Texture Mapping

Based on slides by Steve Marschner

Texture mapping

- Objects have properties that vary across the surface

Based on slides by Steve Marschner

Texture Mapping

- So we make the shading parameters vary across the surface

[Foley et al. / Perlin]

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Texture mapping

- Adds visual complexity; makes appealing images

[Pixar / *Toy Story*]

Texture mapping

- Color is not the same everywhere on a surface
  - one solution: multiple primitives
- Want a function that assigns a color to each point
  - the surface is a 2D domain, so that is essentially an image
  - can represent using any image representation
  - raster texture images are very popular

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A definition

Texture mapping: a technique of defining surface properties (especially shading parameters) in such a way that they vary as a function of position on the surface.

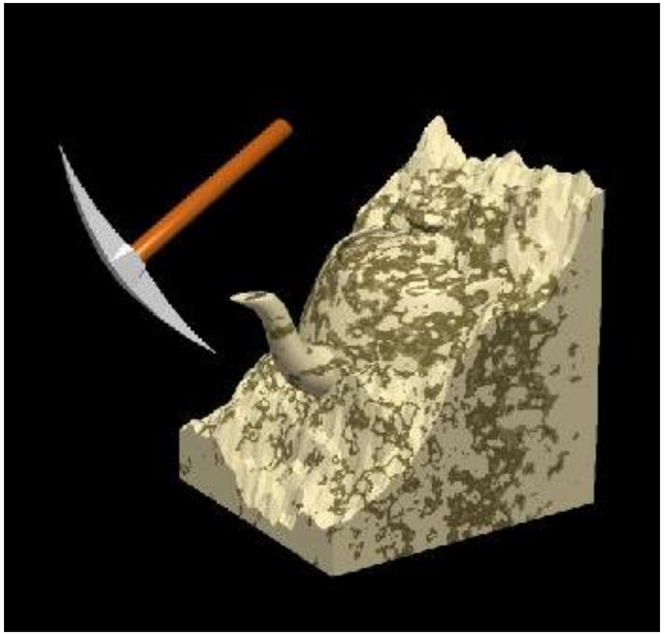
- This is very simple!
  - but it produces complex-looking effects

Examples

- Wood gym floor with smooth finish
  - diffuse color k_D varies with position
  - specular properties k_S, n are constant
- Glazed pot with finger prints
  - diffuse and specular colors k_D, k_S are constant
  - specular exponent n varies with position
- Adding dirt to painted surfaces
- Simulating stone, fabric, …
  - to approximate effects of small-scale geometry
    - they look flat but are a lot better than nothing

Mapping textures to surfaces

- Usually the texture is an image (function of *u,* v)
  - the big question of texture mapping: where on the surface does the image go?
  - obvious only for a flat rectangle the same shape as the image
  - otherwise more interesting
- Note that *3D textures* also exist
  - texture is a function of (*u*, *v*, *w*)
  - can just evaluate texture at 3D surface point
  - good for solid materials
  - often defined procedurally



[Wolfe / SG97 Slide set]

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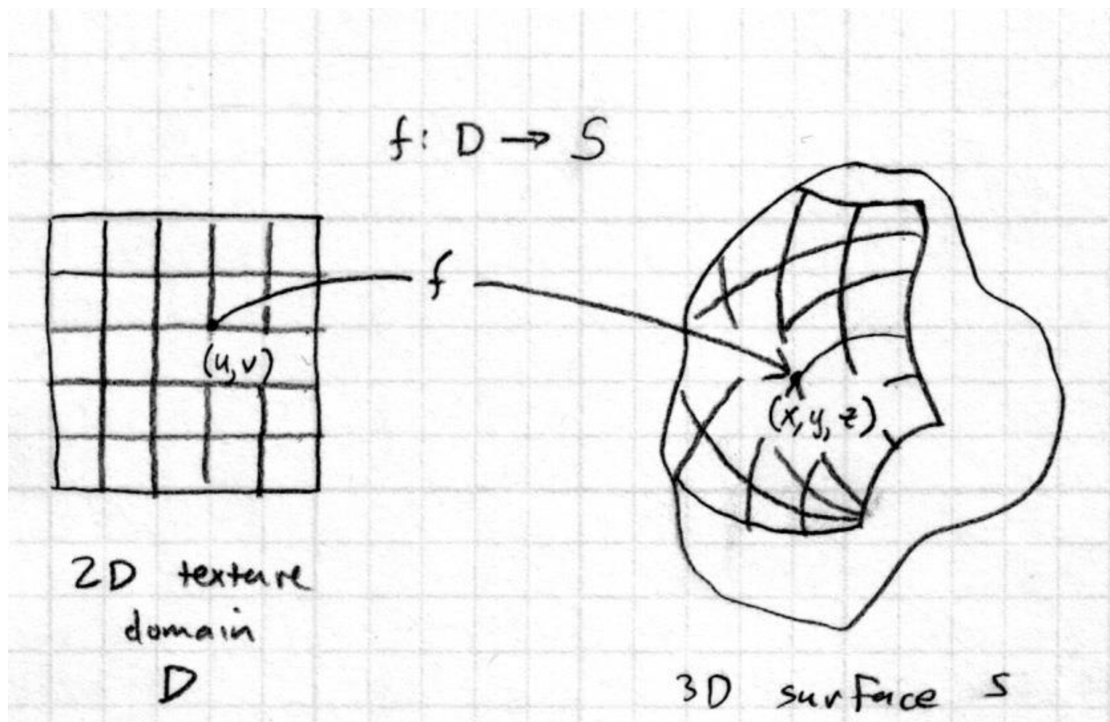
Mapping textures to surfaces

- “Putting the image on the surface”
  - this means we need a function *f* that tells where each point on the image goes
  - this looks a lot like a parametric surface function
  - for parametric surfaces you get *f* for free



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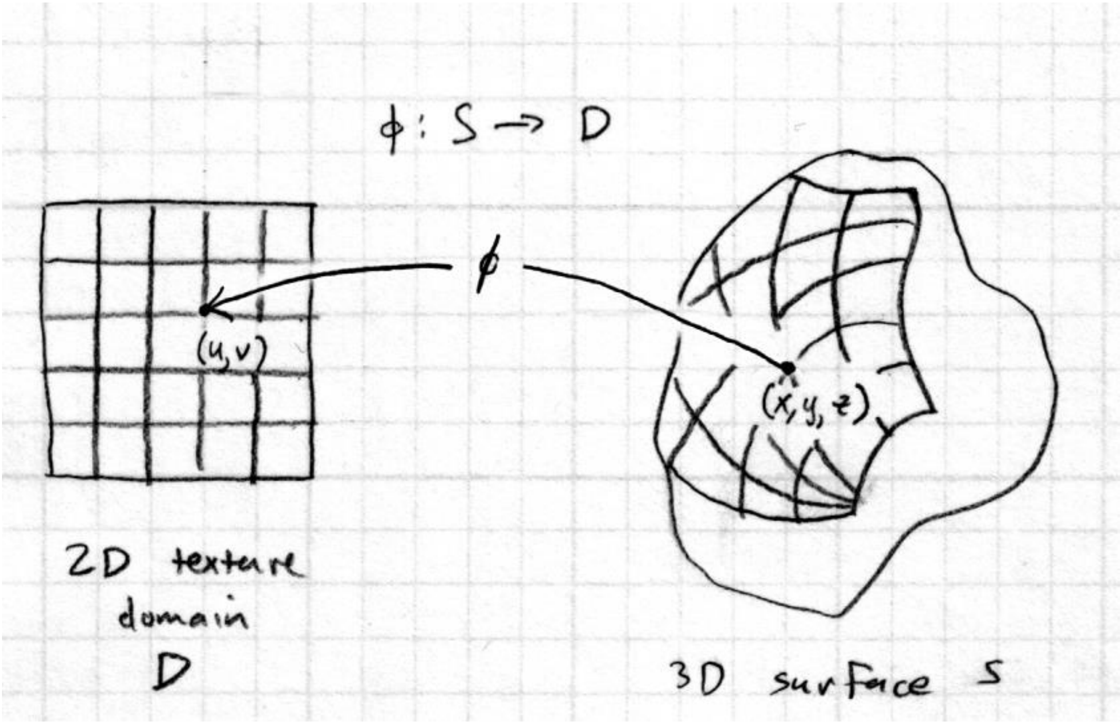
Texture coordinate functions

- Non-parametrically defined surfaces: more to do
  - can't assign texture coordinates as we generate the surface
  - need to have the *inverse* of the function *f*
- Texture coordinate function

  $$\phi : S \to \mathbb{R}^2$$

  - for a vertex at **p** get texture at ϕ (**p**)



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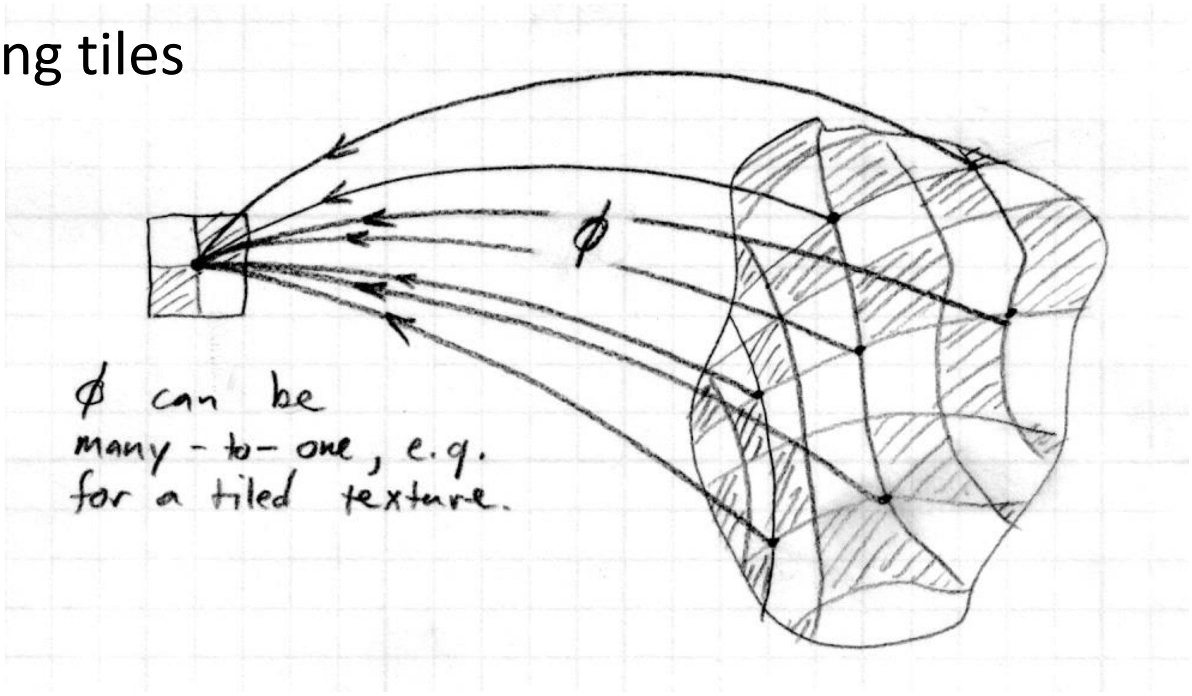
Texture coordinate functions

- Mapping from *S* to *D* can be many-to-one
  - that is, every surface point gets only one color assigned
  - but it is OK (and in fact useful) for multiple surface points to be mapped to the same texture point
    - e.g., repeating tiles



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Texture coordinate functions

- Define texture image as a function

  $$T : D \to C$$

  – where *C* is the set of colors for the diffuse component

- Diffuse color (for example) at point **p** is then

  $$k_D(\mathbf{p}) = T(\phi(\mathbf{p}))$$

Based on slides by Steve Marschner

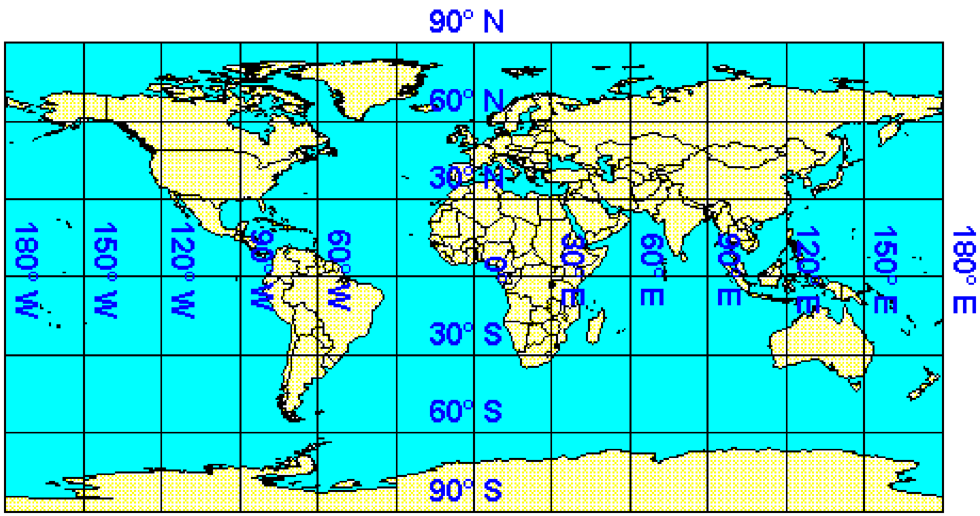
Examples of coordinate functions

- A rectangle
  - image can be mapped directly, unchanged

Examples of coordinate functions

- For a sphere: latitude-longitude coordinates
  - ϕ maps point to its latitude and longitude

[map: Peter H. Dana]



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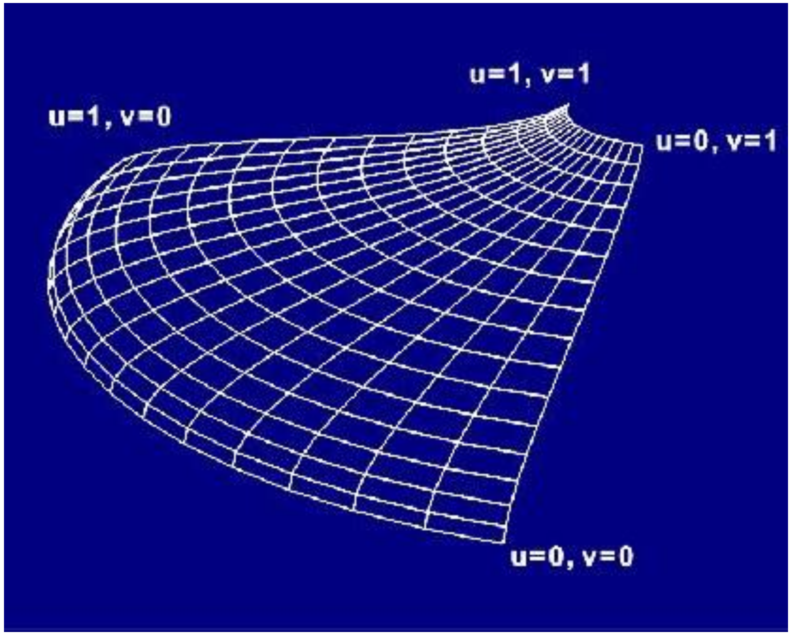
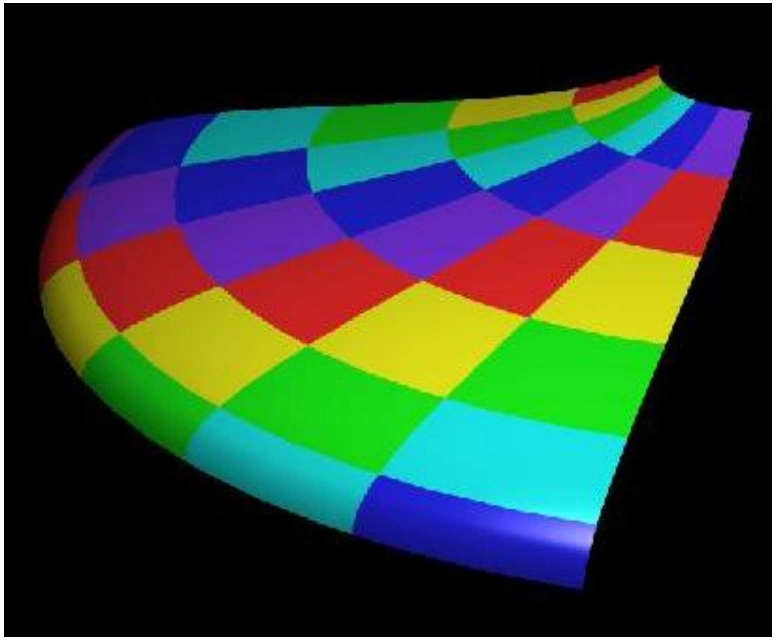
Examples of coordinate functions

- A parametric surface (e.g. spline patch)
  - surface parameterization gives mapping function directly (well, the inverse of the parameterization)





[Wolfe / SG97 Slide set]

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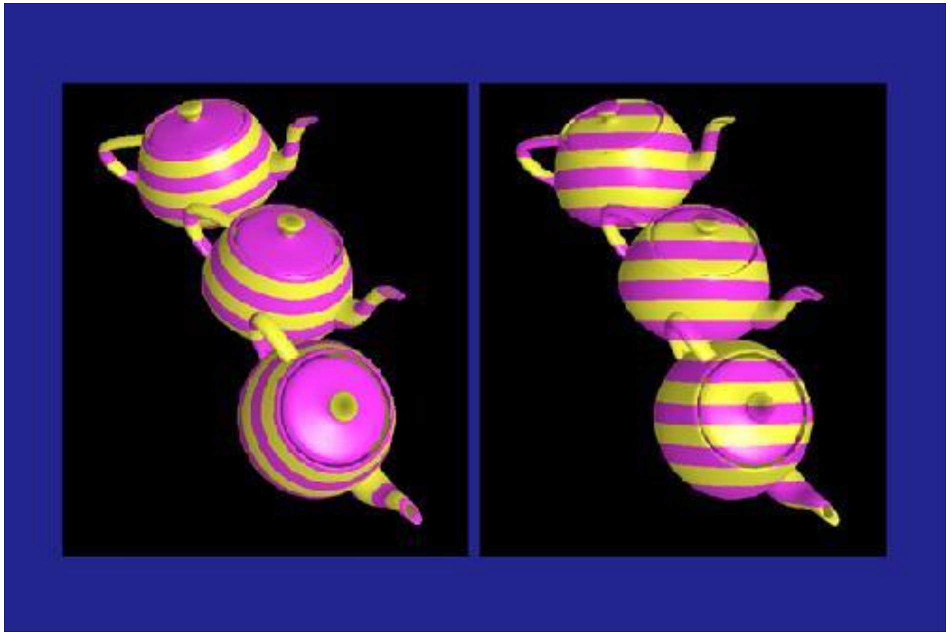
Examples of coordinate functions

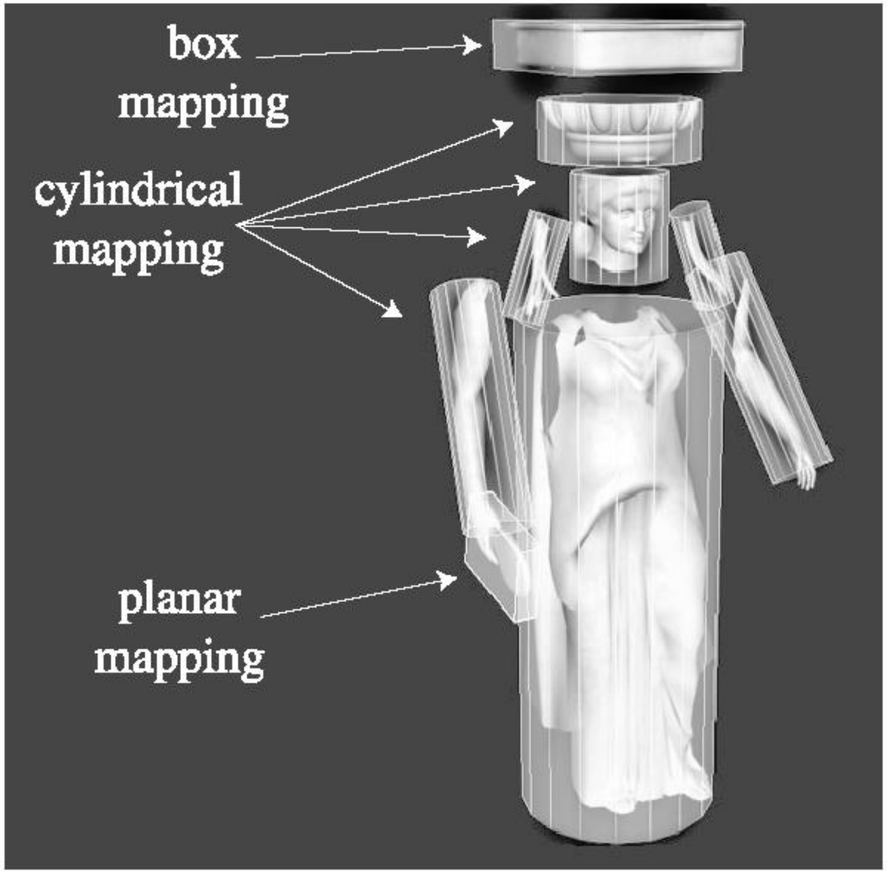
- For non-parametric surfaces it is trickier
  - directly use 3D coordinates (body or world)
    - need to project one out



[Wolfe / SG97 Slide set]

Examples of coordinate functions

- Non-parametric surfaces: project to parametric surface



[Moller & Haines 2002]

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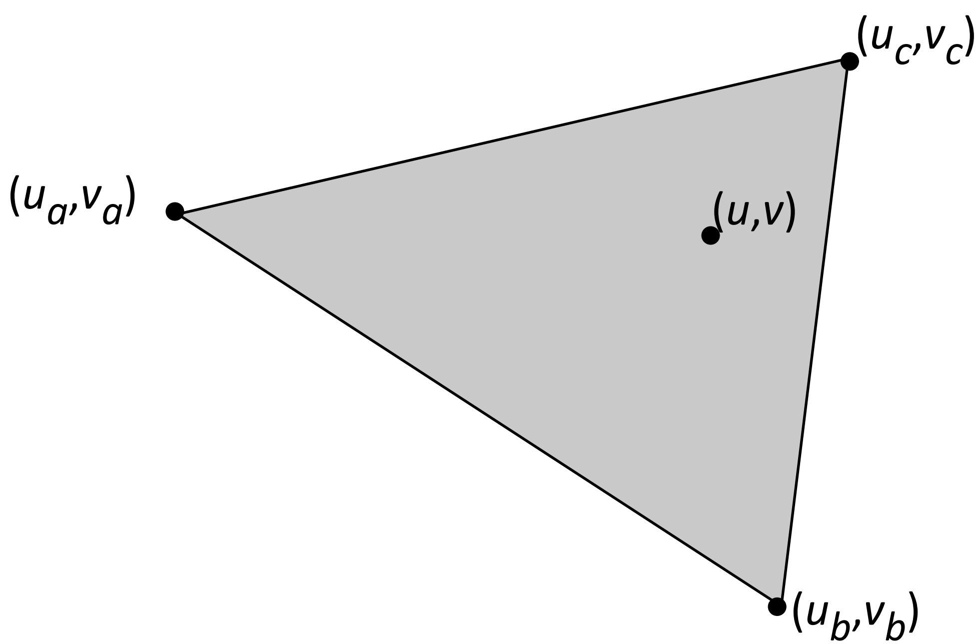
Examples of coordinate functions

- Triangles
  - specify (u,v) for each vertex
  - define (u,v) for interior by linear ***barycentric*** interpolation



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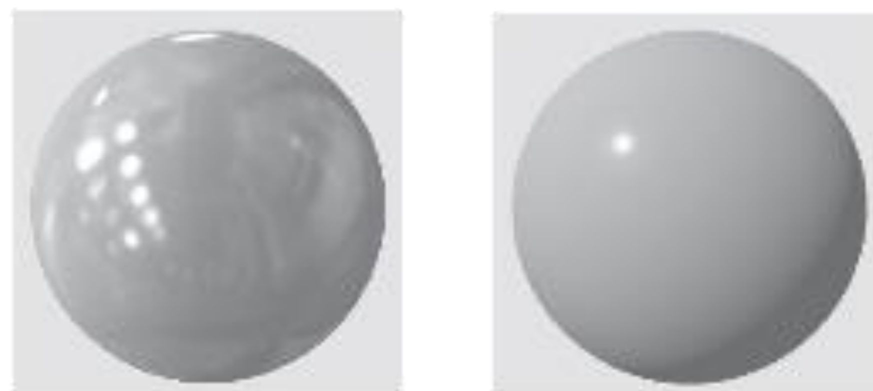
Texture coordinates on meshes

- Texture coordinates become per-vertex data like vertex positions
  - can think of them as a second position: each vertex has a position in 3D space and in 2D texure space
- How to come up with vertex (*u*,*v*)s?
  - use any or all of the methods just discussed
    - in practice this is how you implement those for curved surfaces approximated with triangles
  - use some kind of optimization (or an artist)
    - try to choose vertex (*u*,*v*)s to result in a smooth, low distortion map

Reflection mapping

- Early (earliest?) non-decal use of textures
- Appearance of shiny objects
  - Phong highlights produce blurry highlights for glossy surfaces.
  - A polished (shiny) object reflects a sharp image of its environment.
- The whole key to a shiny-looking material is providing something for it to reflect.



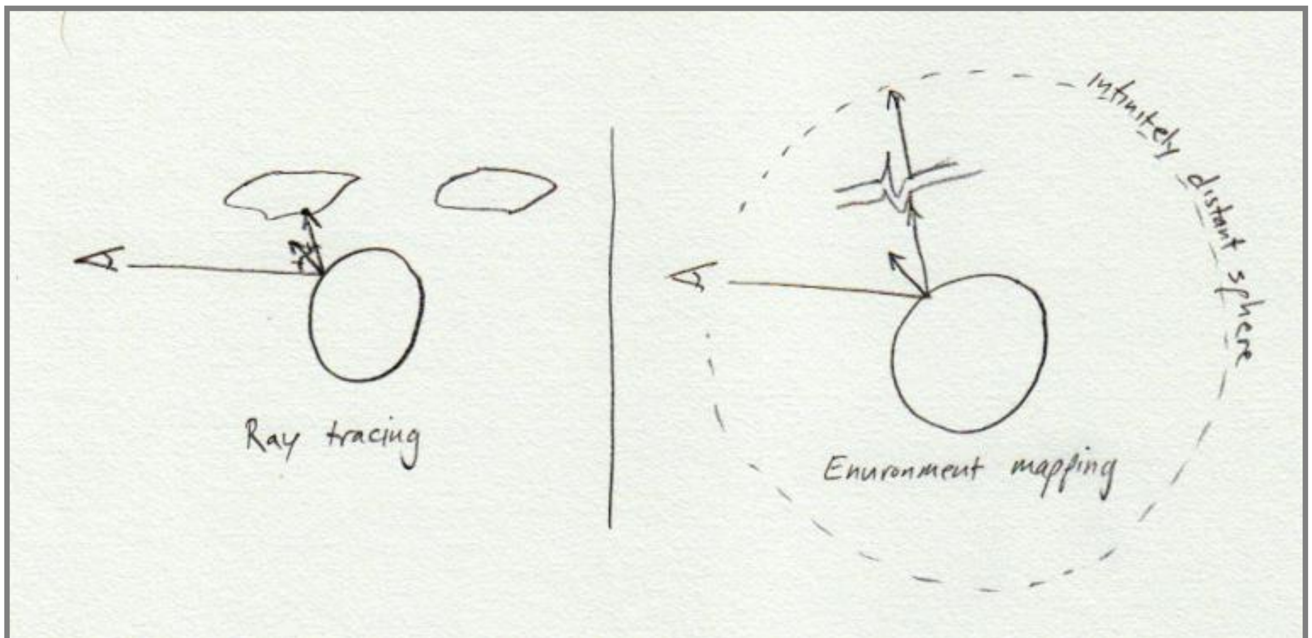
(a) (b)

Figure 2. (a). A shiny sphere rendered under photographically acquired real-world illumination. (b). The same sphere rendered under illumination by a point light source.

[Dror, Willsky, & Adelson 2004]

Reflection mapping

- From ray tracing we know what we'd like to compute
  - trace a recursive ray into the scene—too expensive
- If scene is infinitely far away, depends only on direction
  - a two-dimensional function



Based on slides by Steve Marschner

Environment map

- A function from the sphere to colors, stored as a texture.

[Blinn & Newell 1976]

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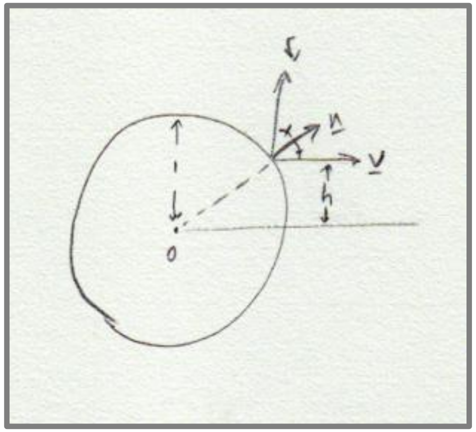
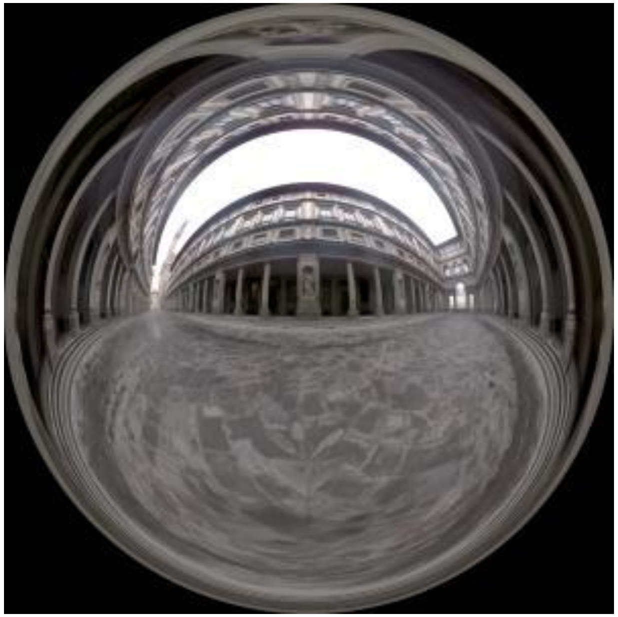
Spherical environment map

- If assuming distant viewer (orthographic projection) then reflected viewing direction only depends on normal.
  - The x and y coordinate of the 3D normal are in $[-1,1]^2$ and can be easily remapped to $[0,1]^2$ with a windowing transform to use as texture coordinates in the sphere map shown at right.





[Paul Debevec]

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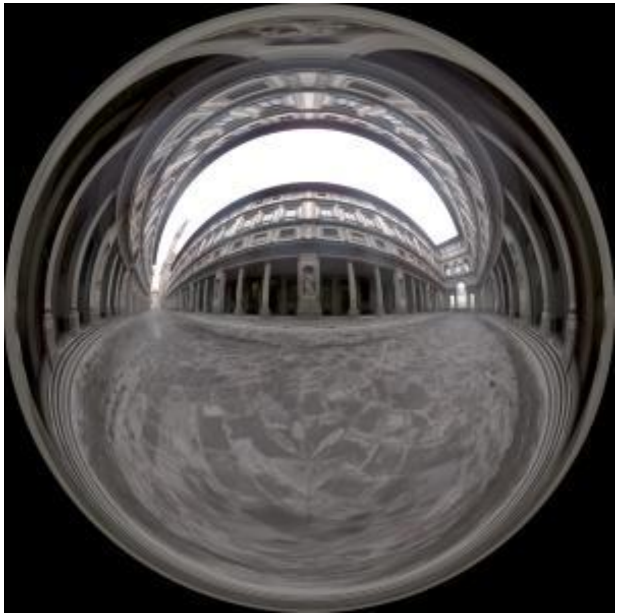
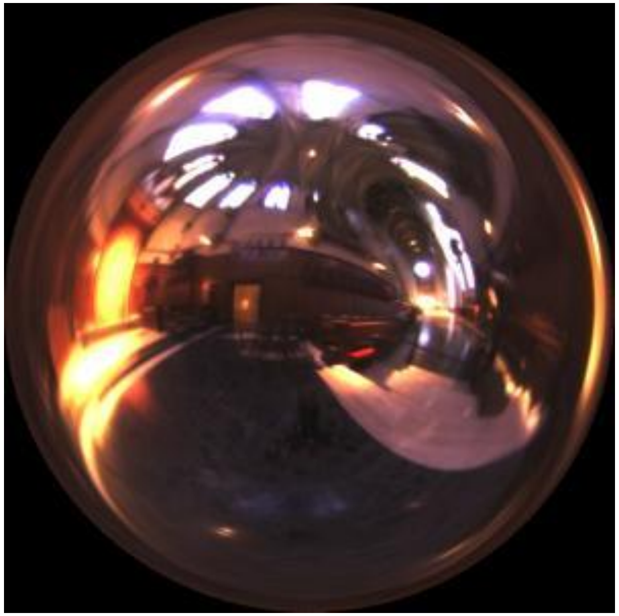
Environment Maps

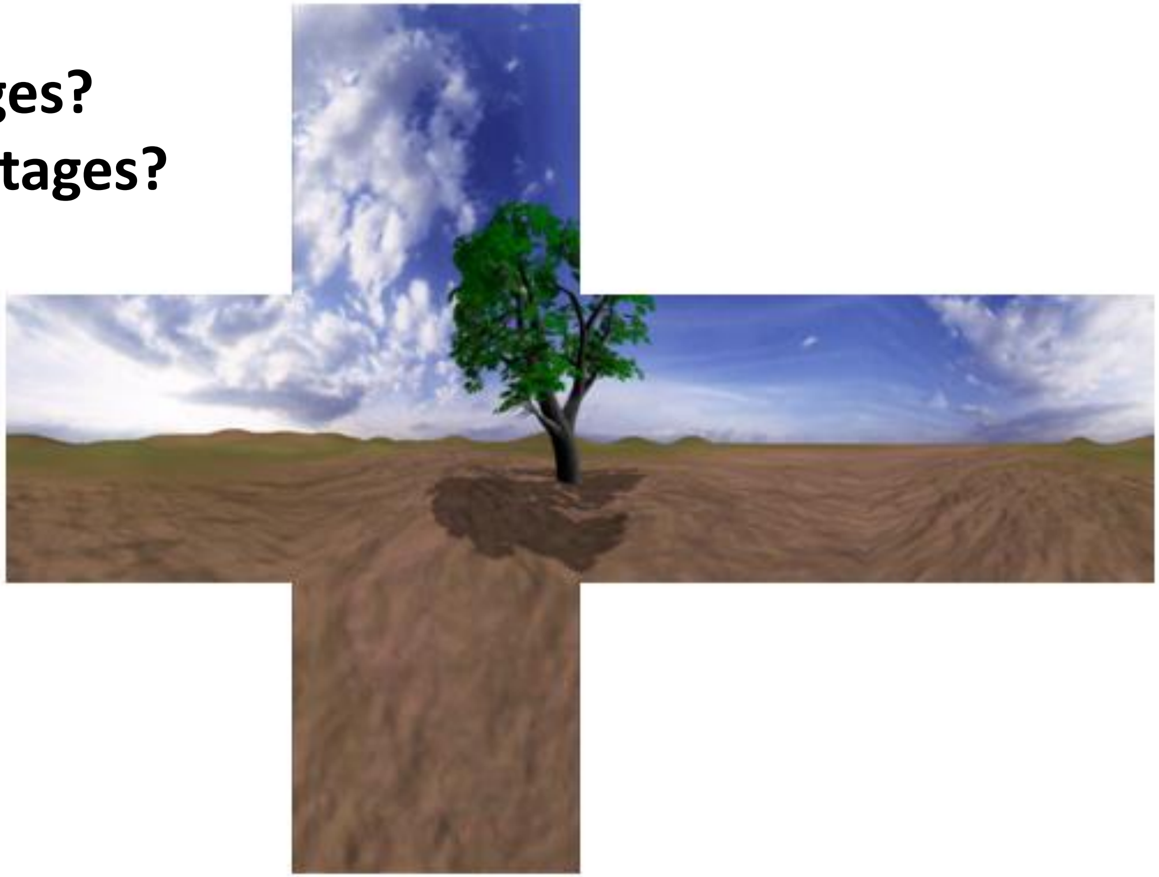
[Paul Debevec]

Based on slides by Steve Marschner

[CS467 slides]

Cube environment map

Advantages?
Disadvantages?



[Ned Greene]

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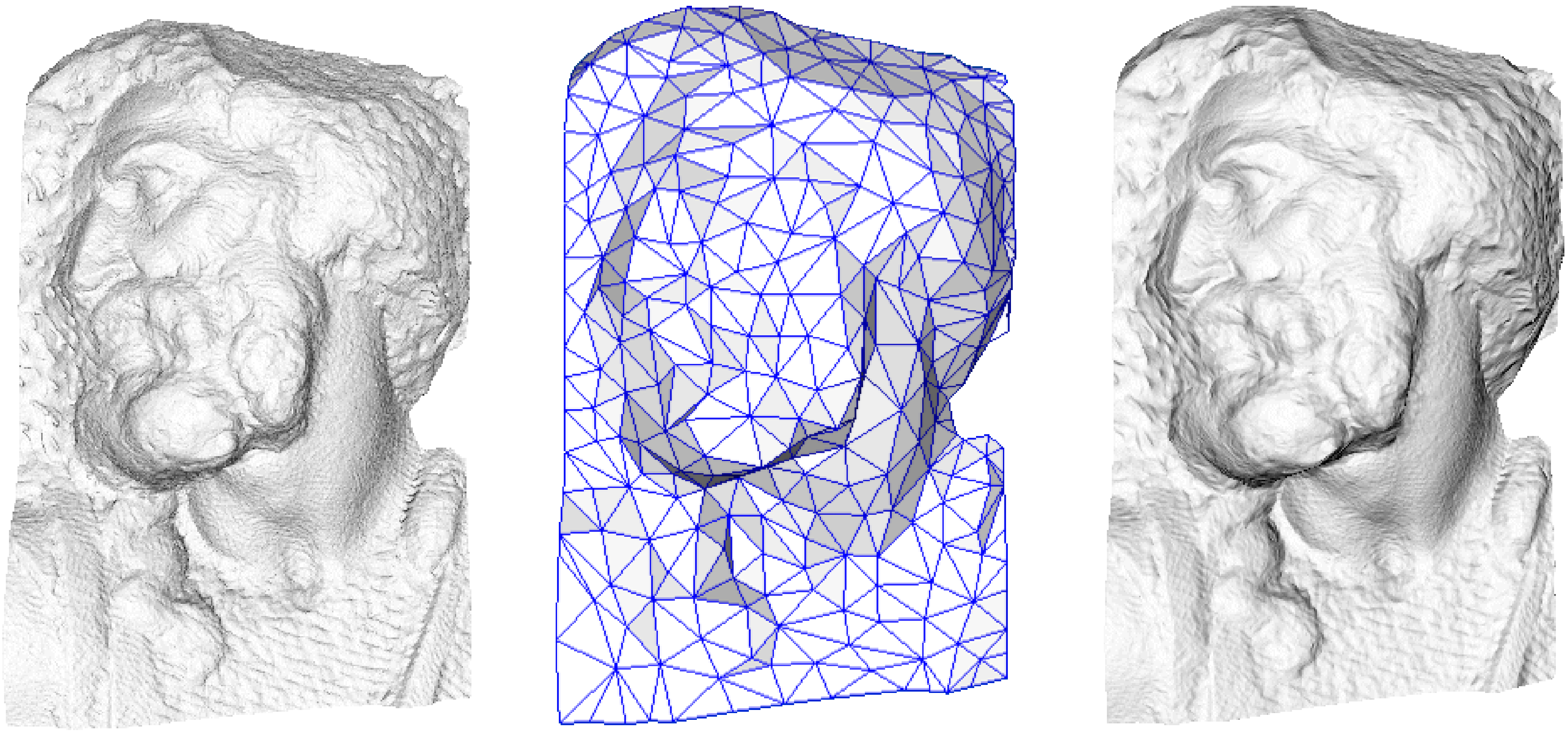
Normal mapping

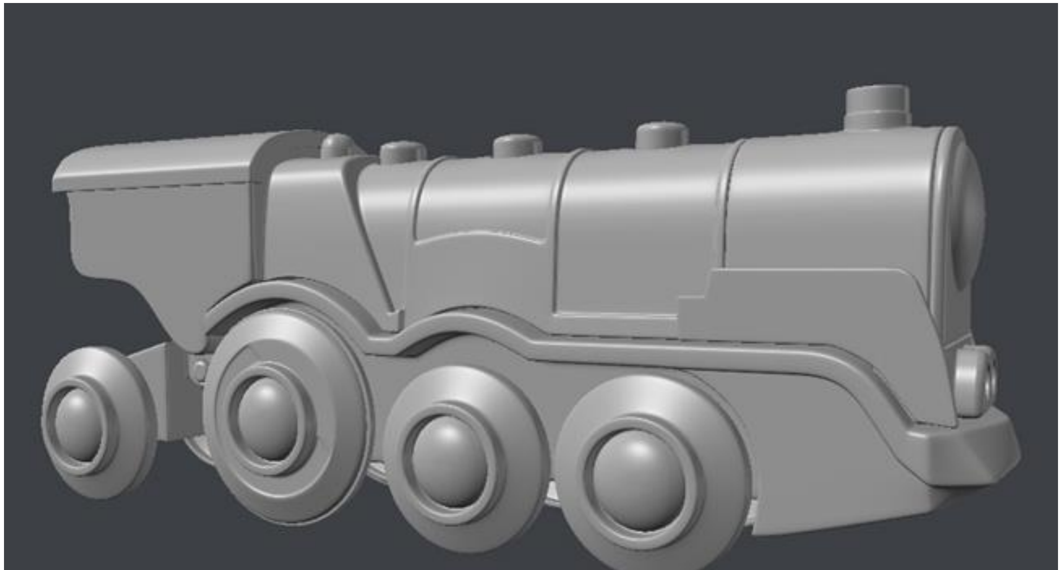


original mesh
4M triangles

simplified mesh
500 triangles

simplified mesh
and normal mapping
500 triangles

[Paolo Cignoni]



base subdivision surface

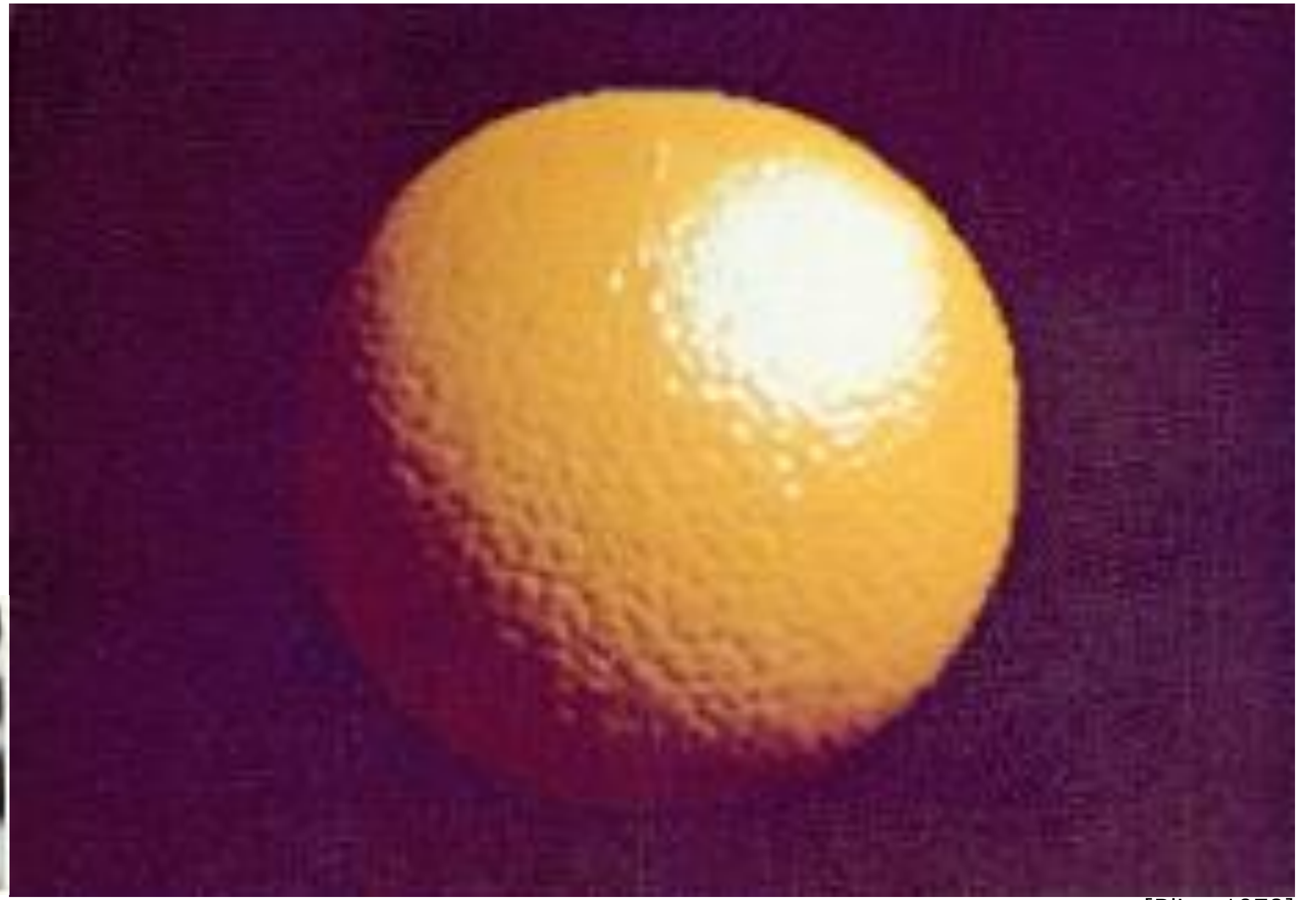
hand-painted displacement map (detail)

displaced surface

Paweł Filip
tolas.wordpress.com

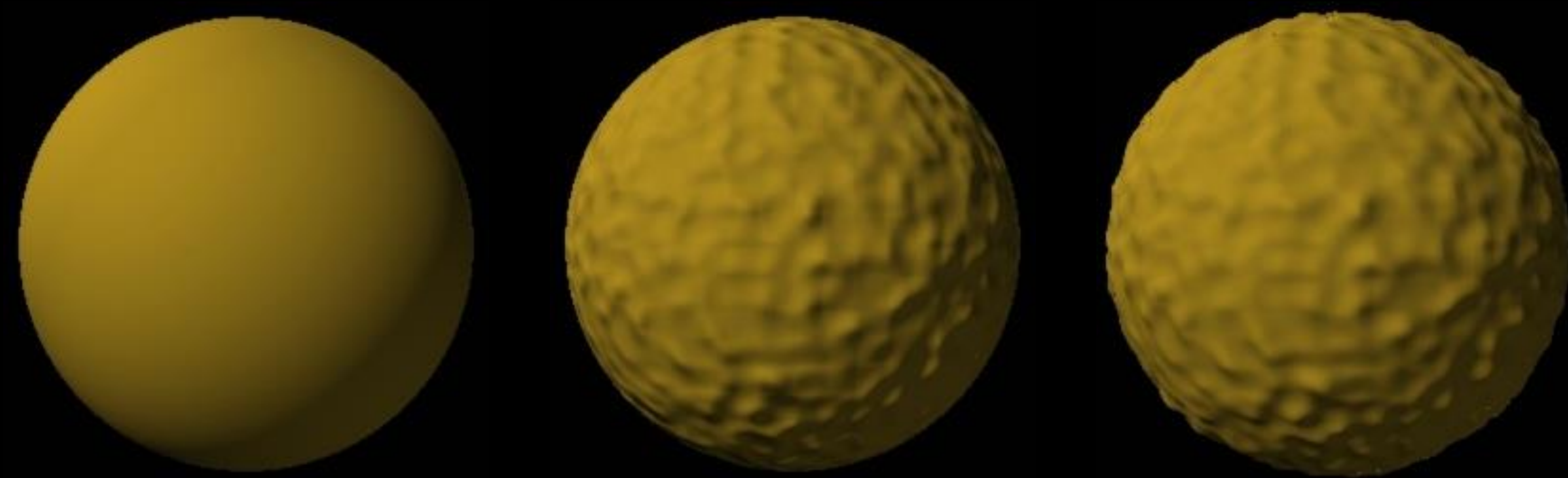

521
fryrender
physically-based render engine
©2007 Paweł Filip

Bump mapping



[Blinn 1978]

Displacement mapping



Geometry

Bump mapping

Displacement mapping

[CS467 slides]

Another definition

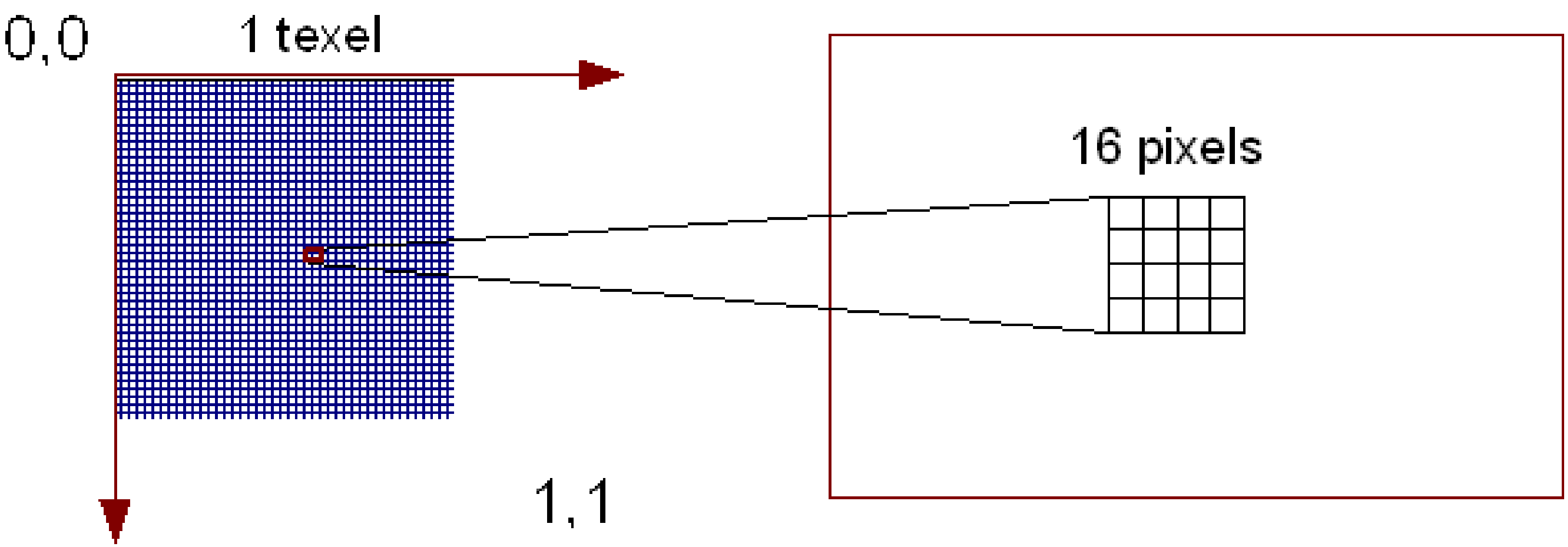
Texture mapping: a general technique for storing and evaluating functions.

- They're not just for shading parameters any more!

Based on slides by Steve Marschner

Texture mapping – sampling problems

- Too few texels map to a large region of the image
  - ***Texture Magnification*** when a textured objects are viewed up close
  - Can use nearest texel, or map bi-linearly the 4 nearest

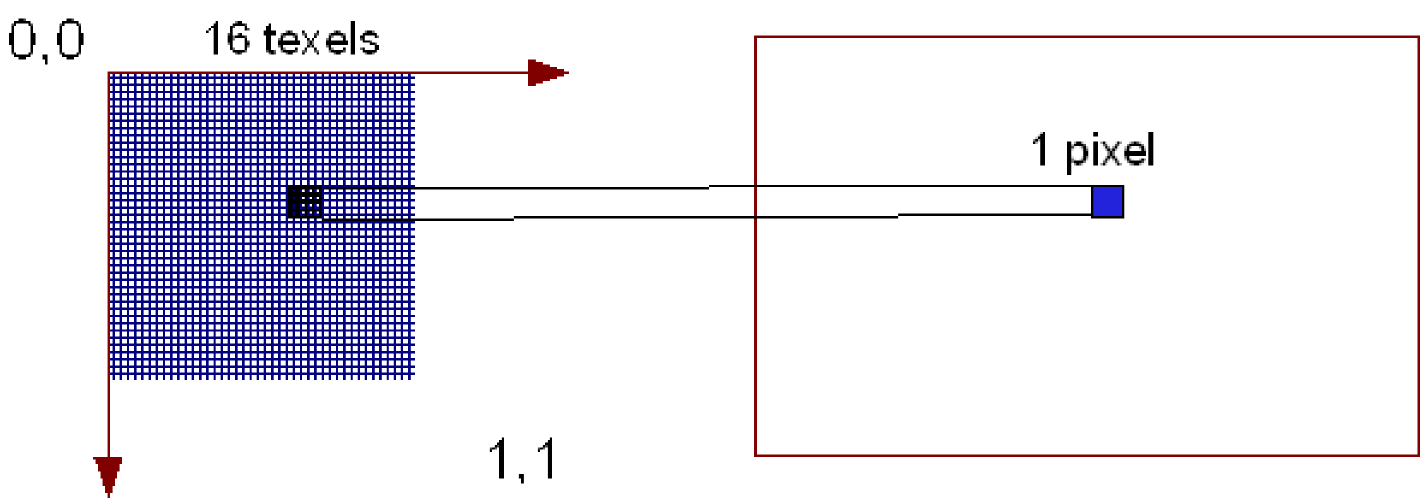


https://cs.senecac.on.ca/~chris.szalwinski/archives/gam666.073/content/textu.html

Based on slides by Steve Marschner

Texture mapping – sampling problems

- Too many texels map to a single image pixel
  - ***Texture Minification*** when textured objects are in the background of the scene.
  - Can use nearest texel, or bi-linearly combine the 4 nearest, but this quickly fails when there is too much minification

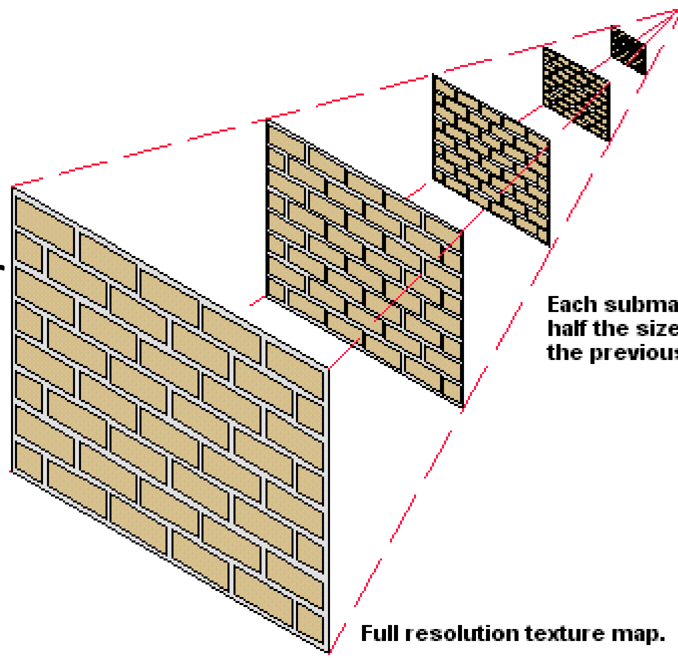


https://cs.senecac.on.ca/~chris.szalwinski/archives/gam666.073/content/textu.html

Based on slides by Steve Marschner

Texture mapping – sampling problems

- ***Mipmapping*** constructs texture at many scales to improve minification
  - Can choose best level, based on how quickly the rasterizer is stepping through texture space
  - Can linearly interpolate between two levels to improve quality



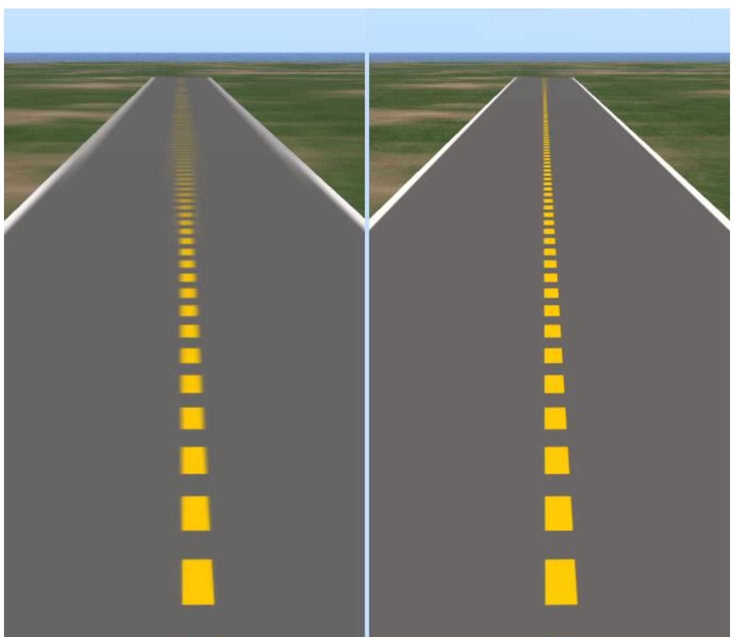
LINEAR_MIPMAP_LINEAR uses 8 samples, bi-linear interpolation of 4 samples at the two closest mipmap resoultions.

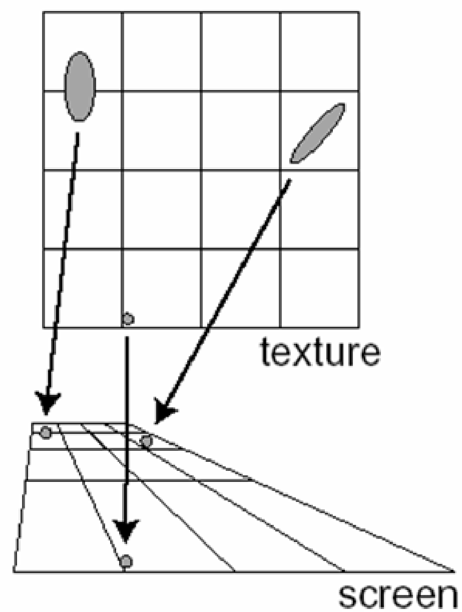
http://www.shinvision.com/wp-content/uploads/2009/06/mipmap.gif

Based on slides by Steve Marschner

Texture mapping – sampling problems

- ***Anisotropic filtering*** can further improve quality by avoiding the use of low resolution mipmaps.
  - Useful for when texture sampling only requires minification in one direction,
  - Choose samples based on where they are needed!





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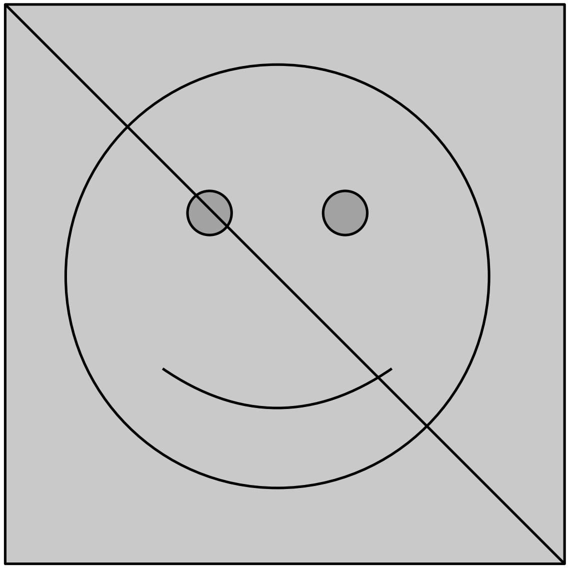
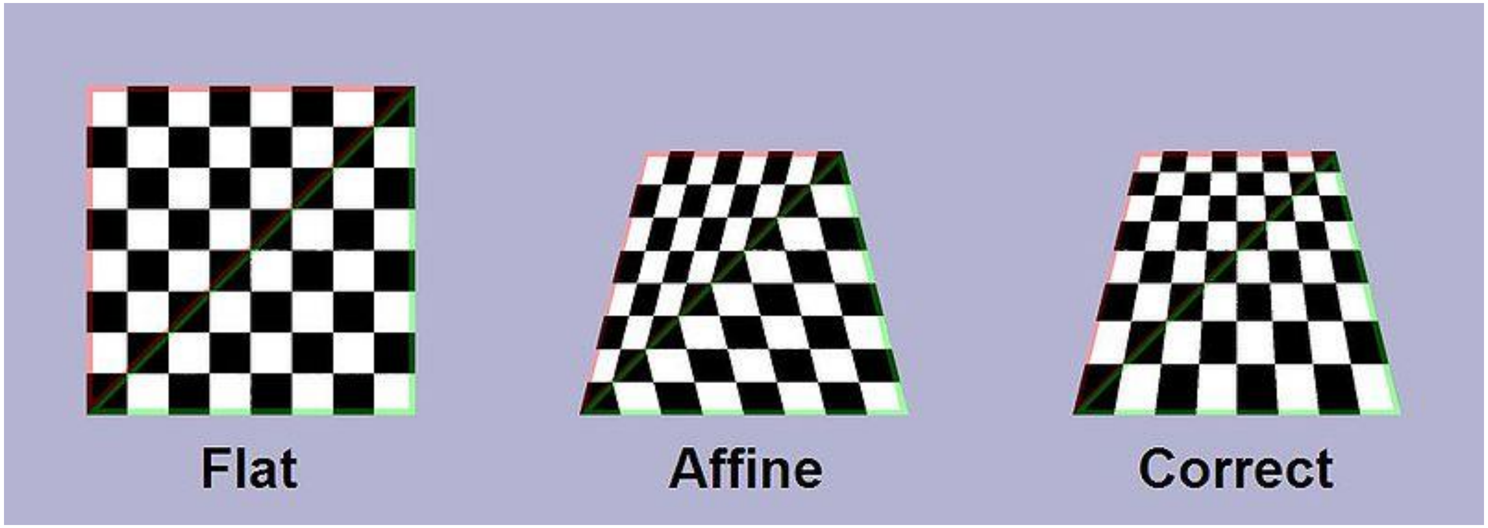
Texture mapping issues

- Quadrilaterals



Texture mapping issues

- Perspective projection



[wikipedia]

Affine texture mapping directly interpolates a texture coordinate u_α between two endpoints u_0 and u_1:

$$u_\alpha = (1-\alpha)u_0 + \alpha u_1 \text{ where } 0 \leq \alpha \leq 1$$

Perspective correct mapping interpolates after dividing by depth z, then uses its interpolated reciprocal to recover the correct coordinate:

$$u_\alpha = \frac{(1-\alpha)\frac{u_0}{z_0} + \alpha\frac{u_1}{z_1}}{(1-\alpha)\frac{1}{z_0} + \alpha\frac{1}{z_1}}$$

Based on slides by Steve Marschner

Review and More Information

- Textbook
  - 11.1 3D Texture Mapping
  - 11.2 2D Texture Mapping
  - 11.3 Texture Mapping for Rasterized Triangles
  - 11.3.1 Perspective correct textures (as an aside)
  - 11.6 Environment Maps
  - Other sections touch on bumps, displacement, shadow maps
- OpenGL Red Book
  - Mipmaps and texturing in general in Chapter 9 (lots of API details beyond what we saw here)
  - http://www.glprogramming.com/red/chapter09.html