

# Texture Mapping

## Reading

Angel, pages 373-386

### Optional

- Paul S. Heckbert. Survey of texture mapping. *IEEE Computer Graphics and Applications* 6(11): 56-67, November 1986  
<http://www.cs.cmu.edu/afs/cs/user/ph/www/texsurv.ps.gz>

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# 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
- ensures that “all the right things” happen as a texture polygon is transformed and rendered

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## Non-parametric texture mapping

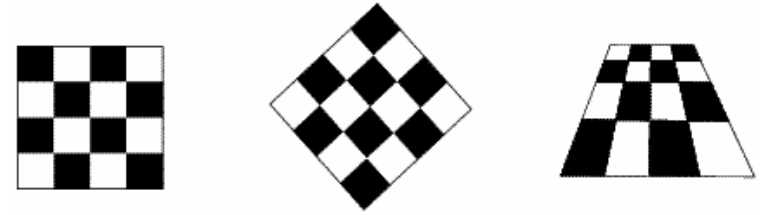


With non parametric texture mapping:

- Texture size and orientation are fixed
- Unrelated to size and orientation of polygon
- Gives a cookie-cutter effect

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## Parametric texture mapping



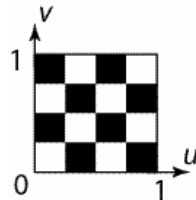
With parametric texture mapping, texture size and orientation are tied to the polygon:

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

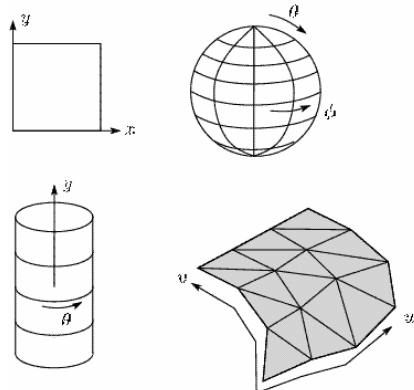
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## Implementing texture mapping

A texture lives in its own image coordinates parameterized by  $(u, v)$ :



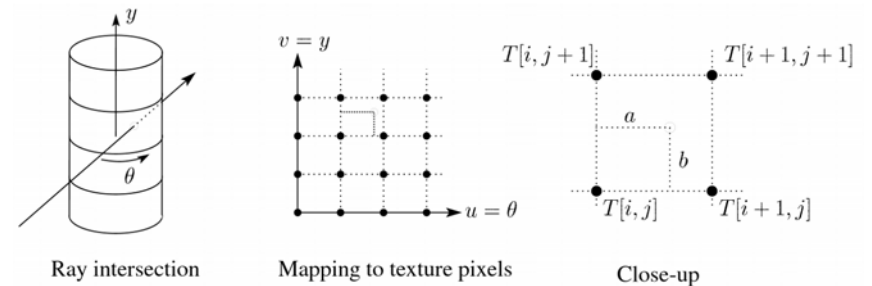
It can be wrapped around many different surfaces:



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## Texture resampling

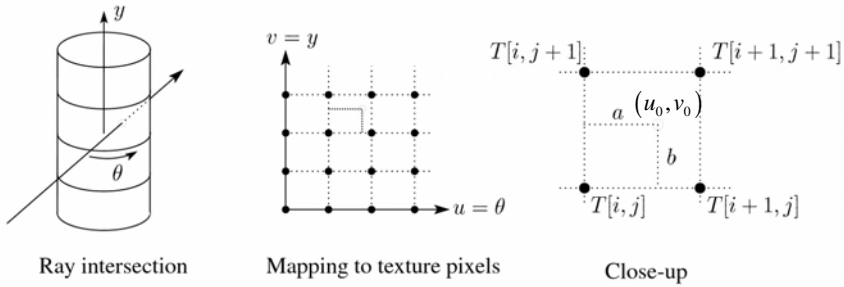
What do we do when the texture sample lands between the texture pixels?



We resample. Common choice is **bilinear resampling**.

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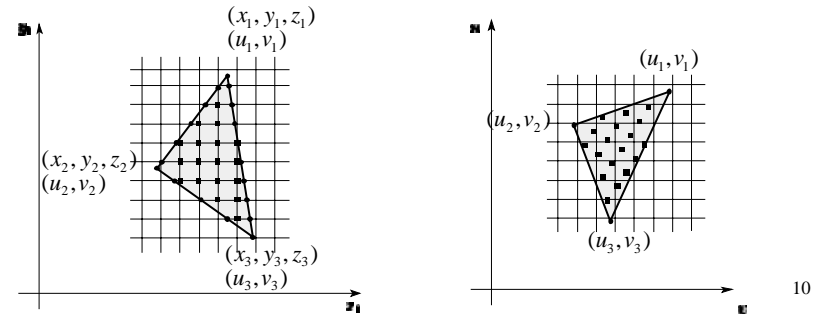
# Bilinear Resampling



$$T(u_\theta, v_\theta) = T(i\Delta + a, j\Delta + b) = \frac{a}{b} T[i, j] + \frac{b-a}{b} T[i+1, j] + \frac{a}{a+b} T[i, j+1] + \frac{b-a}{a+b} T[i+1, j+1]$$

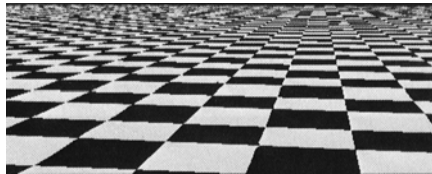
# Implementing, cont.

- Texture mapping can also be handled in z-buffer algorithms:
  - 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

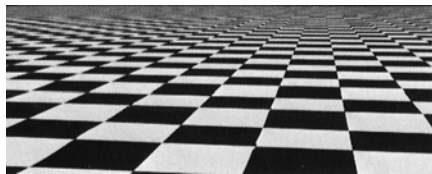


# Antialiasing

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



- Proper antialiasing requires area averaging in the texture:

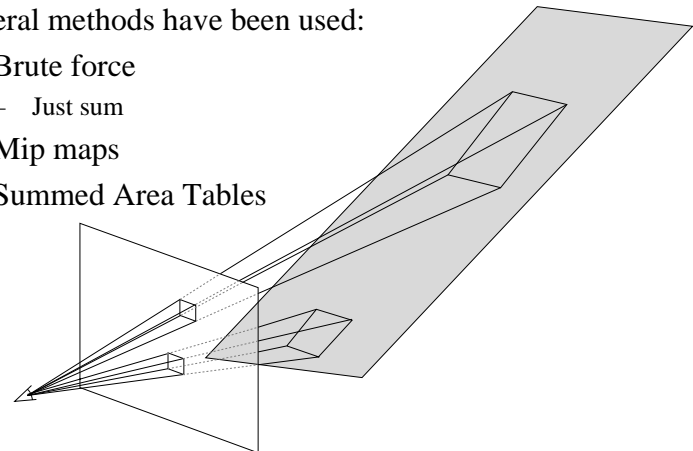


# Computing average color

Computationally difficult part is summing over the covered pixels:

Several methods have been used:

1. Brute force
  - Just sum
2. Mip maps
3. Summed Area Tables

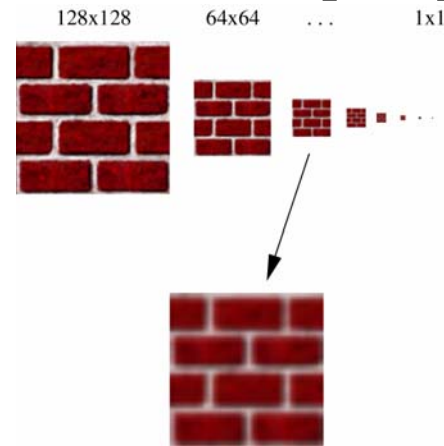


# Mip Maps



- Lance Williams, 1983
- “multum in parvo” – many things in a small place
- Keep textures prefiltered at multiple resolutions

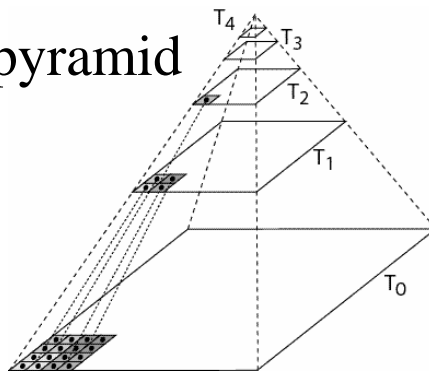
# Mip maps, cont'd



1. Figure out two closest levels
2. Linear interpolate between the two

Q: What would the mip map return for an average over a 65x65 neighborhood at  $(u,v)$ ?

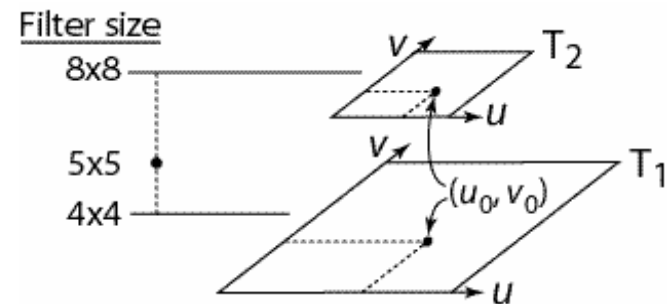
# Mip map pyramid



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

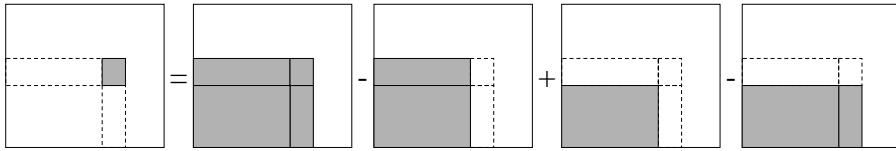
# Mip map resampling

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



- How do we measure the fractional distance between levels?
- What if you need to average over a non-square region?

## Summed area tables



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

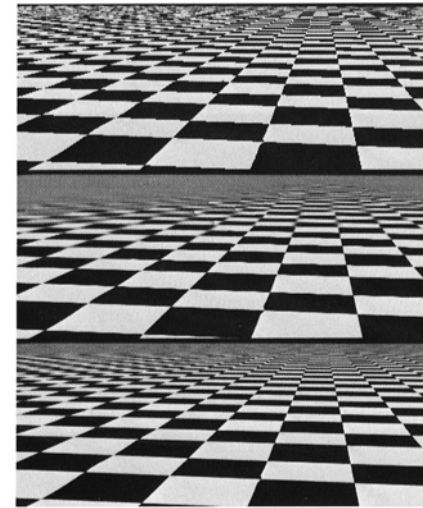
Or in discrete form:

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

- Due to Frank Crow, 1984
- Keep sum of everything below and to the left
- Use four table lookups
- Requires more memory (2-4 times the original image)
- Gives less blurry textures

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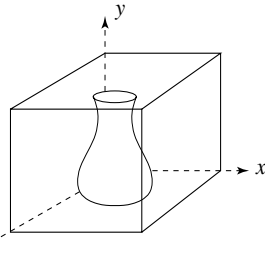
## Comparison of techniques



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## Solid textures

Q: what kinds of artifacts might you see from using a marble veneer instead of a 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...

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## Solid textures, cont.

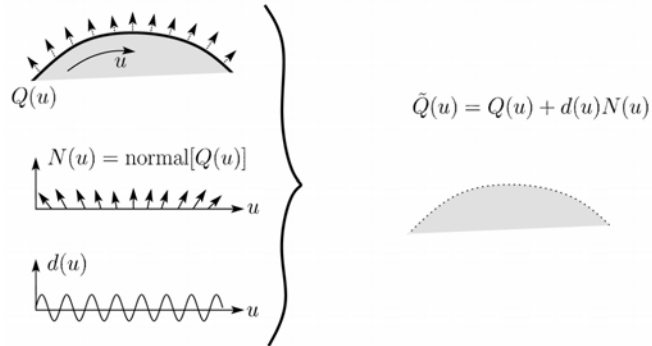
Instead of using texture coordinates to index into an image, use them to compute a function that defines the texture



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# Displacement mapping

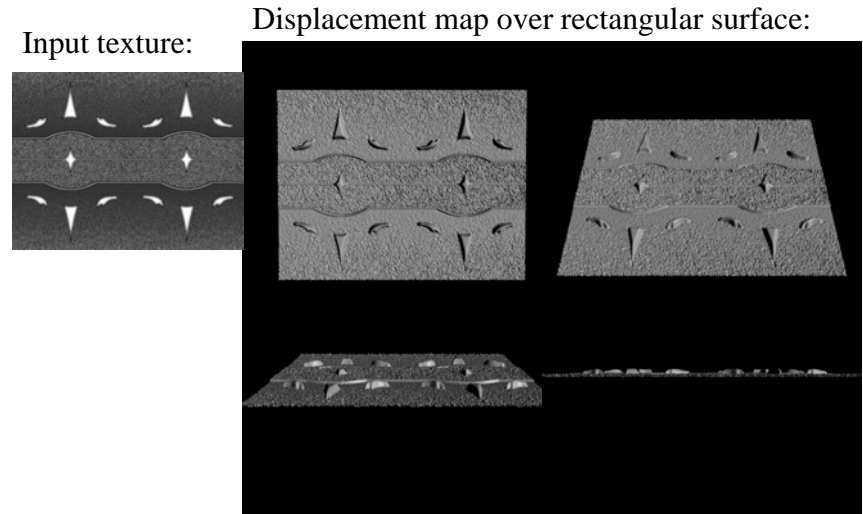
In displacement mapping, a texture is used to perturb the surface geometry itself:



- Silhouettes are correct
- Requires doing additional hidden surface calculations

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# Displacement mapping, cont.



# Bump mapping

Textures can be used for more than just color

$$I = k_a I_a + \sum_i f(d_i) I_{li} (k_d (\mathbf{N} \cdot \mathbf{L}_i)_+ + k_s (\mathbf{V} \cdot \mathbf{R})_+^{n_s})$$

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

- The normal is perturbed in each parametric direction according to the partial derivatives of the texture



- These bumps “animate” with the surface

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

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# Bump mapping example



Original rendering

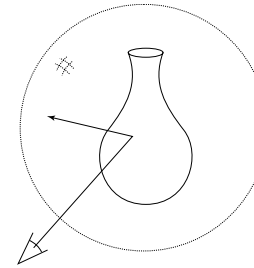
Rendering with bump map wrapped around a cylinder

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## Environment mapping



- A.k.a. reflection mapping
- Use texture to model object's environment
- Rays are bounced off objects into environment to determine color of illumination
- Works well when there is just a single object
- With some simplifications can be implemented in hardware
- Raytracer can be extended to handle refractions as well

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## Combining texture maps

- Using texture maps in combination give even better effects



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## Combining texture maps, cont.

Phong lighting  
with  
diffuse texture



(a)



(b)

Environment-  
mapped  
mirror reflection

Bump mapping +  
Glossy reflection



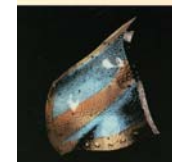
(c)



(d)

Combine textures  
and add dirt

Rivet stains +  
Shinier reflections



(e)



(f)

Close-up

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# Summary

What to take from this lecture:

- What texture mapping is and what is it good for
- Understanding the various approaches to antialiased textured mapping
  - Brute force
  - Mip maps
  - Summed area tables
- Additional effect with texture mapping techniques
  - Bump mapping
  - Displacement mapping
  - Environment mapping