Textures

Images courtesy, Foley, van Dam, Feiner, Hughes

Textures

- Introduced by Catmull in 1974
- Simulate Surface Detail / Micro Geometry
- Initially, map images to geometry
- Now generalization to bumps, normals, displacements, environments, volumes, …

Texture Mapping

Texture Space (u, v)

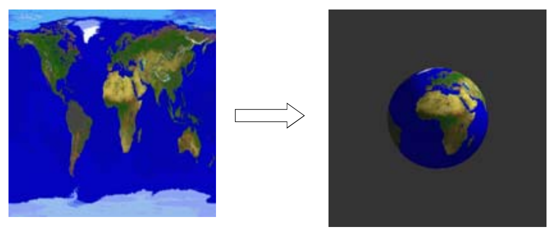
↓

Object Space (x, y, z)

↓

Screen Space (x_s, y_s, z_s)

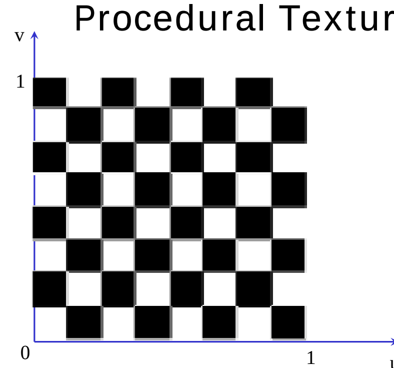
Texture Image



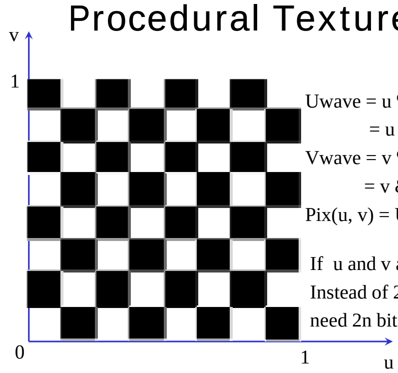
Texture Image

Courtesy, http://titan.spaceports.com/~seymor

Procedural Texture



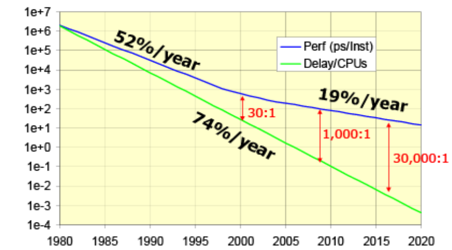
Procedural Texture



Uwave = u % 2
= u & 0x01
Vwave = v % 2
= v & 0x01
Pix(u, v) = Uwave⊕Vwave

If u and v are n bits each,
Instead of 2^{2n} bits we only need 2n bits + code

Capability Gap



Graph courtesy of Bill Dally

Texture Mapping

- Back to the problem of mapping label to a Can
- For now, let the Can be represented by a cylinder

Parametric Equation of a Cylinder:
$x = r\cos\theta,\ y = r\sin\theta,\ z = h,\ 0 \le h \le H,\ 0 \le \theta \le 2\pi$

Let $u = \theta / 2\pi,\ v = h/H,\quad 0 \le u, v \le 1$
$x = r\cos 2\pi u,\ y = r\sin 2\pi u,\ z = Hv$

Texture Mapping

From the previous equations:
$u = \tan^{-1}(y/x)$
$v = z/H$

So given object-space (x, y, z), we can find (u, v).
We then look up color at (u, v) and place it at (x_s, y_s, z_s)

General Texture Mapping

- In general, need a 2D parameterization of a 3D surface
  - Trivial for some objects: sphere, cylinder, cone, cube, …
  - Difficult for most objects
- Current schemes involve :
  - Two-stage mapping
  - Converting a 3D surface into an atlas of different parameterizations

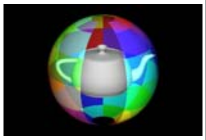
Two-Stage Texture Mapping

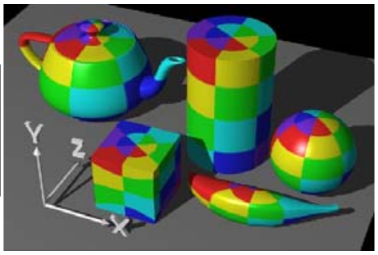
- Introduced by Bier and Sloan (1986)
- *S-Map*: Map from 2D texture space to an intermediate 3D surface (cylinder, sphere, cube, …)

  $T(u, v) \rightarrow S(r, \theta, \phi)$
- *O-Map*: Map from 3D intermediate space to 3D object:

  $S(r, \theta, \phi) \rightarrow O(x, y, z)$

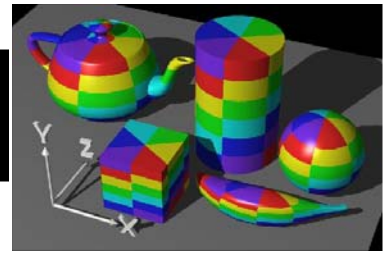
Spherical Mapping





Images courtesy, David Ebert, Purdue

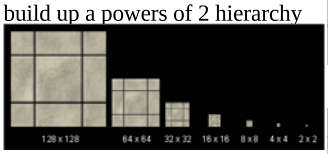
Cylindrical Mapping



Images courtesy, David Ebert, Purdue

Pre-Filtering

- What if one screen-space pixel corresponds to multiple texture image pixels (texels)?
- Do successive averaging to build up a powers of 2 hierarchy (MIP-map) and index at the right scale factor into this hierarchy.

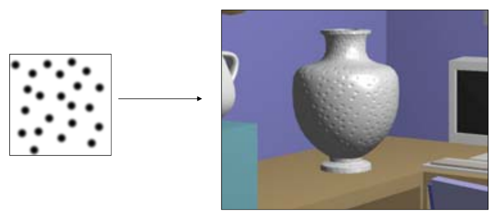


Without MIP-mapping

With MIP-mapping

Bump Mapping

- Introduced by Blinn (1978)

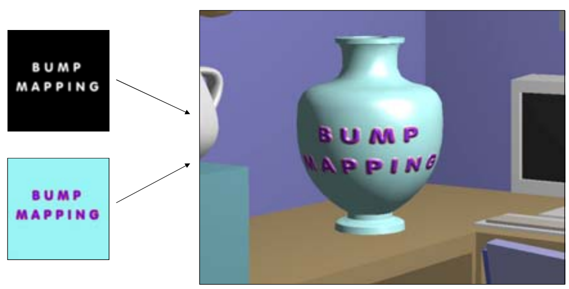


Images courtesy, Alan Watt, *3D Computer Graphics*

Procedural Bump Mapping

Images courtesy, Alan Watt, *3D Computer Graphics*

Bump & Texture Mapping



Images courtesy, Alan Watt, *3D Computer Graphics*

Bump Mapping

- Consider a surface $\boldsymbol{P}(u, v)$
- Its normal is given by: $\boldsymbol{N} = \boldsymbol{P}_u \times \boldsymbol{P}_v$
- Perturb the surface by a bump map function B(u, v) along its normals: $\boldsymbol{Q}(u, v) = \boldsymbol{P}(u, v) + B(u, v)\,\boldsymbol{N}$
- Now compute and use the perturbed normal for illumination :

$$\boldsymbol{N'} = \boldsymbol{Q}_u \times \boldsymbol{Q}_v = \boldsymbol{N} + B_u\boldsymbol{N} \times \boldsymbol{P}_v - B_v\boldsymbol{N} \times \boldsymbol{P}_u$$

Normal Mapping

- Similar to bump mapping, except normals are directly specified instead of the bump map function
- Similar generalizations exist for Phong shading using texture mapping

Environment Mapping

- Introduced by Blinn & Newell (1976) as *reflection mapping*
- Compute the reflection vector at each mesh vertex:

  $\mathbf{R} = 2(\mathbf{N}.\mathbf{V})\mathbf{N} - \mathbf{V}$
- Interpolate the reflection vector across the triangle
- Modern GPUs provide hardware *cube-maps* for this
- Use the reflection vectors to index into the environment (texture) map

Environment Mapping

- Index into texture map not by (u, v) but by reflection rays

Image by Jim Blinn via debevec.org

Image by Aravind Kalaiah & Amitabh Varshney

Displacement Mapping

- In contrast to Bump Mapping, the actual geometry is displaced here
- The surface as well as silhouettes appear non-smooth
- Presents a challenge for deferred shading systems (when shading is performed after visibility)

Image courtesy SIGGRAPH Education Materials
Rendered by Pixar Renderman

Displacement Mapping

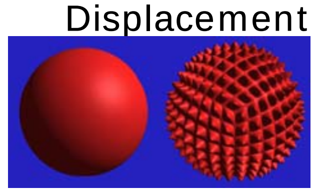
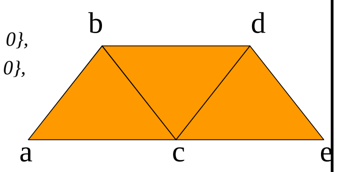


Image by Michael Capps (NPS)

Image by Wang *et al.* (SIGGRAPH 2003)

Direct Mesh Representation

Let $a = \{0, 0, 0\}$, $b = \{1, 1, 0\}$,
$c = \{2, 0, 0\}$, $d = \{3, 1, 0\}$,
$e = \{4, 0, 0\}$



Simplest File Format

t 3 // # triangles = 3
0, 0, 0, 1, 1, 0, 2, 0, 0 // abc
1, 1, 0, 2, 0, 0, 3, 1, 0 // bcd
2, 0, 0, 3, 1, 0, 4, 0, 0 // cde

Slide 25 Lecture 4

Direct Mesh Representation

More Generally:

f n // # faces = n
$i_1\ x_{11}\ y_{11}\ z_{11}\ x_{12}\ y_{12}\ z_{12} \ldots x_{1i_1}\ y_{1i_1}\ z_{1i_1}$ *// first face has* i_1 *vertices*
$i_2\ x_{21}\ y_{21}\ z_{21}\ x_{22}\ y_{22}\ z_{22} \ldots x_{2i_2}\ y_{2i_2}\ z_{2i_2}$ *// second face has* i_2 *vertices*
…
…
…
$i_n\ x_{n1}\ y_{n1}\ z_{n1}\ x_{n2}\ y_{n2}\ z_{n2} \ldots x_{ni_n}\ y_{ni_n}\ z_{ni_n}$ *//* n^{th} *face has* i_n *vertices*

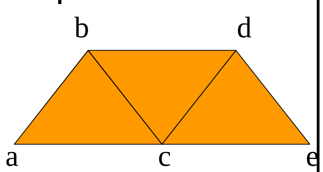
For vertices with colors, normals etc:

$i_1\ x_{11}\ y_{11}\ z_{11}\ r_{11}\ g_{11}\ b_{11}\ nx_{11}\ ny_{11}\ nz_{11}$
$x_{12}\ y_{12}\ z_{12}\ r_{12}\ g_{12}\ b_{12}\ nx_{12}\ ny_{12}\ nz_{12} \ldots$
$x_{1i_1}\ y_{1i_1}\ z_{1i_1}\ r_{1i_1}\ g_{1i_1}\ b_{1i_1}\ nx_{1i_1}\ ny_{1i_1}\ nz_{1i_1}$

Slide 26 Lecture 4

Indexed Mesh Representation

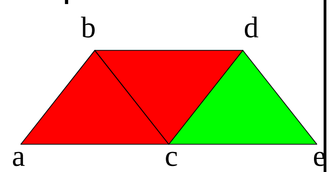
v 5 // #vertices = 5
0 0 0
1 1 0
2 0 0
3 1 0
4 0 0
t 3 // # triangles = 3
0 1 2 // abc
1 2 3 // bcd
2 3 4 // cde



Slide 27 Lecture 4

Indexed Mesh Representation

v 5 // #vertices = 5
0 0 0
1 1 0
2 0 0
3 1 0
4 0 0
c 2 // # colors = 2
255 0 0 // red in byte rep
0 255 0 // green in byte rep
t 3 // # triangles = 3
0 0 1 0 2 0 // abc
1 0 2 0 3 0// bcd
2 1 3 1 4 1// cde



Slide 28 Lecture 4

Indexed Mesh Representation

v 5 // #vertices = 5
0 0 0
1 1 0
2 0 0
3 1 0
4 0 0
c 2 // # colors = 2
255 0 0 // red in byte rep
0 255 0 // green in byte rep
t 3 // # triangles = 3
0 0 1 0 2 0 // abc
1 0 2 0 3 0// bcd
2 1 3 1 4 1// cde

- File format consists of a *Vertex Array*, *Color Array*, *Normal Array*, … and a *Face Array* with indices pointing to the above arrays.
- Indexed face sets used in numerous file formats including VRML/X3D, Wavefront OBJ, …

Slide 29 Lecture 4