Slide Credit: Don Fussell

CS354 Computer Graphics
Texture Mapping

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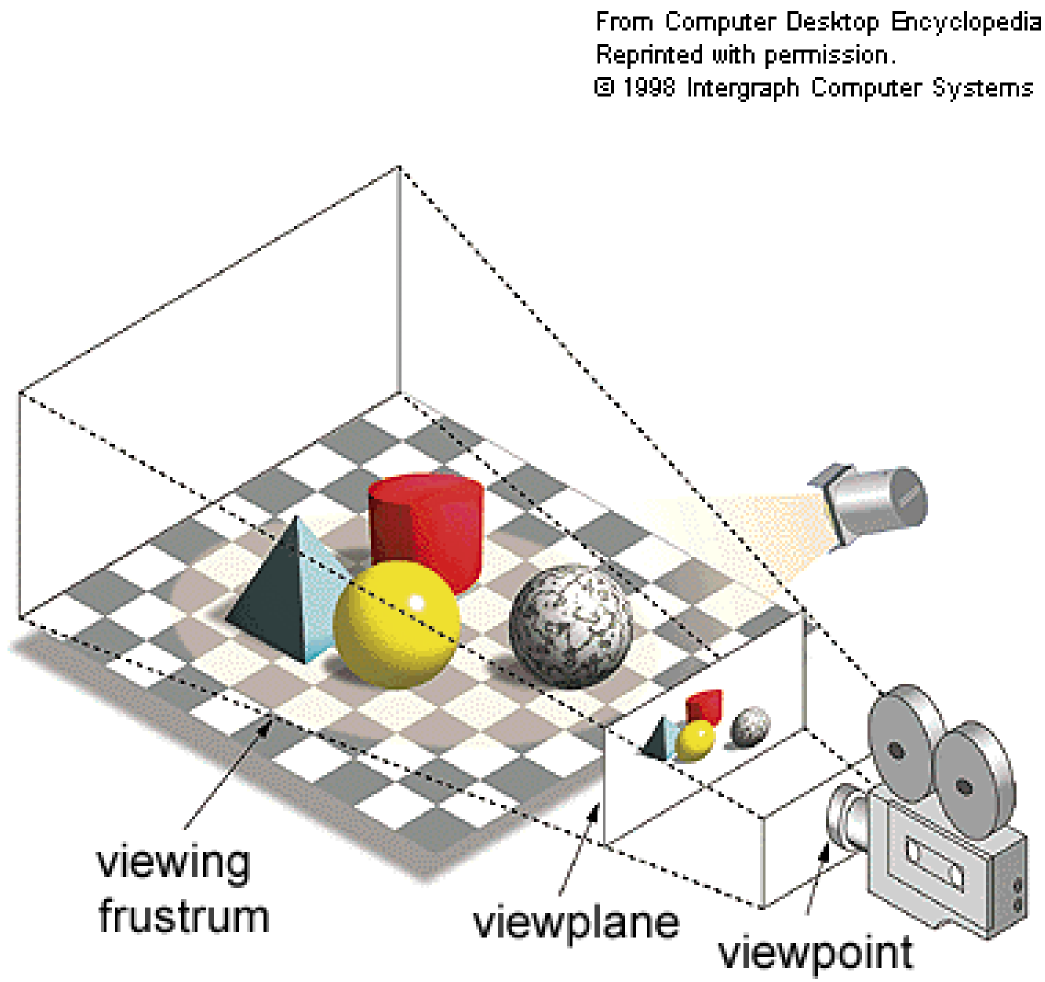
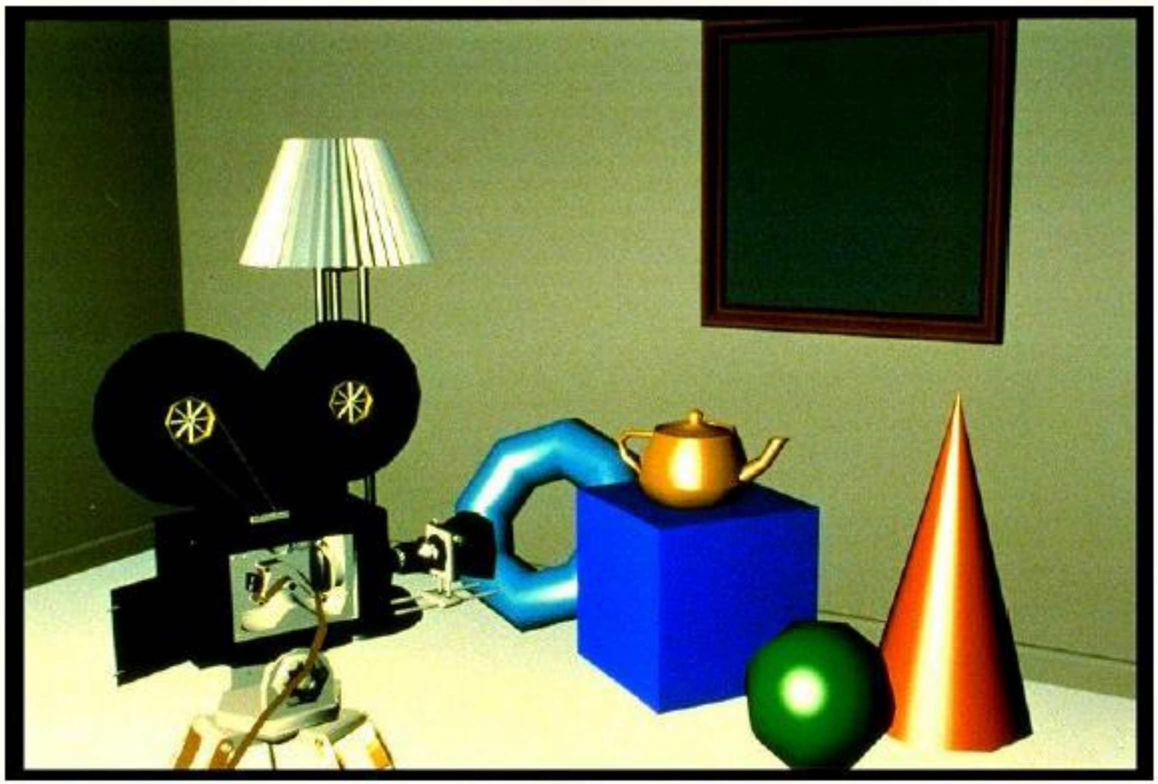
Graphics Pipeline



What adds visual realism?

Geometry Only

What adds visual realism?

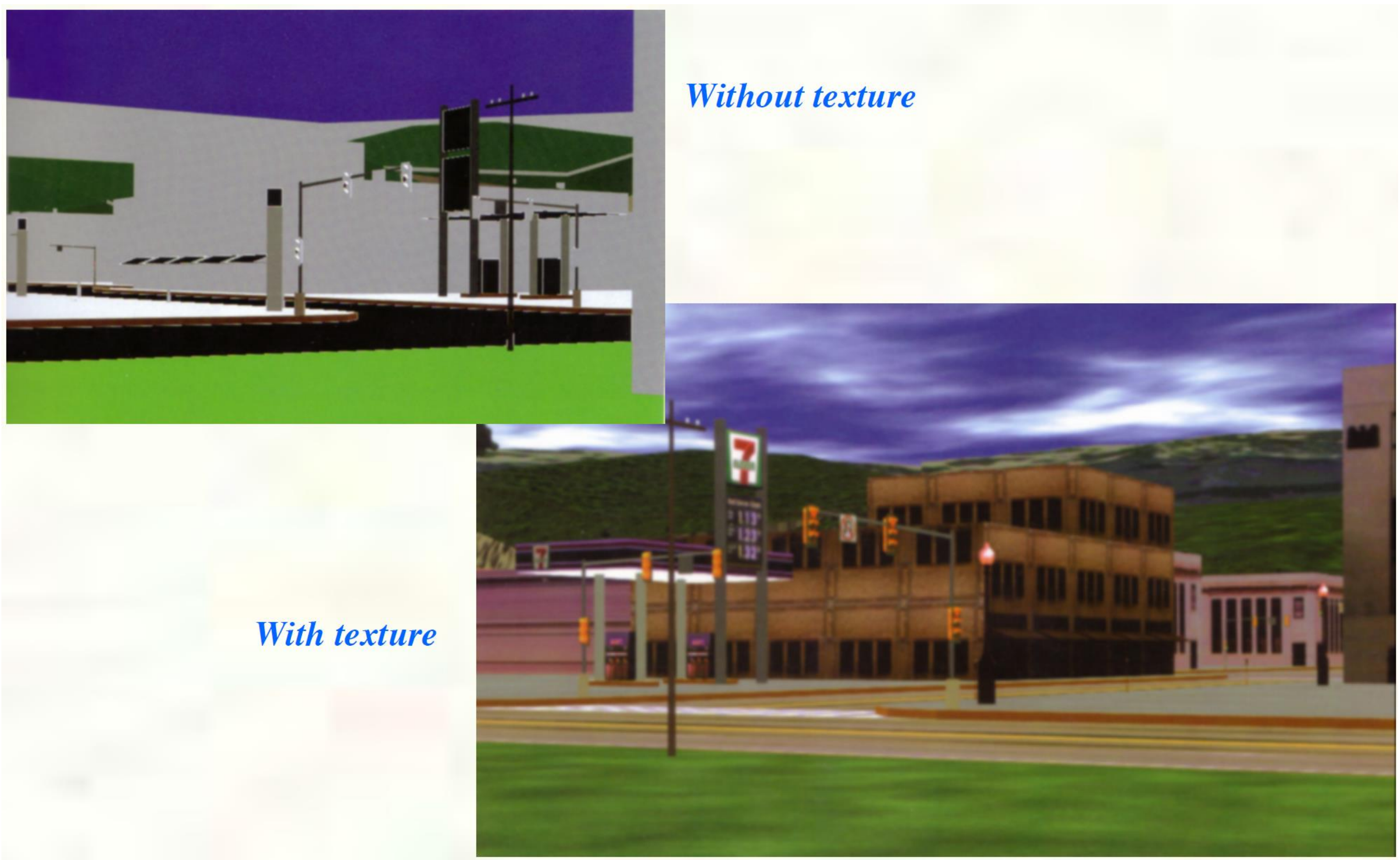


Phong Shading

What adds visual realism?

Phong shading + Texture Maps

Textures Supply Rendering Detail



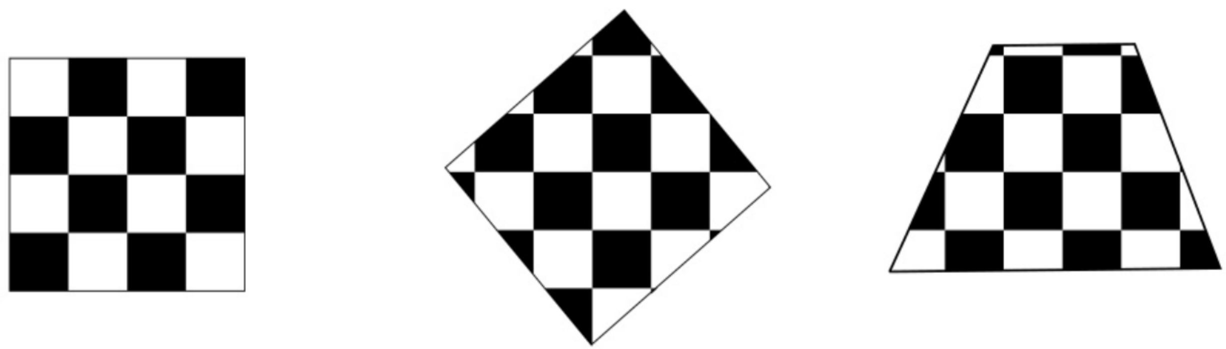
Textures Make Graphics Pretty

Texture Mapping

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

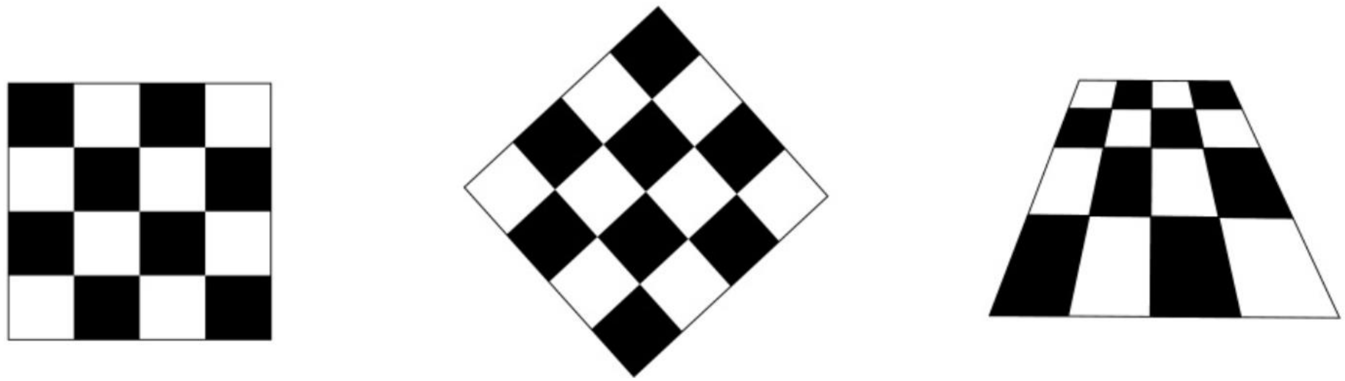
- Texture mapping allows you to take a simple polygon and give it the appearance of something much more complex
  - Due to Ed Catmull, PhD thesis, 1974
  - Refined by Blinn & Newell, 1976

Non-parametric Texture Mapping



- With “non-parametric texture mapping”
  - Texture size and orientation are fixed
  - They are unrelated to size and orientation of polygon

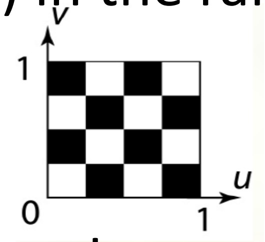
Parametric Texture Mapping



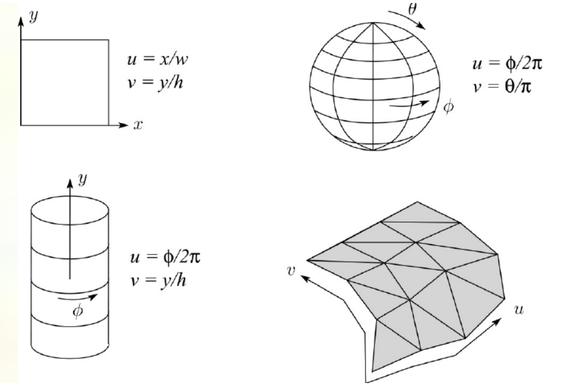
- With “parametric texture mapping,” texture size and orientation are tied to the polygon
  - Separate “texture space” and “screen space”
  - Texture the polygon as before, but in texture space
  - Deform (render) the textured polygon into screen space
  - Deformation is given by parameterization
- A 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:



- Computing (*u,v*) texture coordinates in a ray tracer is fairly straightforward
- Note: if the surface moves/deforms, the texture goes with it

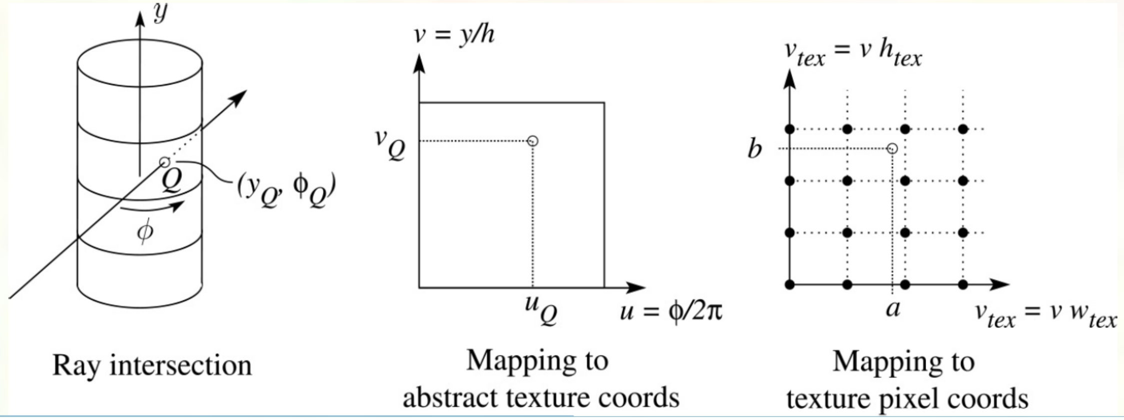
Mapping to Texture Image Coords

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

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

to texture image coordinates:

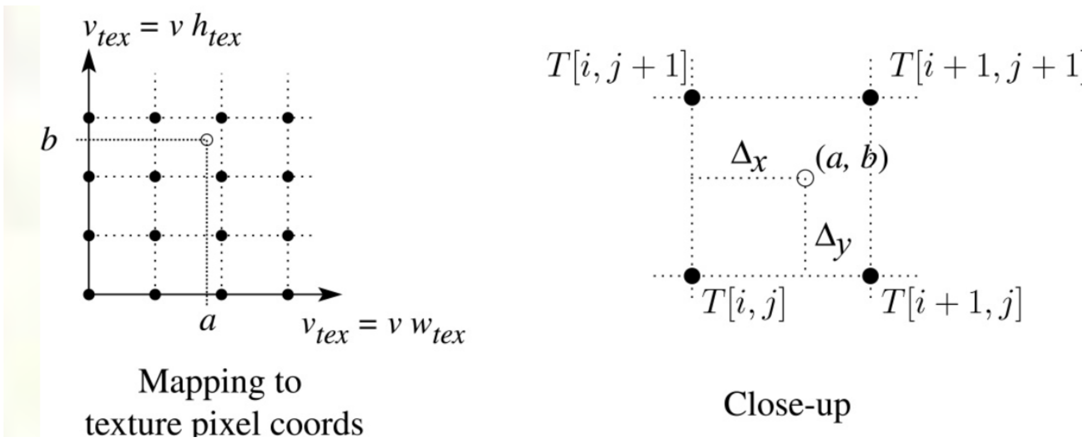
(u_{tex}, v_{tex}) in the range $([0..\ w_{tex}], [0..\ h_{tex}])$



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

Texture Resampling

- We need to resample the texture:



Mapping to texture pixel coords

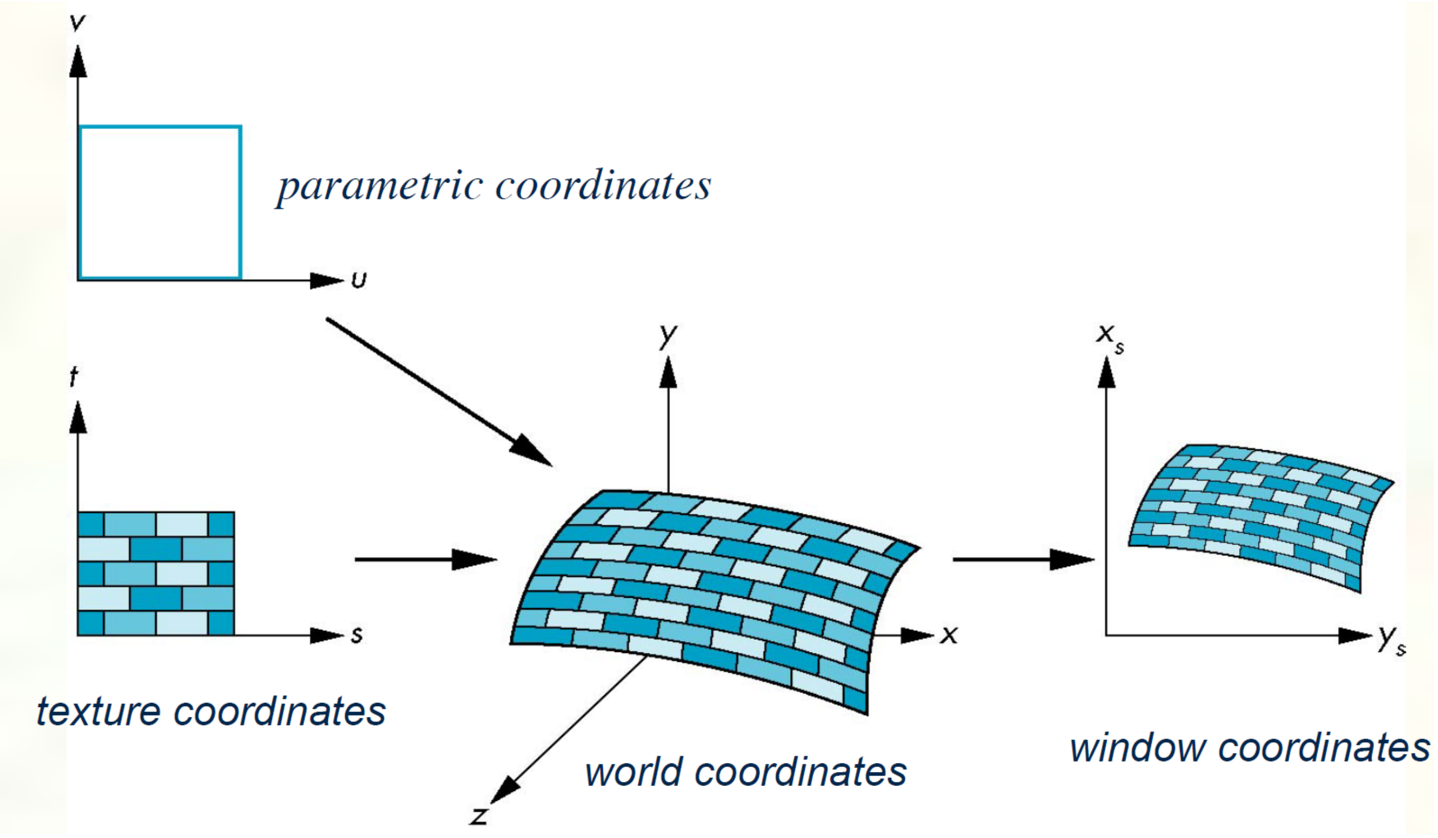
Close-up

- A common choice is **bilinear interpolation**:

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

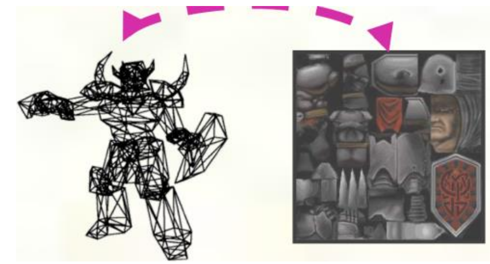
Texture Coordinates

- Interpolated over rasterized primitives



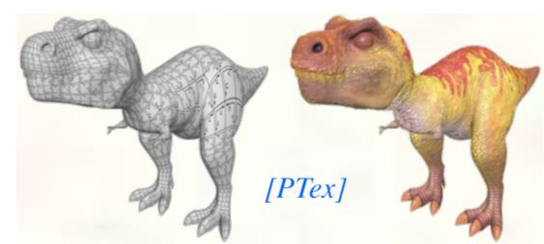
Source of Texture Coordinates?

- Assigned ad-hoc by artist
  - Tedious!
  - Has gift wrapping problem



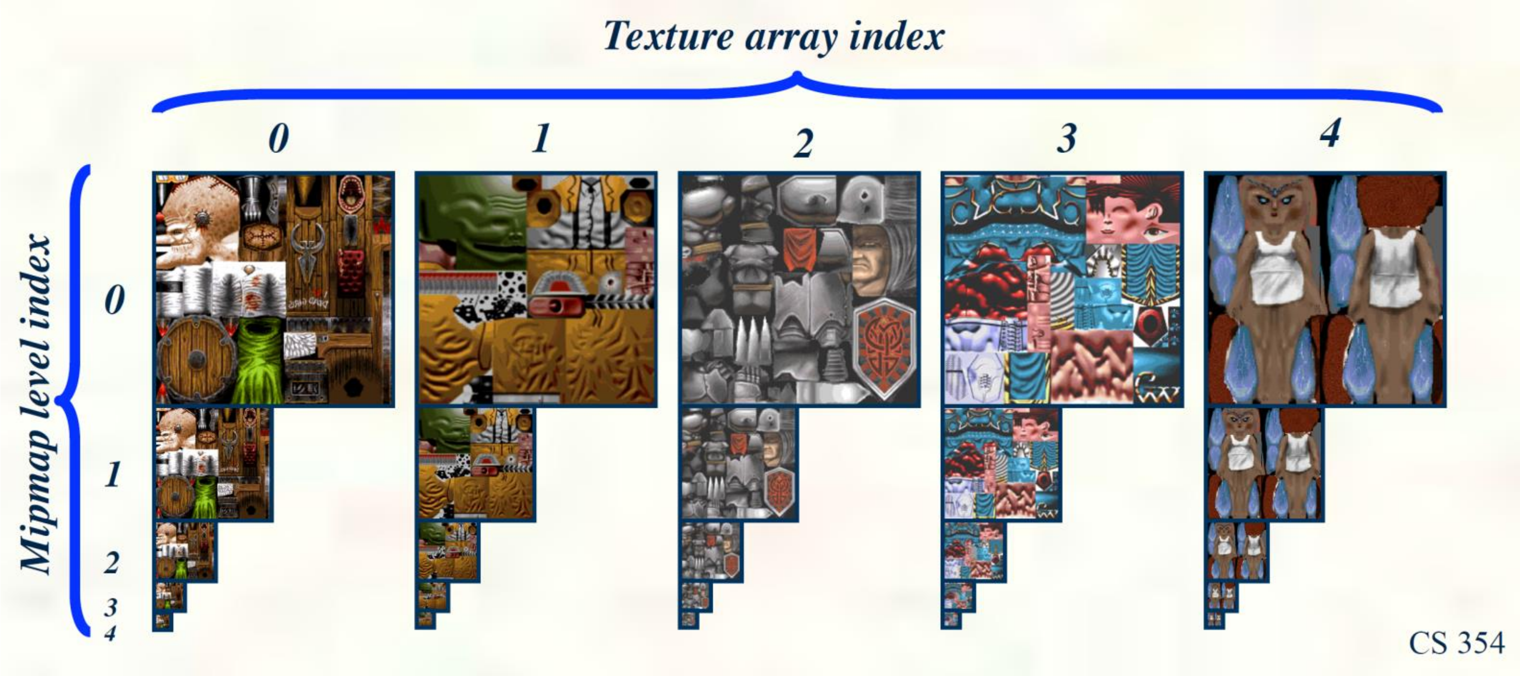
- Computed based on XYZ position
  - Texture coordinate generation ("texgen")
  - Hard to map to "surface space"

- From bi-variate parameterization of geometry
  - Good when geometryis generated from patches
  - So (*u*,*v*) of patch maps to (*x*,*y*,*z*) and (*s*,*t*)

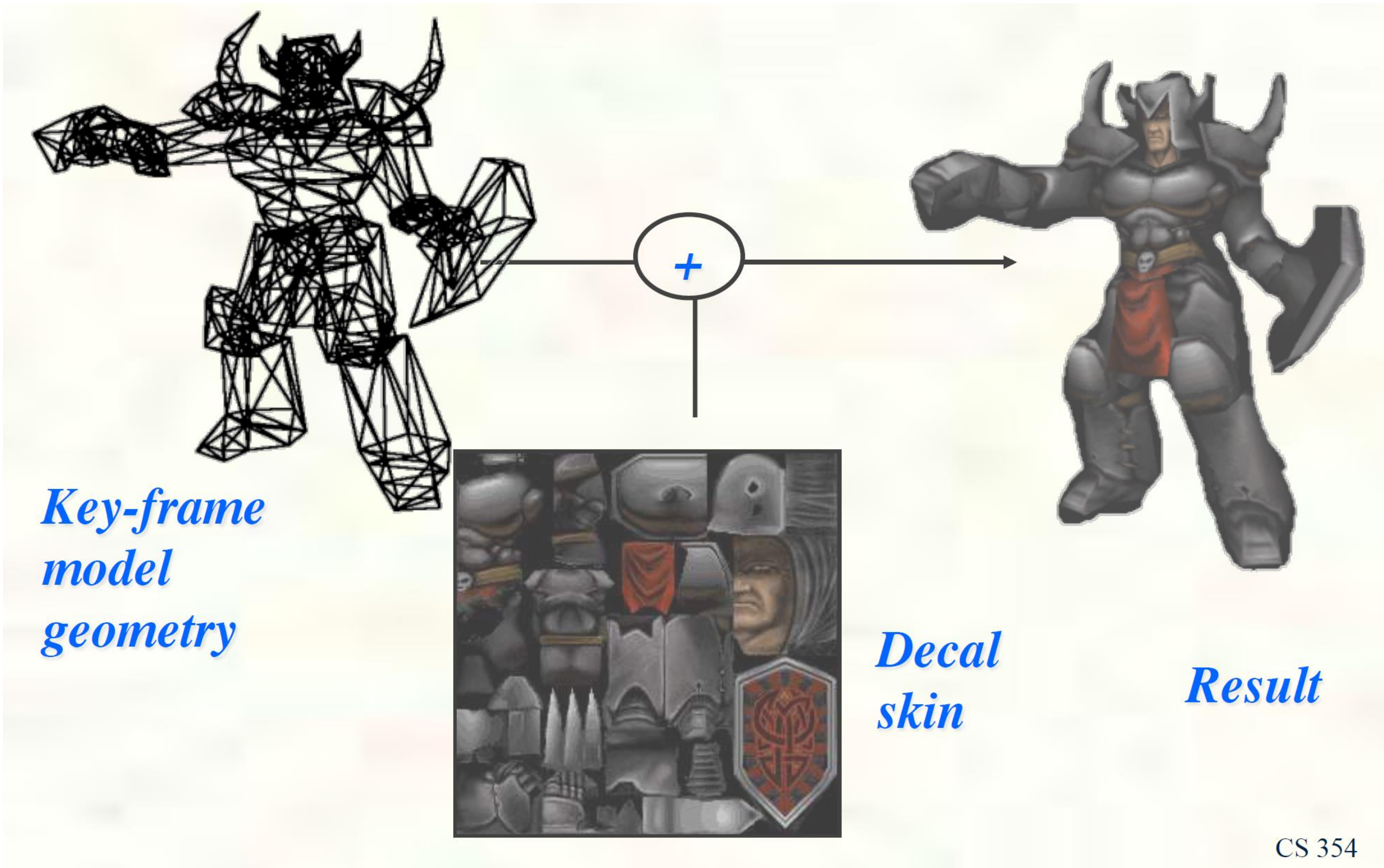


Texture Arrays

- **Multiple skins packed in texture array**
  - Motivation: binding to one multi-skin texture array avoids texture bind per object



Textured Polygonal Models



Multiple Textures

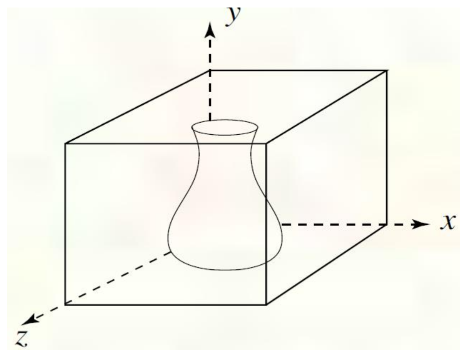
Can Define Material by Program

- A ‘surface shader’ computes the color of each ray that hits the surface
- Example: Renderman surface shader

```
surface checker(float Kd=.5, Ka=.1) {
  float smod = mod(10*s, 1);
  float tmod = mod(10*t, 1);
  if (smod < 0.5) {
    if (tmod < 0.5) Ci=Cs; else Ci=color(0,0,0);
  } else {
    if (tmod < 0.5) Ci=color(0,0,0); else Ci=Cs;
  }
  Oi = Os;
  Ci = Oi*Ci*(
          Ka*ambient() +
          Kd*diffuse(faceforward(normalize(N),I)));
}
```

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

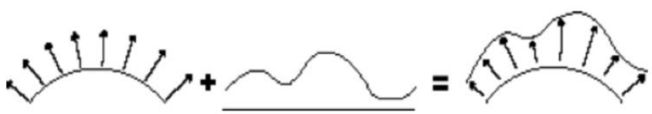
Solid Textures

- Here's an example for a vase cut from a solid marble texture:

Solid marble texture by Ken Perlin, (Foley, IV-21)

Displacement and Bump Mapping

- Use surface offsets stored in texture
  - Perturb or dispute the surface
  - Shade on the resulting surface normals



$$\mathbf{P}(u,v)$$

$$\mathbf{S}(u,v) = \frac{\partial \mathbf{P}(u,v)}{\partial u} \qquad \mathbf{T}(u,v) = \frac{\partial \mathbf{P}(u,v)}{\partial v}$$

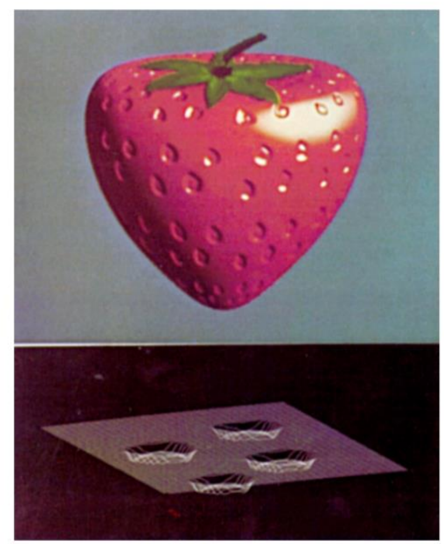
$$\mathbf{N}(u,v) = \mathbf{S} \times \mathbf{T}$$

- **Displacement**

$$\mathbf{P}'(u,v) = \mathbf{P}(u,v) + h(u,v)\mathbf{N}(u,v)$$

- **Perturbed normal**

$$\mathbf{N}'(u,v) = \mathbf{P}'_u \times \mathbf{P}'_v = \mathbf{N} + h_u(\mathbf{T} \times \mathbf{N}) + h_v(\mathbf{S} \times \mathbf{N})$$

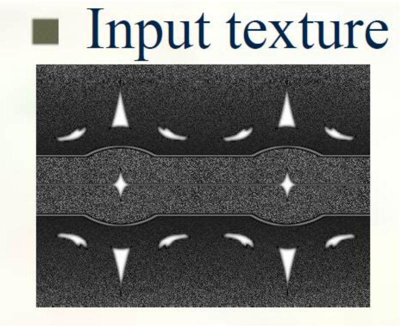


From Blinn 1976

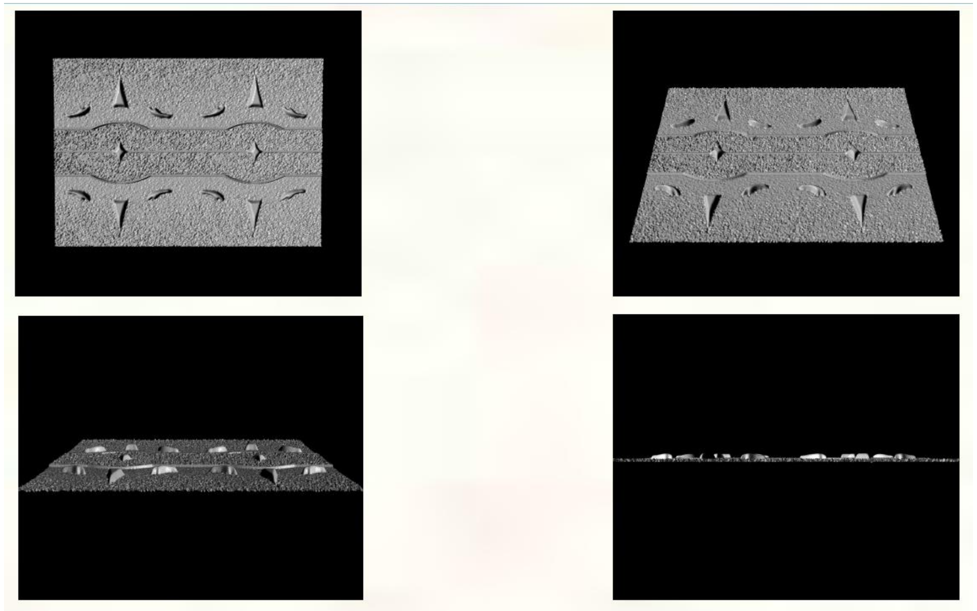
Normal Mapping

- Bump mapping via a normal map texture
  - Normal map – x,y,z components of actual normal
  - Instead of a height field 1 value per pixel
  - The normal map can be generated from the height field
  - Otherwise have to orient the normal coordinates to the surface

Displacement vs. Bump Mapping

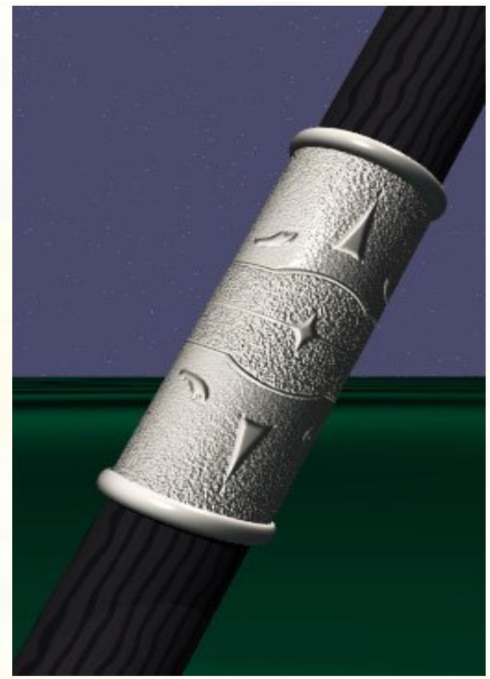


- Rendered as displacement map over a rectangular surface



Displacement vs. Bump Mapping

Original rendering

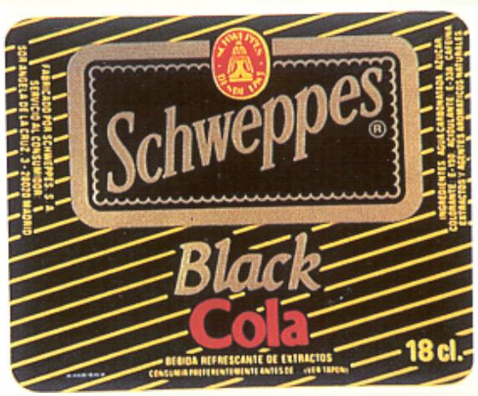


Rendering with
bump map wrapped
around a cylinder

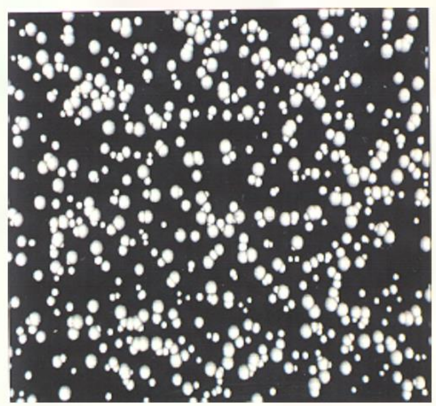
Bump mapping is much faster and consumes less resources for the same level of detail compared to displacement mapping because the geometry remains unchanged.

Bump Mapping Example

Texture #1
(diffuse color)



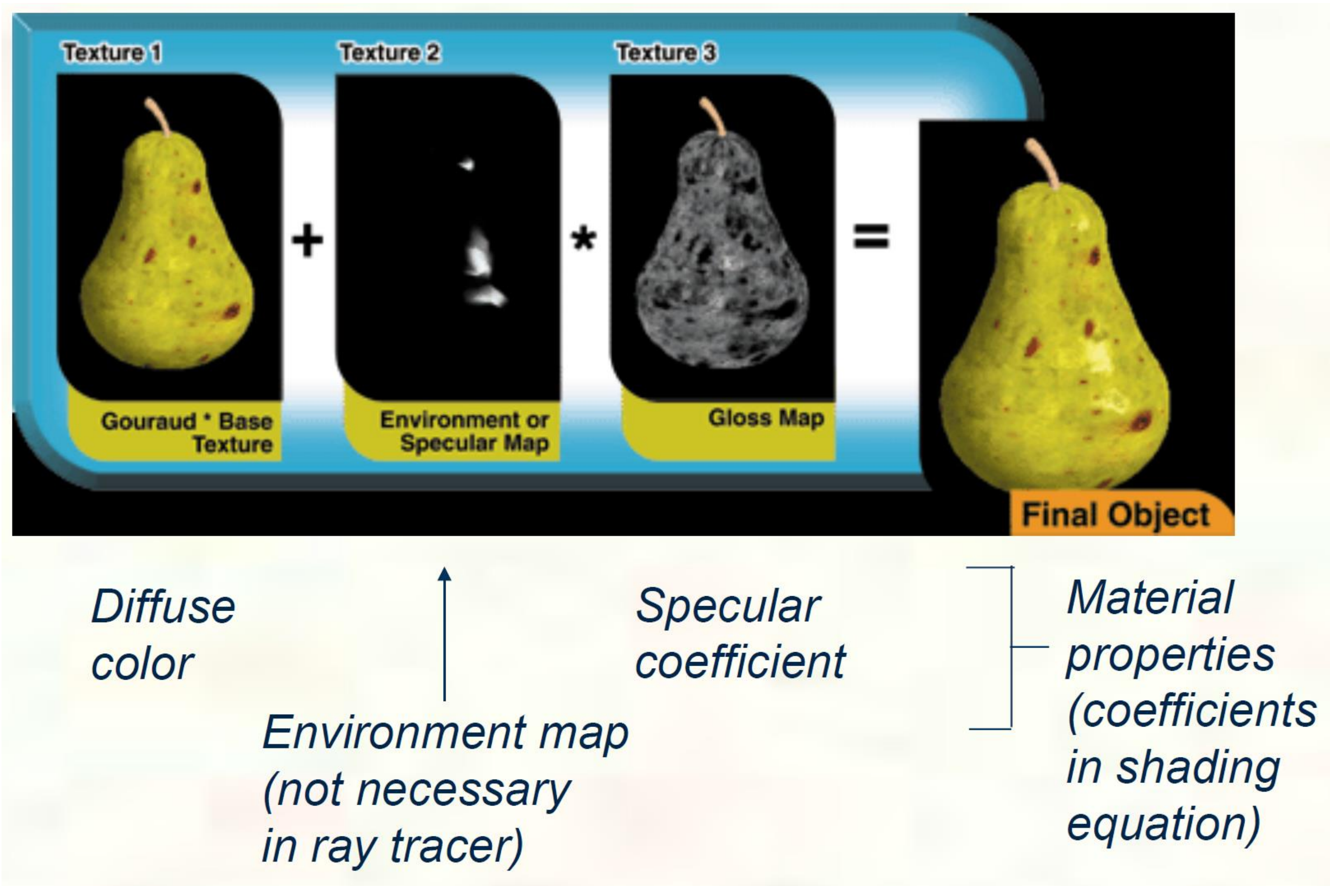
Texture #2
(bump map)



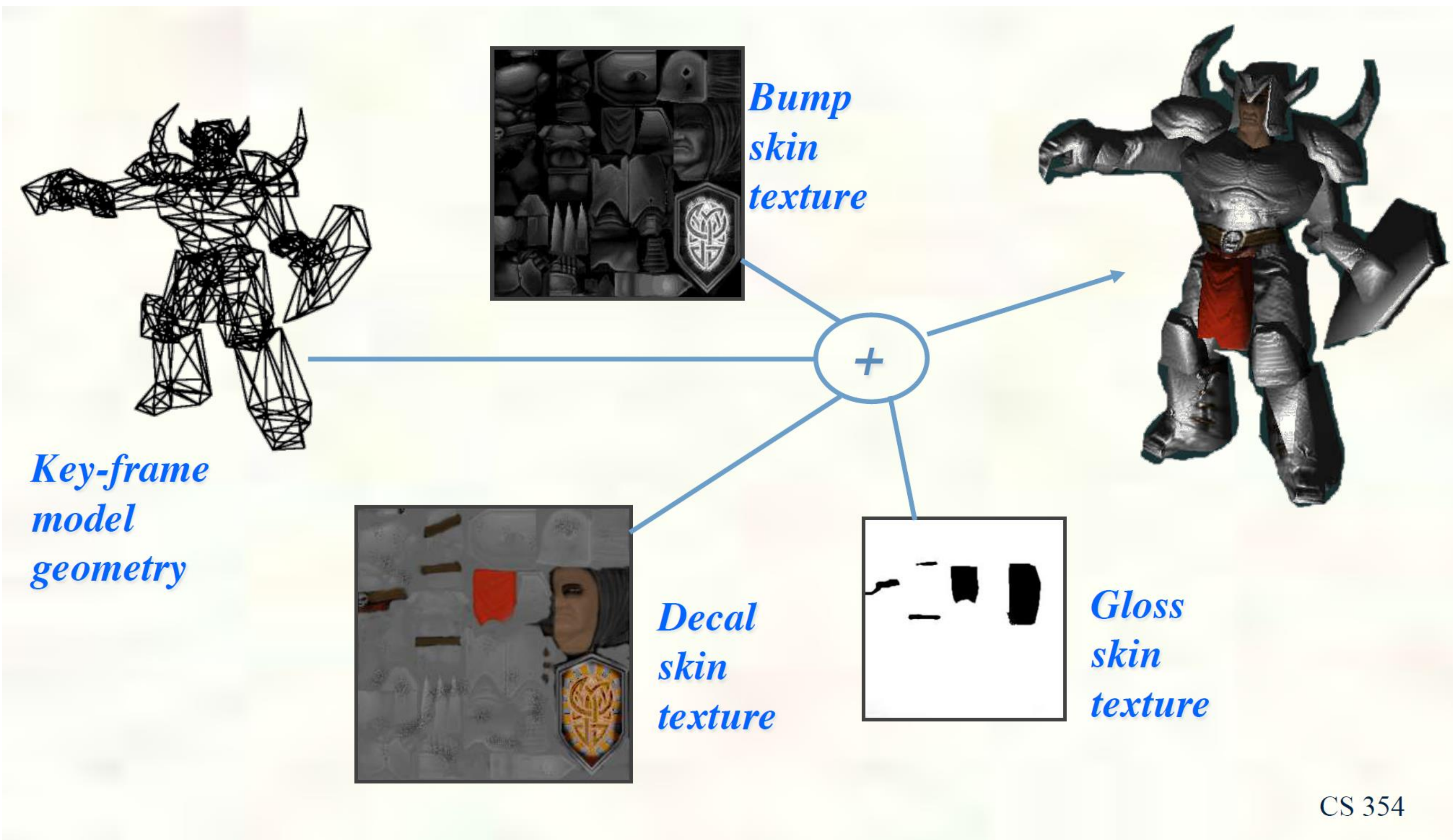
Rendered Image

Combing Texture Maps

- Using texture maps in combination gives even better effects



Multiple Textures



Multitexturing

Next Lecture

- Continue texture mapping

- Spatial data structure

Questions?