# Texture Mapping

CSE 457, Autumn 2003

Graphics

http://www.cs.washington.edu/education/courses/457/03au/

# Readings and References

## Readings

- Intro to Chapter 8 and intros to 8.1, 8.4, 8.6, 8.8*, 3D Computer Graphics*, Watt

## Other References

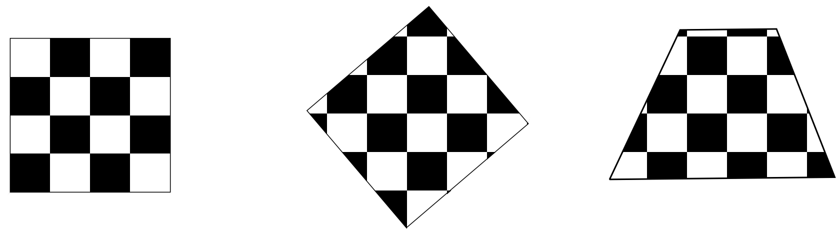
- Watt, the rest of Chapter 8
- *Survey of Texture Mapping*, Paul S. Heckbert, IEEE Computer Graphics and Applications, Nov 1986, pp 56-67
- *Texture and reflection in computer generated images.* James F. Blinn and Martin E. Newell. Communications of the ACM 19(10): 542--547, October 1976.

# 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.

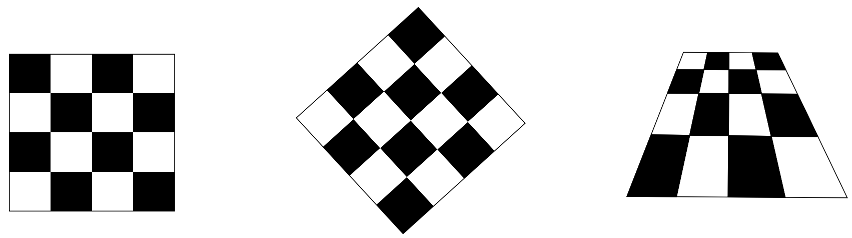
*Texture mapping (Woo et al., fig. 9-1)*

# 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

# Parametric texture mapping

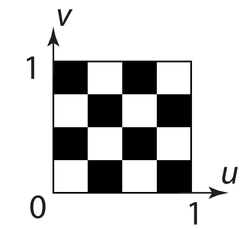


- With “parametric texture mapping,” texture size and orientation are tied to the polygon.
- Idea:
  - » Separate “texture space” and “screen space”
  - » Texture the polygon as before, but in texture space
  - » Deform (render) the textured polygon into screen space

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

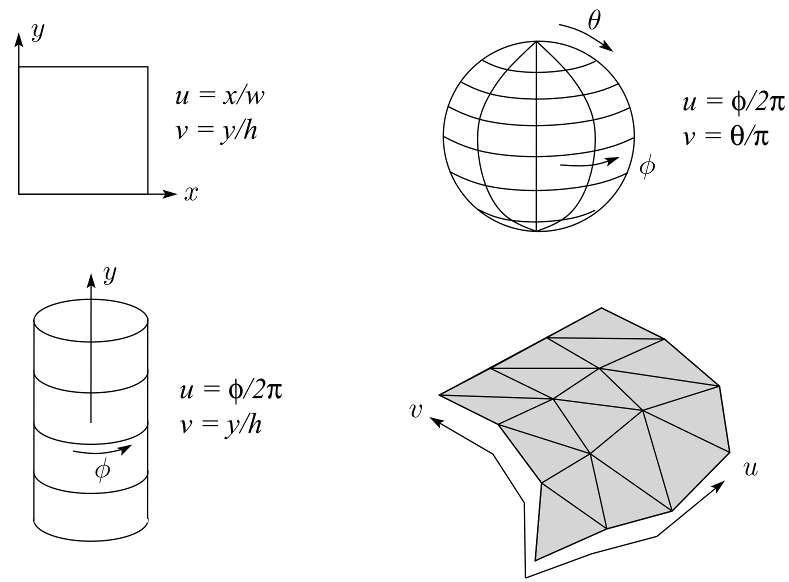
# Implementing texture mapping

- A texture lives in it own abstract image coordinates parameterized by (*u,v*) in the range ([0..1], [0..1]):




- It can be wrapped around many different surfaces

- If the surface moves/deforms, the texture goes with it.



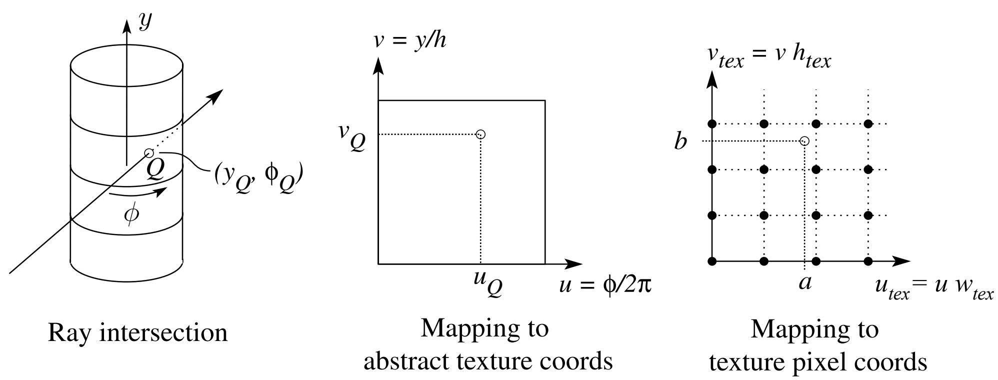
# Mapping to texture image coords

The texture is usually stored as an image. Thus, we need to convert from abstract texture coordinates:

$(u,v)$ in the range ([0..1], [0..1])

to texture image coordinates:

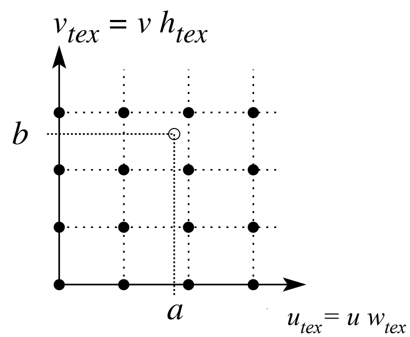
$(u_{tex}, v_{tex})$ in the range ([0.. $w_{tex}$], [0.. $h_{tex}$ ])



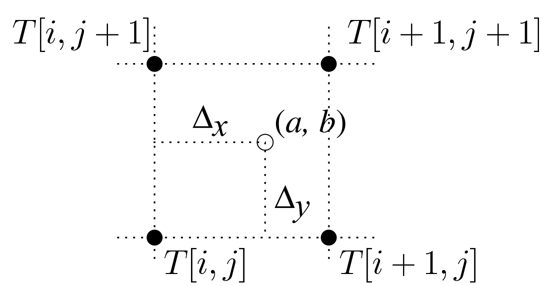

**Q**: What do you do when the texture sample you need lands between texture pixels?

# Texture resampling

To get the "in between" values, we need to **resample** the texture.




Mapping to
texture pixel coords



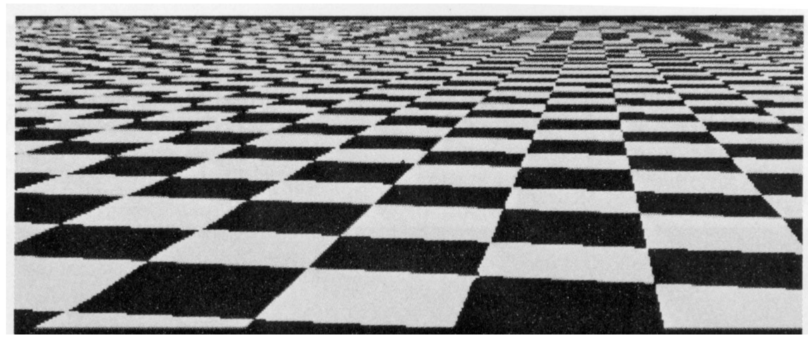

Close-up

A common choice is **bilinear interpolation**:

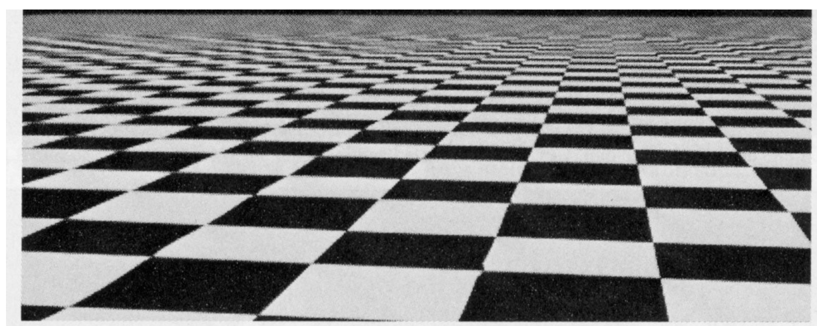
$$
\begin{aligned}
T(a,b) &= T\left(i+\Delta_x, j+\Delta_y\right) \\
&= \underline{\qquad\qquad} T[i,j] \;+ \\
&\quad\; \underline{\qquad\qquad} T[i+1,j] \;+ \\
&\quad\; \underline{\qquad\qquad} T[i,j+1] \;+ \\
&\quad\; \underline{\qquad\qquad} T[i+1,j+1]
\end{aligned}
$$

# Antialiasing

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



Proper antialiasing requires area averaging in the texture:



*From Crow, SIGGRAPH '84*

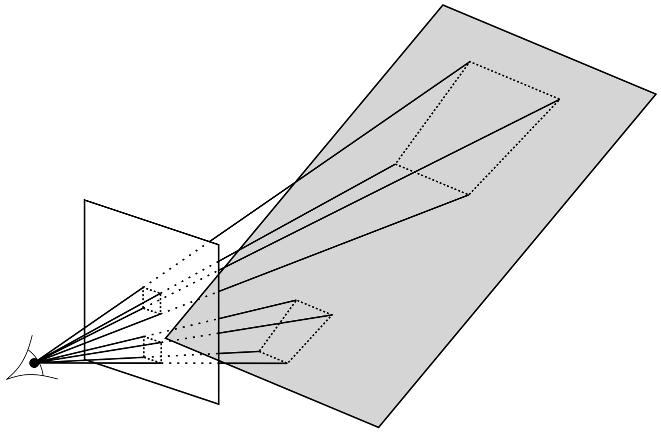
# Computing the average color

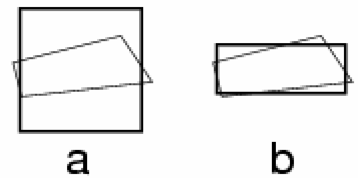
The computationally difficult part is summing over the covered pixels.

Several methods have been used:

The simplest is **brute force**:

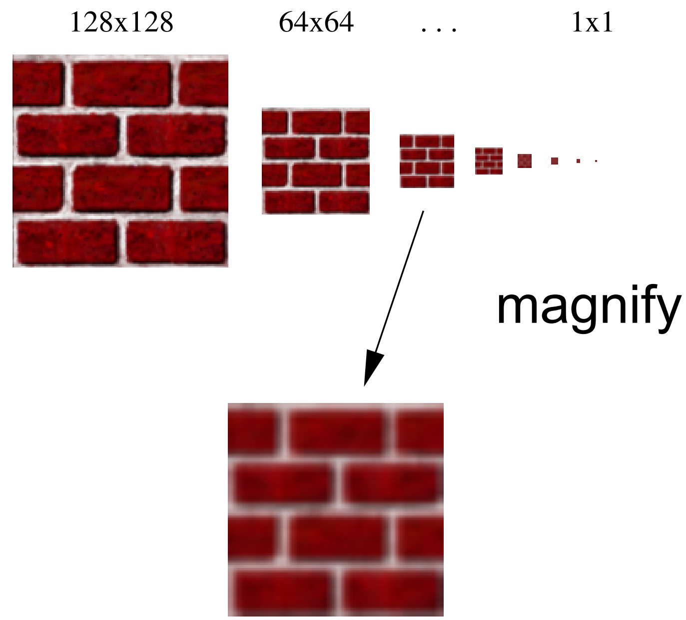
- Figure out which texels are covered and add up their colors to compute the average.






Approximating a quadrilateral texture area with (a) a square, (b) a rectangle. Too small an area causes aliasing; too large an area causes blurring. After Heckbert 86.

# Mip maps

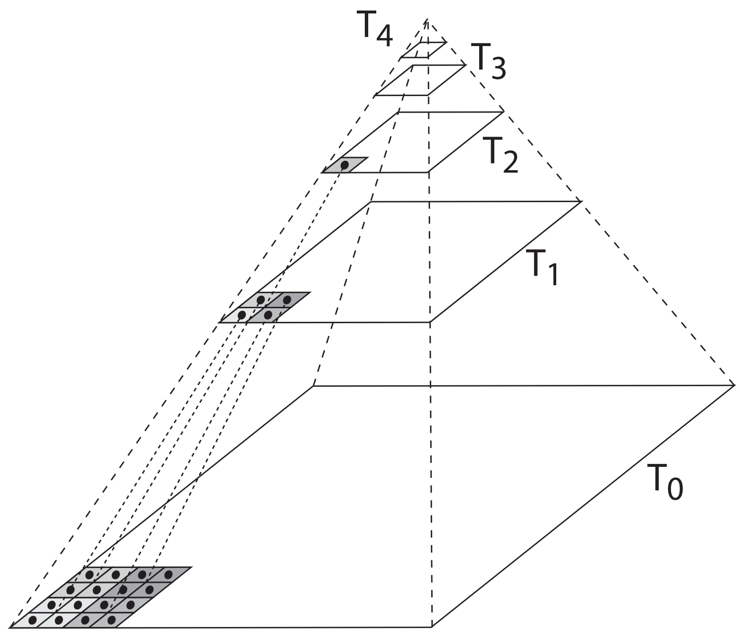



A faster method is **mip maps** developed by Lance Williams (1983)

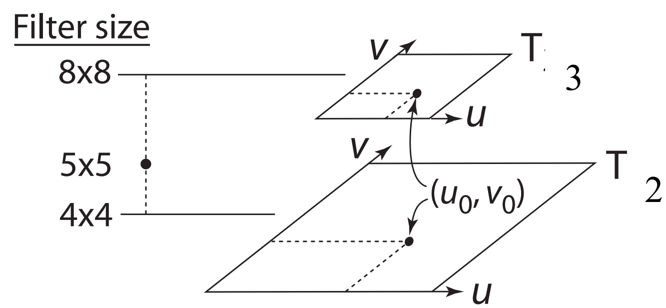
- » Stands for "multum in parvo" – many things in a small place
- » Keep textures prefiltered at multiple resolutions
- » Has become the graphics hardware standard

# Mip map pyramid

- The mip map hierarchy can be thought of as an image pyramid:
  - » Level 0 ($T_0$[i,j]) is the original image.
  - » Level 1 ($T_1$[i,j]) averages over 2x2 neighborhoods of original.
  - » Level 2 ($T_2$[i,j]) averages over 4x4 neighborhoods of original
  - » Level 3 ($T_3$[i,j]) averages over 8x8 neighborhoods of original



# Mip map resampling




- What would the mip-map return for an average over a 5x5 neighborhood at location $(u_0,v_0)$?

# Summed area tables

A more accurate method than mip maps is **summed area tables** invented by Frank Crow (1984). Rectangles vs squares.

Recall from calculus:

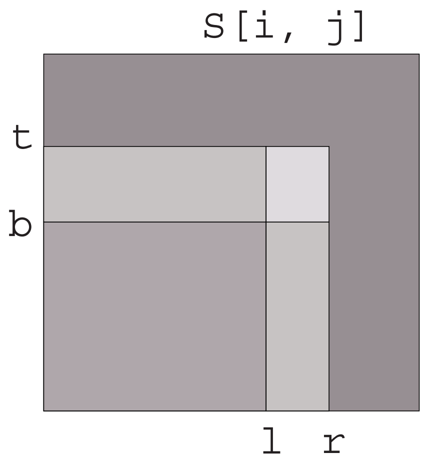
$$\int_a^b f(x)dx = \int_{-\infty}^{b} f(x)dx - \int_{-\infty}^{a} f(x)dx$$

In discrete form:

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

# 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.




**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

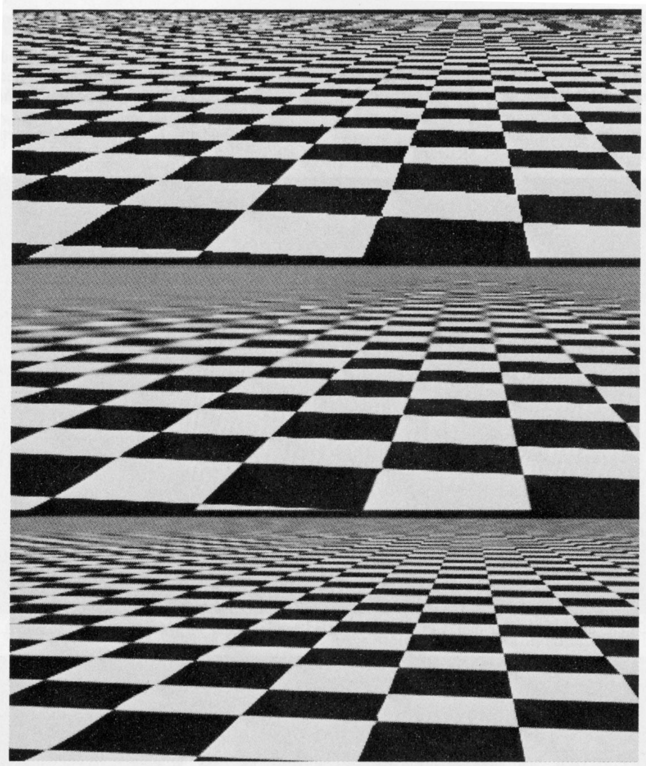
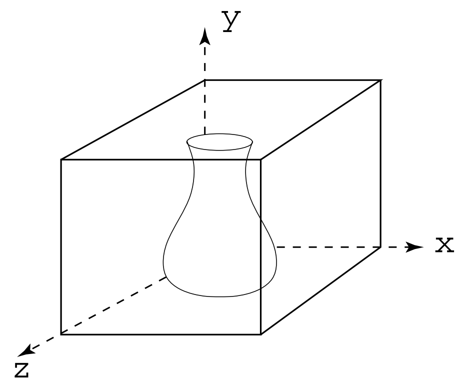


Figure 5: CheckerBoards mapped onto a square showing vertically compressed texture.

*From Crow, SIGGRAPH '84*

# Solid textures

- **Q**: What kinds of artifacts might you see from using a marble veneer instead of solid 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.

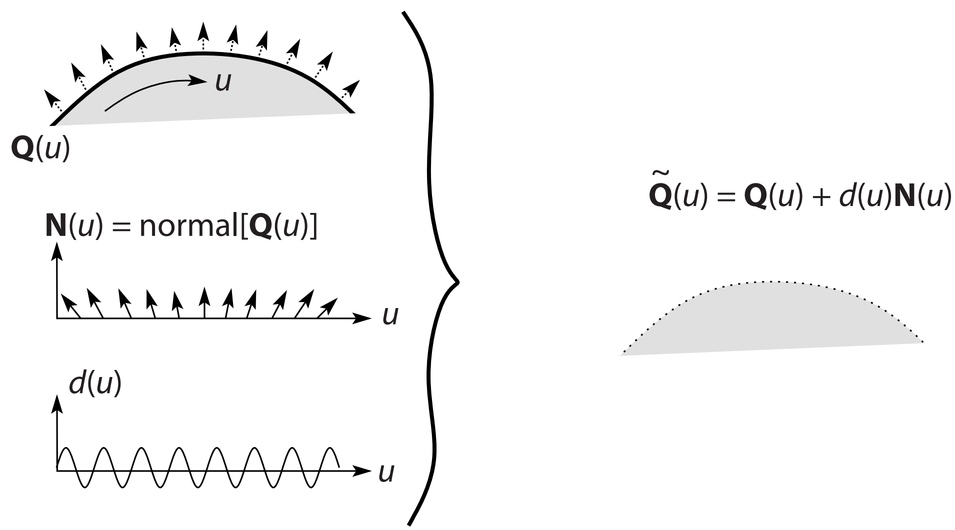
# Solid textures (cont'd)

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:




  » These displacements "animate" with the surface

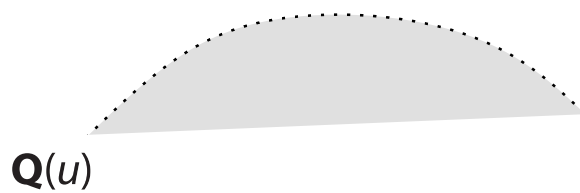
**Q**: Do you have to do hidden surface calculations on $\tilde{\mathbf{Q}}$?

# Bump mapping

In **bump mapping**, a texture is used to perturb the normal:

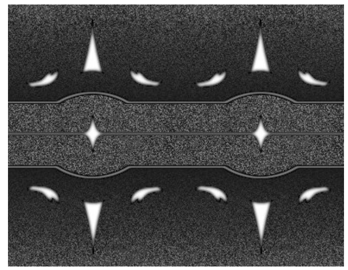
- Use the original, simpler geometry, $\mathbf{Q}(u)$, for hidden surfaces
- Use the normal from the displacement map for shading:

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

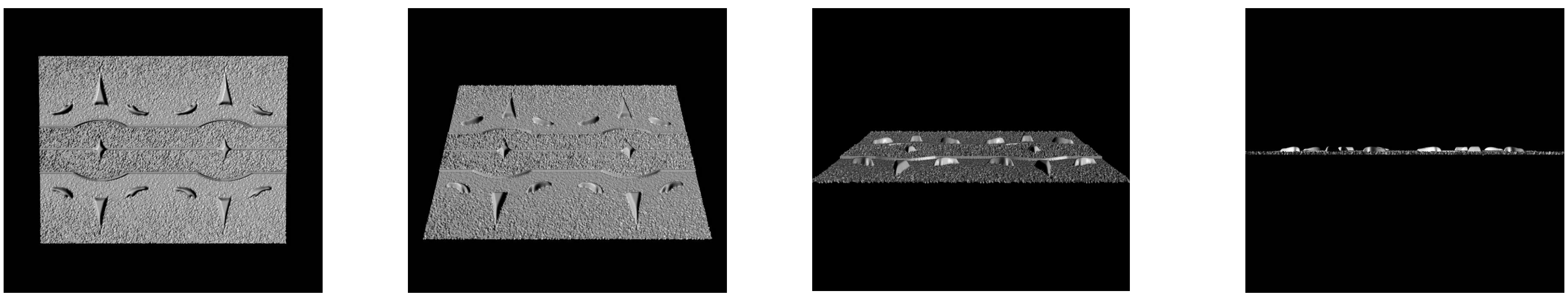



**Q**: What artifacts in the images would reveal that bump mapping is a fake?

# Displacement vs. bump mapping



Input texture



Rendered as displacement map over a rectangular surface

# Displacement vs. bump mapping

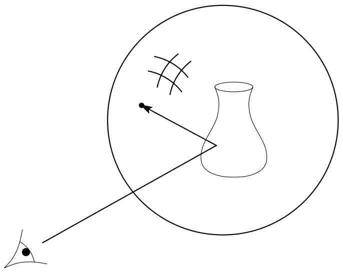
Original rendering

Rendering with bump map wrapped around a cylinder

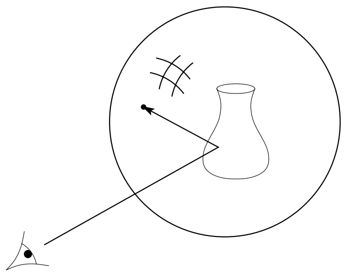
*Bump map and rendering by Wyvern Aldinger*

# Environment 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.

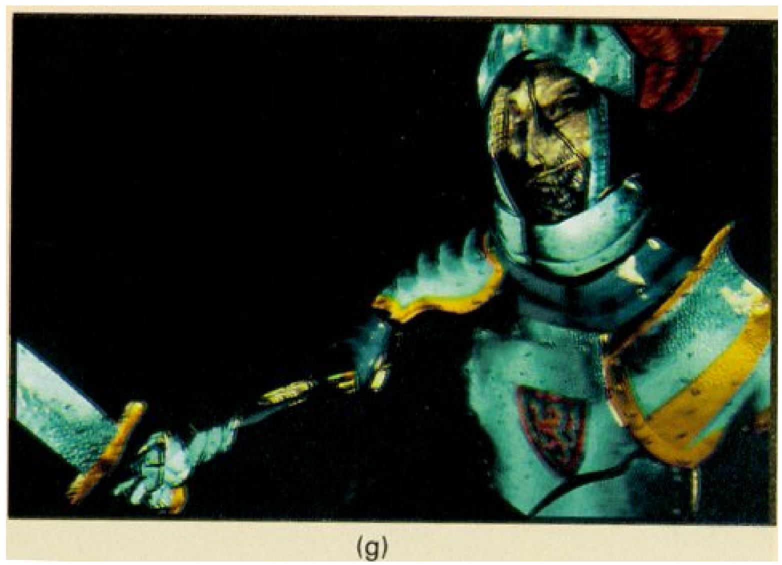


# Environment mapping example



# Combining texture maps

- Using texture maps in combination gives even better effects, as in *Young Sherlock Holmes* …




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

# Combining texture maps (cont'd)

Phong lighting with diffuse texture

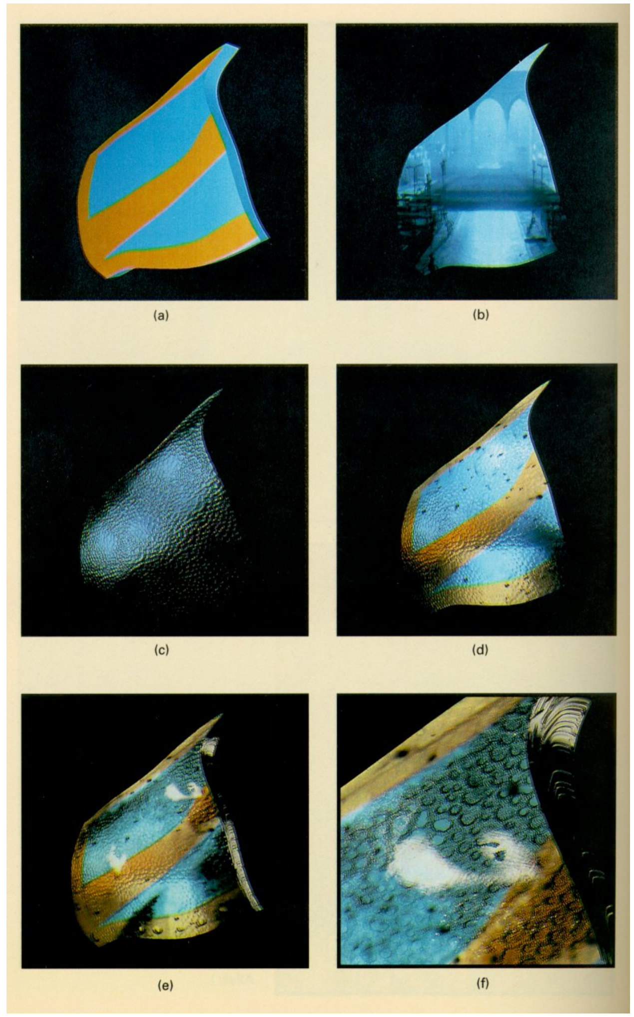
Environment-mapped mirror reflection

Bump mapping + Glossy reflection

Combine textures and add dirt

Rivet stains + Shinier reflections

Close-up




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

# Summary

- What to take home from this lecture:
- The meaning of the boldfaced terms.
- Familiarity with the various kinds of texture mapping, including their strengths and limitations.
- Understanding of the various approaches to antialiased texture mapping:
  - » Brute force
  - » Mip maps
  - » Summed area tables