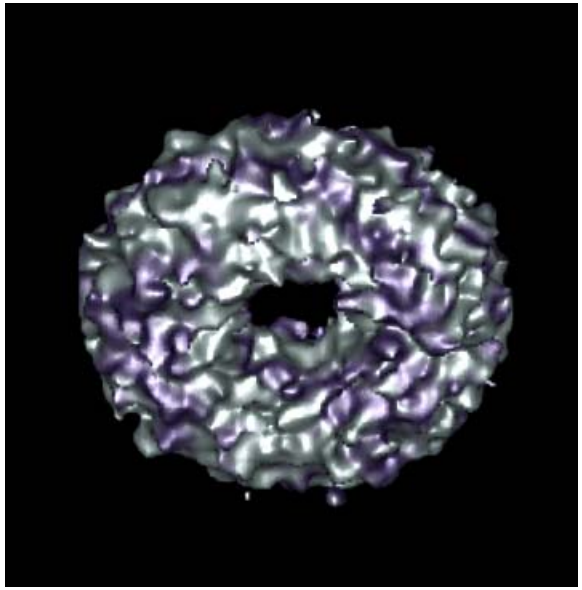


Bump Mapping

- For efficiency, can store B_u and B_v in a 2-component texture map.
- The cross products are geometry terms only.
- **N’** will of course need to be normalized after the calculation and before lighting.
  - This floating point square root and division makes it difficult to embed into hardware.

Displacement Mapping

- Modifies the surface position in the direction of the surface normal.

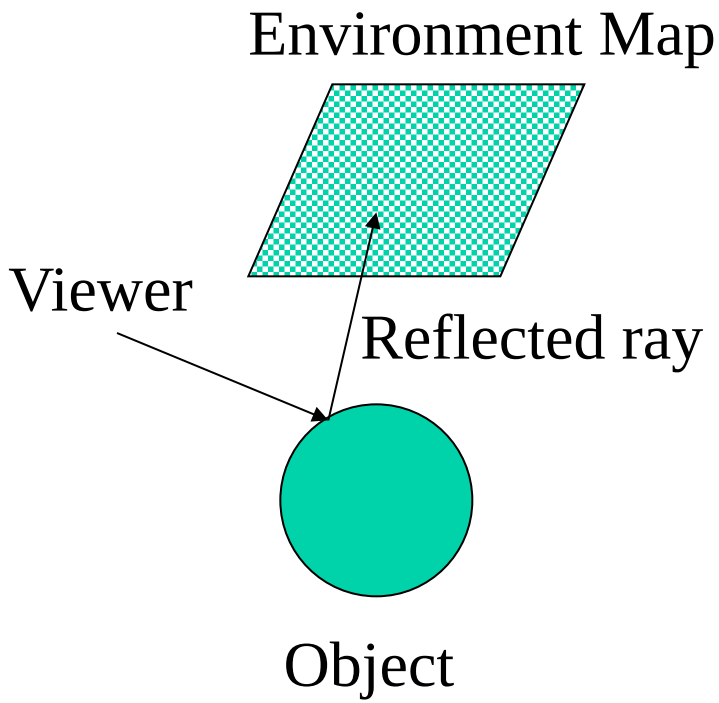


Displacement Mapping

- Bump mapping has a limitation on how much you can tweak
- If the desired amount of change is too large for bump mapping, can use displacement mapping.
- Actually go and modify the surface geometry, and re-calculate the normals
- Quite expensive

Environment Mapping

- Environment mapping produces reflections on shiny objects
- Texture is transferred in the direction of the reflected ray from the environment map onto the object
- Reflected ray: $\boldsymbol{R}=2(\boldsymbol{N}\cdot\boldsymbol{V})\boldsymbol{N}-\boldsymbol{V}$
- What is in the map?



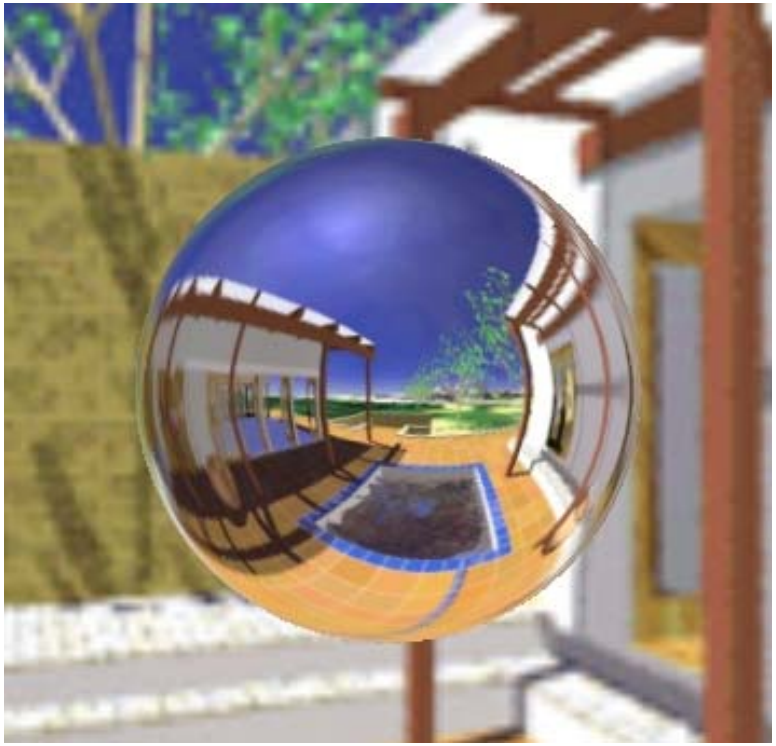
Approximations Made

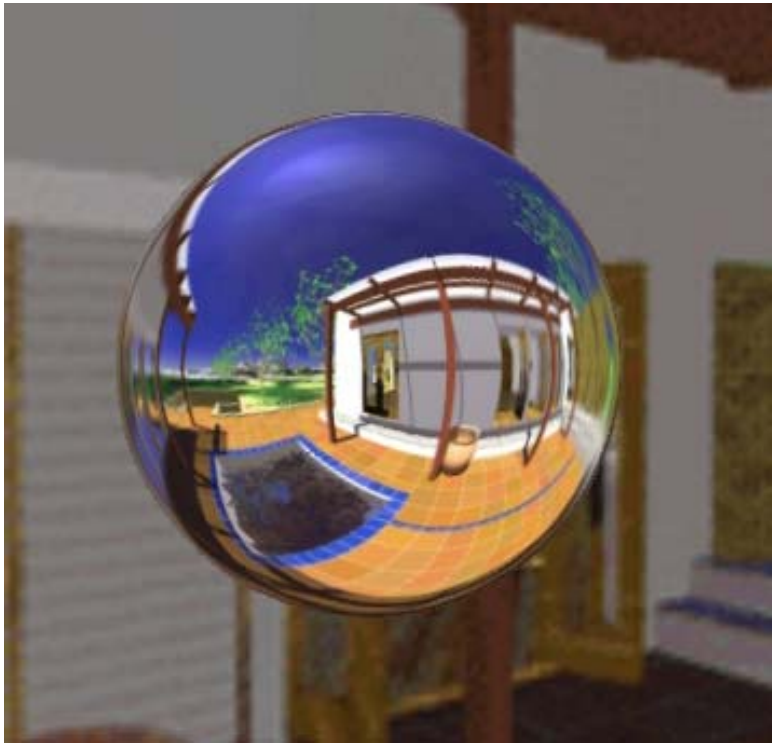
- The map should contain a view of the world with the point of interest on the object as the eye
  - We can’t store a separate map for each point, so one map is used with the eye at the center of the object
  - Introduces distortions in the reflection, but the eye doesn’t notice
  - Distortions are minimized for a small object in a large room
- The object will not reflect itself
- The mapping can be computed at each pixel, or only at the vertices

Environment Maps

- The environment map may take one of several forms:
  - Cubic mapping
  - Spherical mapping (two variants)
  - Parabolic mapping
- Describes the shape of the surface on which the map “resides”
- Determines how the map is generated and how it is indexed
- What are some of the issues in choosing the map?

Example

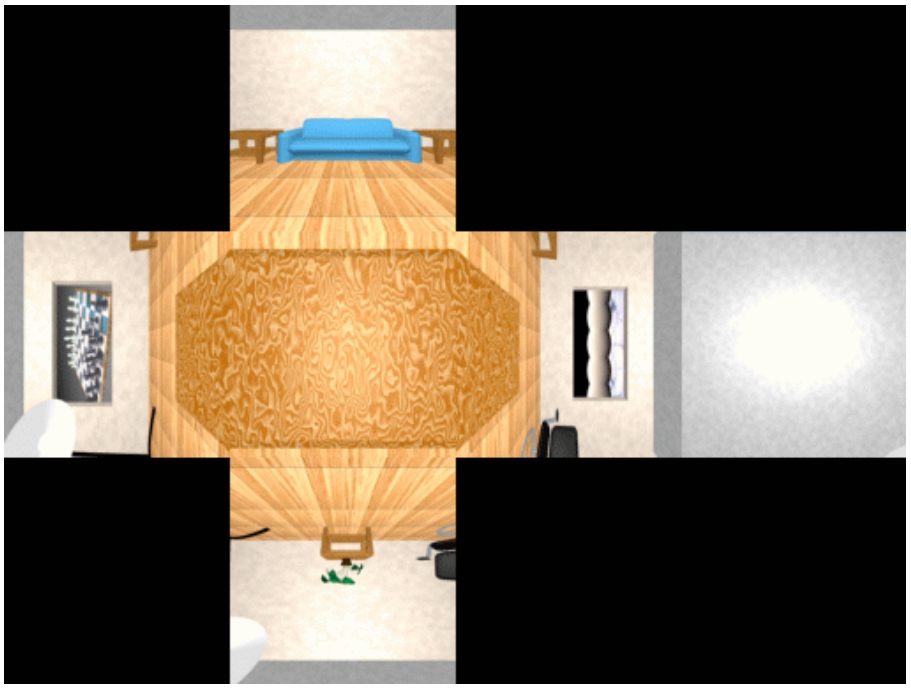




Cubic Mapping

- The map resides on the surfaces of a cube around the object
  - Typically, align the faces of the cube with the coordinate axes
- To generate the map:
  - For each face of the cube, render the world from the center of the object with the cube face as the image plane
    - Rendering can be arbitrarily complex (it's off-line)
  - Or, take 6 photos of a real environment with a camera in the object's position
    - Actually, take many more photos from different places the object might be
    - Warp them to approximate map for all intermediate points
- Remember *The Abyss* and *Terminator 2*?

Cubic Map Example



Indexing Cubic Maps

- Assume you have $\boldsymbol{R}$ and the cube's faces are aligned with the coordinate axes, and have texture coordinates in [0,1]x[0,1]
  - How do you decide which face to use?
  - How do you decide which texture coordinates to use?
- What is the problem using cubic maps when texture coordinates are only computed at vertices?

Lat/Long Mapping

- The original algorithm (1976) placed the map on a sphere centered on the object
- Mapping functions assume that *s*,*t* equate to latitude and longitude on the sphere:

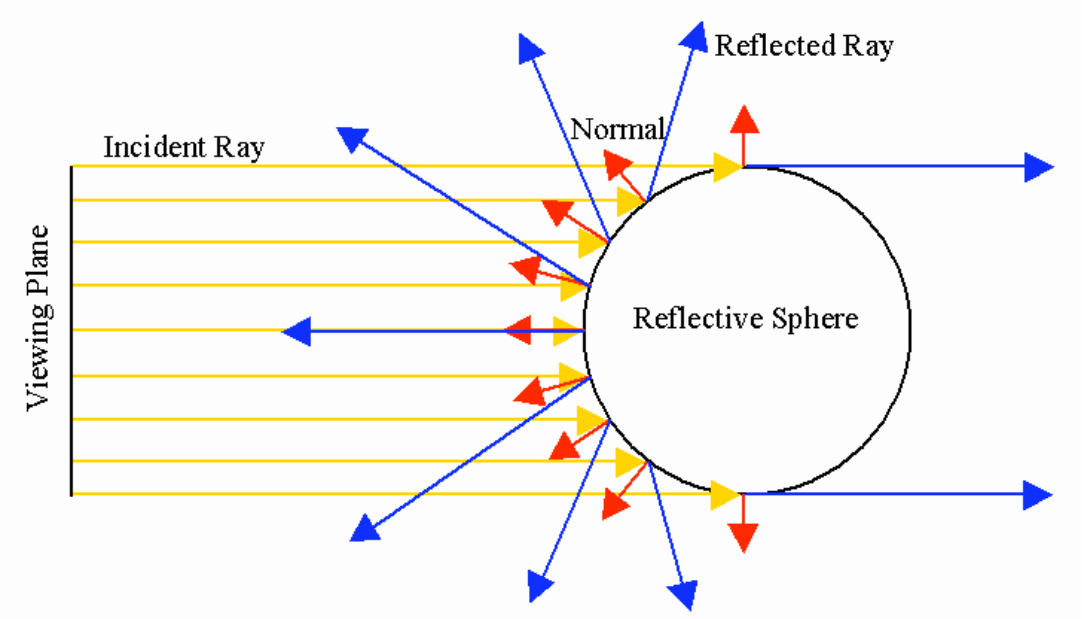
$$s = \frac{1}{2}\left(1 + \frac{1}{\pi}\tan^{-1}\left(\frac{\boldsymbol{R}_y}{\boldsymbol{R}_x}\right)\right), \qquad t = \frac{\boldsymbol{R}_z + 1}{2}$$

- What is bad about this method?
  - Sampling
  - Map generation
  - Complex texture coordinate computations

Sphere Mapping

- Again the map lives on a sphere, but now the coordinate mapping is simplified
- To generate the map:
  - Take a map point *(s,t)*, cast a ray onto a sphere in the ***-Z*** direction, and record what is reflected
  - Equivalent to photographing a reflective sphere with an orthographic camera (long lens, big distance)
    - Again, makes the method suitable for film special effects

A Sphere Map


Reflected Ray
Normal
Incident Ray
Viewing Plane
Reflective Sphere

Indexing Sphere Maps

- Given the reflection vector:

$$s = \frac{R_x}{m} + \frac{1}{2}, \quad t = \frac{R_y}{m} + \frac{1}{2}$$

$$m = 2\left(R_x^2 + R_y^2 + \left(R_z + 1\right)^2\right)^{1/2}$$

- Implemented in hardware
- Problems:
  - Highly non-uniform sampling
  - Highly non-linear mapping

Example

Parabolic Mapping

- Assume the map resides on a parabolic surface
  - Two surfaces, facing each other
- Improves on sphere maps:
  - Texture coordinate generation is a near linear process
  - Sampling is more uniform
  - Result is more view-independent
- However, requires multi-passes to implement, so not generally used

Partially Reflective Objects

- Use multi-texturing hardware
  - First stage applied color texture
  - Second stage does environment mapping using alpha blend with existing color