13. Texture Mapping

Texture mapping

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

Texture mapping ensures that “all the right things” happen as a textured polygon is transformed and rendered.

Non-parametric texture mapping

With “non-parametric texture mapping”:

- Texture size and orientation are fixed
- They are unrelated to size and orientation of polygon
- Gives cookie-cutter effect

Reading

Required

- Watt, intro to Chapter 8 and intros to 8.1, 8.4, 8.6, 8.8.

Recommended


Optional

- Watt, the rest of Chapter 8
- Woo, Neider, & Davis, Chapter 9
Parametric texture mapping

With “parametric texture mapping,” texture size and orientation are tied to the polygon.

Idea:

- Separate “texture space” and “screen space”
- Texture the polygon as before, but in texture space
- Deform (render) the textured polygon into screen space

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

Implementing texture mapping

A texture lives in its own image coordinates parameterized by \((u,v)\) in the range \(([0..1],[0..1])\):

It can be wrapped around many different surfaces:

Computing \((u,v)\) texture coordinates in a ray tracer is fairly straightforward.

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

Texture resampling

The texture is usually stored as an image.

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

Where:

\[
(u_0, v_0) = (i\Delta_x + a\Delta_x, j\Delta_y + b\Delta_y)
\]

\[
\Delta_x = 1/w_{\text{tex}}
\]

\[
\Delta_y = 1/h_{\text{tex}}
\]

To get the “in between” values, we need to resample the texture.

A common choice is bilinear resampling:

\[
T(u_0, v_0) = T(i\Delta_x + a\Delta_x, j\Delta_y + b\Delta_y)
\]

\[
= \frac{1}{T[i,j]} + \frac{1}{T[i+1,j]} + \frac{1}{T[i,j+1]} + \frac{1}{T[i+1,j+1]}
\]
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 if you want to do perspective right!

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)

Displacement mapping

Textures can be used for more than just color.

In displacement mapping, a texture is used to perturb the surface geometry itself:

\[
\tilde{Q}(u) = Q(u) + d(u)N(u)
\]

- These displacements “animate” with the surface

Q: Do you have to do hidden surface calculations on \( \tilde{Q} \)?
Bump mapping

In bump mapping, a texture is used to perturb the normal:
- Use the normal from the displacement map for shading:

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

\( Q(u) \): What artifacts in the images would reveal that bump mapping is a fake?

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Displacement vs. bump 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
- Really, a simplified form of ray tracing
- Environment mapping works well when there is just a single object – or in conjunction with ray tracing

Under simplifying assumptions, environment mapping can be implemented in hardware.

With a ray tracer, the concept is easily extended to handle refraction as well as reflection.
Combining texture maps

Using texture maps in combination gives even better effects, as Young Sherlock Holmes demonstrated ...

Construction of the glass knight, (Foley, IV-24)

Combining texture maps (cont’d)

Phong lighting with diffuse texture

Environment-mapped mirror reflection

Bump mapping + Glossy reflection

Combine textures and add dirt

Rivet stains + Shinier reflections

Close-up

Construction of the glass knight, (Foley, IV-24)

Antialiasing

If you point-sample the texture map, you get aliasing:

From Crow, SIGGRAPH ’84

Proper antialiasing requires area averaging in the texture:

From Crow, SIGGRAPH ’84

Computing the average color

The computationally difficult part is summing over the covered pixels.

Several methods have been used:

The simplest is brute force:

- Figure out which texels are covered and add up their colors to compute the average.
Mip maps

A faster method is **mip maps** developed by Lance Williams in 1983:
- Stands for "multum in parvo" – many things in a small place
- Keep textures prefiltered at multiple resolutions
- Has become the graphics hardware standard

Mip map pyramid

The mip map hierarchy can be thought of as an image pyramid:
- Level 0 (T0[i,j]) is the original image.
- Level 1 (T1[i,j]) averages over 2x2 neighborhoods of original.
- Level 2 (T2[i,j]) averages over 4x4 neighborhoods of original
- Level 3 (T3[i,j]) averages over 8x8 neighborhoods of original

What’s a fast way to pre-compute the texture map for each level?

Mip map resampling

What would the mip-map return for an average over a 5x5 neighborhood at location (u0,v0)?

How do we measure the fractional distance between levels?

What if you need to average over a non-square region?

Summed area tables

A more accurate method than mip maps is **summed area tables** invented by Frank Crow in 1984.

Recall from calculus:

\[
\int_a^b f(x)dx = \int_a^c f(x)dx - \int_c^b f(x)dx
\]

In discrete form:

\[
\sum_{i=k}^m f[i] = \sum_{i=0}^m f[i] - \sum_{i=0}^{k-1} f[i]
\]

Q: If we wanted to do this real fast, what might we pre-compute?
Summed area tables (cont’d)

We can extend this idea to 2D by creating a table, $S[i,j]$, that contains the sum of everything below and to the left.

![Summed area table diagram]

Q: How do we compute the average over a region from $(l, b)$ to $(r, t)$?

Characteristics:
- Requires more memory
- Gives less blurry textures

Comparison of techniques

Point sampled

MIP-mapped

Summed area table

From Crow, SIGGRAPH '84

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.
3. Understanding of the various approaches to antialiased texture mapping:
   - Brute force
   - Mip maps
   - Summed area tables