Texture Mapping

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Objectives

• Introduce Mapping Methods
  - Texture Mapping
  - Environment Mapping
  - Bump Mapping

• Consider basic strategies
  - Forward vs backward mapping
  - Point sampling vs area averaging
The Limits of Geometric Modeling

- Although graphics cards can render over 10 million polygons per second, that number is insufficient for many phenomena
  - Clouds
  - Grass
  - Terrain
  - Skin

Modeling an Orange

- Consider the problem of modeling an orange (the fruit)
- Start with an orange-colored sphere
  - Too simple
- Replace sphere with a more complex shape
  - Does not capture surface characteristics (small dimples)
  - Takes too many polygons to model all the dimples
Modeling an Orange (2)

• Take a picture of a real orange, scan it, and “paste” onto simple geometric model
  - This process is known as texture mapping
• Still might not be sufficient because resulting surface will be smooth
  - Need to change local shape
  - Bump mapping

Three Types of Mapping

• Texture Mapping
  - Uses images to fill inside of polygons

• Environment (reflection mapping)
  - Uses a picture of the environment for texture maps
  - Allows simulation of highly specular surfaces

• Bump mapping
  - Emulates altering normal vectors during the rendering process
Texture mapping

- Texture mapping: adding surface detail by mapping texture patterns to the surface
- Developed by Catmull (1974), Blinn and Newell (1976), and others

Texture Mapping

- Maps a pattern (texture) onto a surface
- Texels fill each pixel
- Texels selected from sample pattern (texture map)
- Pattern is repeated
Texture Maps

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Wallpaper, Analogue Texture Map

Flooring, Tiling, etc
Examples of Mapped Texture

Examples
Texture Mapping

generic model texture mapped

Environment Mapping

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Bump Mapping

Look at smooth silhouettes
Displacement Mapping

Where does mapping take place?

- Mapping techniques are implemented at the end of the rendering pipeline
  - Very efficient because few polygons make it past the clipper

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Is it simple?

- Although the idea is simple—map an image to a surface—there are 3 or 4 coordinate systems involved.

Coordinate Systems

- Parametric coordinates
  - May be used to model curves and surfaces
- Texture coordinates
  - Used to identify points in the image to be mapped
- Object or World Coordinates
  - Conceptually, where the mapping takes place
- Window Coordinates
  - Where the final image is really produced
Texture Mapping

Mapping Functions

- Basic problem is how to find the maps
- Consider mapping from texture coordinates to a point a surface
- Appear to need three functions
  \[ x = x(s,t) \]
  \[ y = y(s,t) \]
  \[ z = z(s,t) \]
- But we really want to go the other way
**Backward Mapping**

- We really want to go backwards
  - Given a texel, we want to know to which point on an object it corresponds
  - Given a point on an object, we want to know to which point in the texture it corresponds
- Need a map of the form
  
  \[ s = s(x,y,z) \]
  \[ t = t(x,y,z) \]
- Such functions are difficult to find in general

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**Basic Concept**

- Relate a 2D image to a 3D model
- *Texture coordinates*
  - Texture coordinate is a 2D coordinate \((s,t)\) which maps to a location on a texture map
- Texture coordinates are over the interval \([0,1]\), typically
Elements of Texture Mapping

- Texture source function (can be 3D)
- Inverse map:
  \[ \text{Texture}(s,t) \leftarrow \text{Surface}(x(s,t), y(s,t), z(s,t)) \]
- Typical texture sources
  - Procedure
  - Tabular data (texture map)

Texture Mapping Techniques

- 2D texture mapping: *paint 2D pattern* onto the surface
- *Environmental* (reflection) *mapping*
- *Bump mapping*: perturb surface normals to fool shading algorithms
- Procedural texture mapping, 3D texture
Make a nice can of soup?

\[ \begin{align*}
\text{Campbell's} & \quad \text{TOMATO} \\
\text{SOUP} & \quad + \\
\text{Andrea's} & \quad \text{SOUP}
\end{align*} \]
Cylindrical Mapping

parametric cylinder   explicit cylinder

\[
\begin{align*}
  x &= r \cos 2\pi u \\
  y &= r \sin 2\pi u \\
  z &= hv
\end{align*}
\]

maps rectangle in u,v space to cylinder of radius \(\theta\) and height \(h\) in world coordinates

\[
\begin{align*}
  s &= u \\
  t &= v
\end{align*}
\]

maps from texture space
Cylindrical Mapping

parametric cylinder  explicit cylinder

\[
\begin{align*}
    x &= r \cos 2\pi u & x &= r \cos 2\pi \\
    y &= r \sin 2\pi u & y &= r \sin 2\pi \\
    z &= hv & z &= h
\end{align*}
\]

maps rectangle in u,v space to cylinder of radius \( \theta \) and height \( h \) in world coordinates

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\begin{align*}
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maps from texture space
Cylindrical Mapping

parametric cylinder   explicit cylinder

\[ x = r \cos 2\pi u \quad x = r \cos 2\pi \]
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\[ z = hv \quad z = h \]

maps rectangle in u,v space to cylinder of radius \( \theta \) and height \( h \) in world coordinates

\[ s = u \]
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maps from texture space
Cylindrical Mapping

<table>
<thead>
<tr>
<th>parametric cylinder</th>
<th>explicit cylinder</th>
</tr>
</thead>
<tbody>
<tr>
<td>( x = r \cos 2\pi u )</td>
<td>( x = r \cos 2\pi )</td>
</tr>
<tr>
<td>( y = r \sin 2\pi u )</td>
<td>( y = r \sin 2\pi )</td>
</tr>
<tr>
<td>( z = hv )</td>
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</tr>
</tbody>
</table>

maps rectangle in \( u,v \) space to cylinder of radius \( \theta \) and height \( h \) in world coordinates

\( s = u \)
\( t = v \)

maps from texture space
Spherical Map

We can use a parametric sphere

\[x = r \cos 2\pi u\]
\[y = r \sin 2\pi u \cos 2\pi v\]
\[z = r \sin 2\pi u \sin 2\pi v\]

in a similar manner to the cylinder but have to decide where to put the distortion

Spheres are used in environmental maps
Box Mapping

- Easy to use with simple orthographic projection
- Also used in environment maps

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Gerri’s Game
Texture Mapping

What if we don’t have a cylinder or sphere?

Two-part mapping

- One solution to the mapping problem is to first map the texture to a simple intermediate surface
- Example: map to cylinder
Two-part mapping

• One solution to the mapping problem is to first map the texture to a simple intermediate surface
• Example: map to cylinder

Second Mapping

• Map from intermediate object to actual object
  - Normals from intermediate to actual
  - Normals from actual to intermediate
  - Vectors from center of intermediate
More Examples

Texture Mapping, Paul Bourke (1987)

http://astronomy.swin.edu.au/~pbourke/texture/texturing

Aliasing

- Point sampling of the texture can lead to aliasing errors

Point samples in u,v (or x,y,z) space

Point samples in texture space
Area Averaging

A better but slower option is to use area averaging.

Note that preimage of pixel is curved.