Games with Texture Mapping

CS 4620 Lecture 15

Recall first 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.

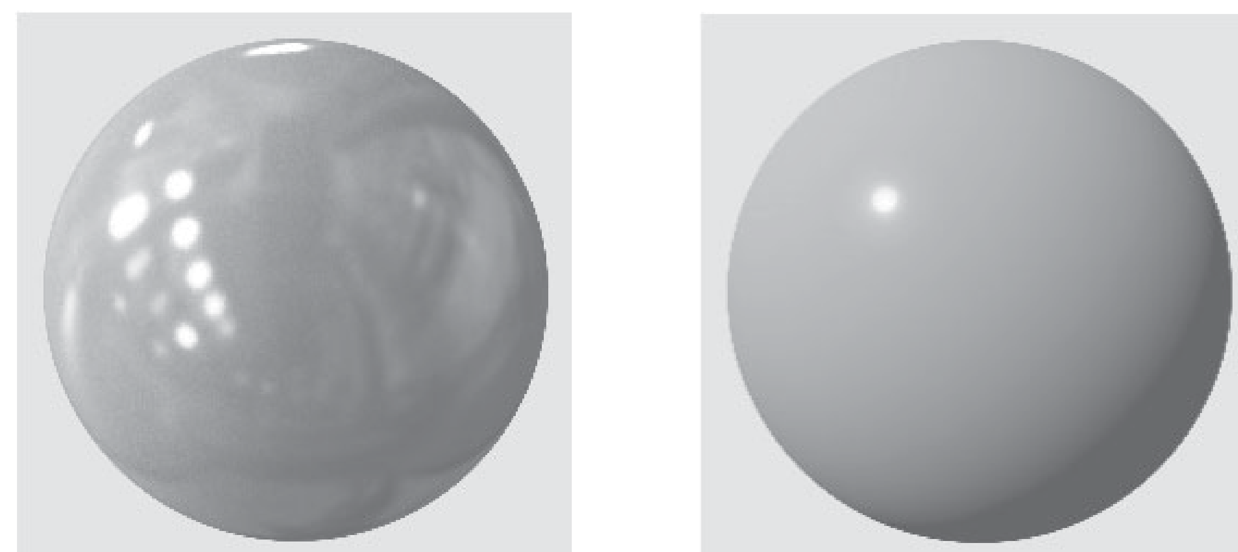
A refined definition

Texture mapping: a set of techniques for defining functions on surfaces, for a variety of uses.

Let's look at some examples of more general uses of texture maps.

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.**



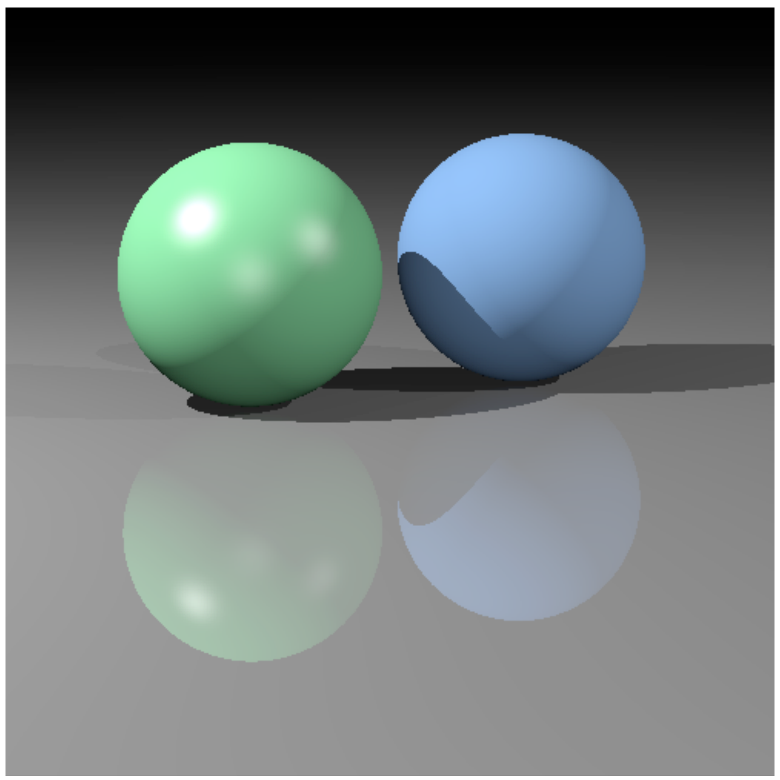
(a) (b)

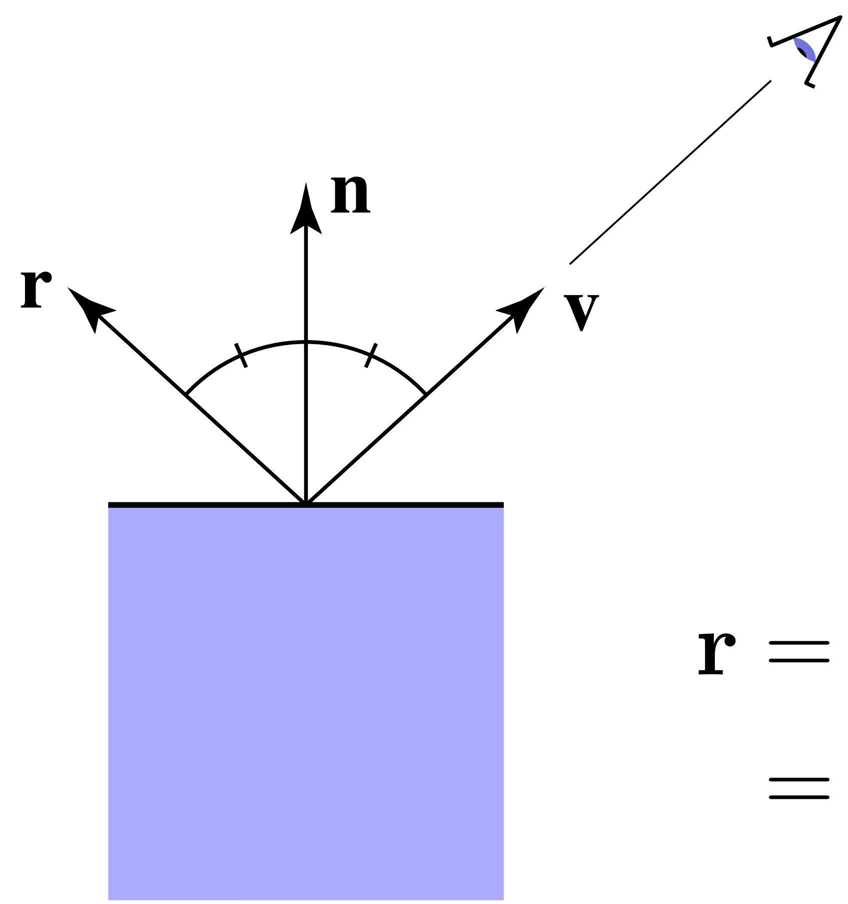
[Dror, Willsky, & Adelson 2004]

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.

Reflections in ray tracing

- **Recall how we can make mirror reflections in ray tracing**





$$\mathbf{r} = \mathbf{v} + 2((\mathbf{n} \cdot \mathbf{v})\mathbf{n} - \mathbf{v})$$
$$= 2(\mathbf{n} \cdot \mathbf{v})\mathbf{n} - \mathbf{v}$$

Reflection mapping

- **If scene is infinitely far away, the color seen by the reflection ray depends only on the direction of the ray**
  – a two-dimensional function
  – represent it with a texture!
- **Environment map: texture that maps directions to colors**
  – one option: axes are (theta, phi)
  – better option: cube map

A spherical panorama, aka. enironment map

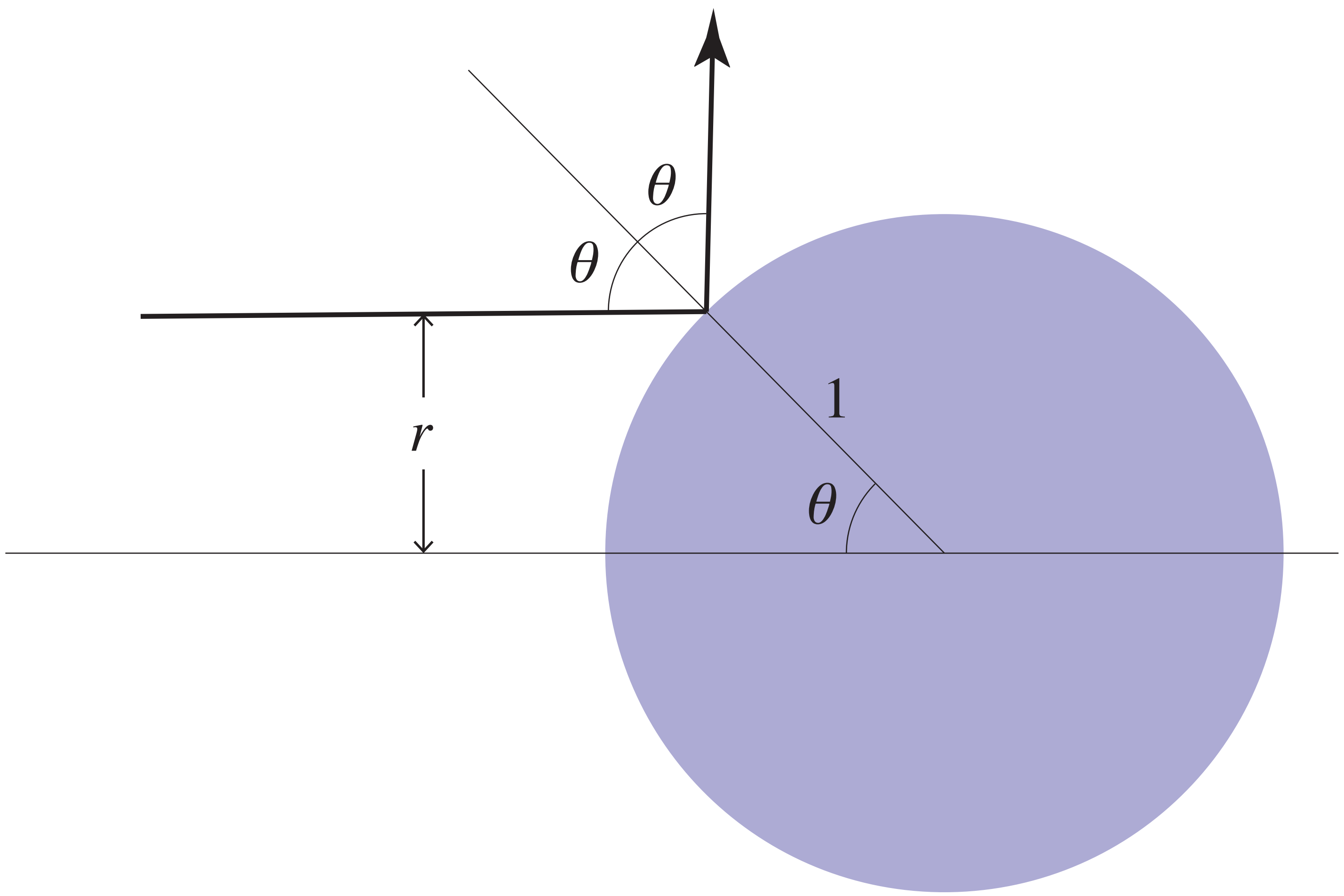
openfootage.net

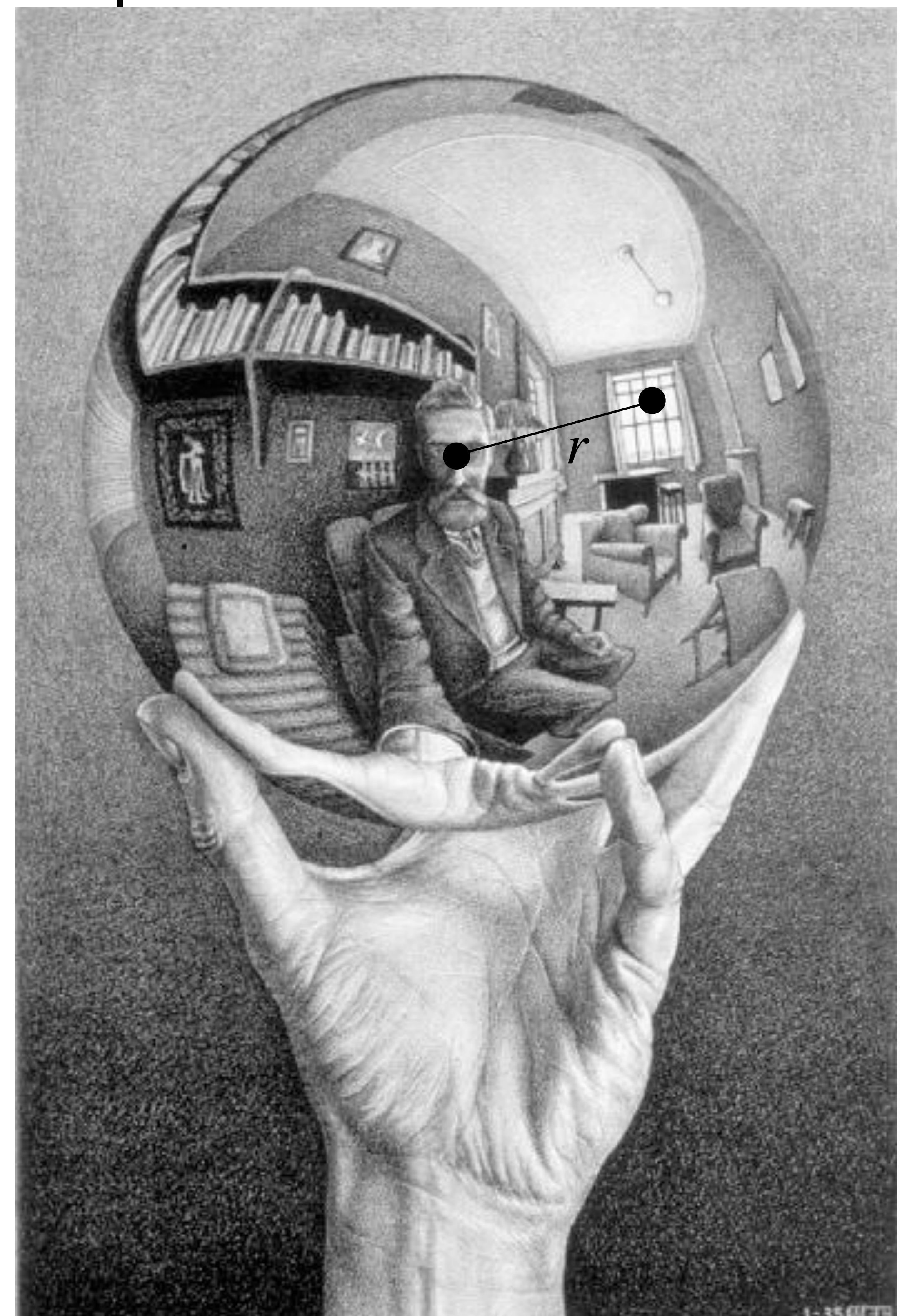
Environment map

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

[Blinn & Newell 1976]

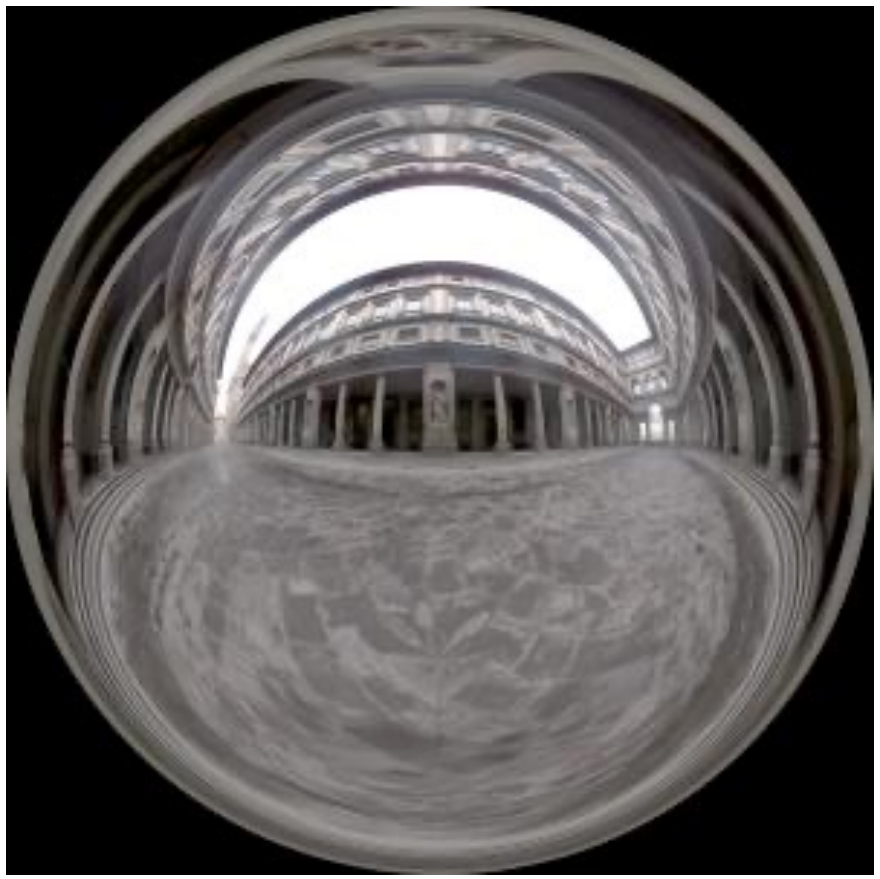
Spherical environment map

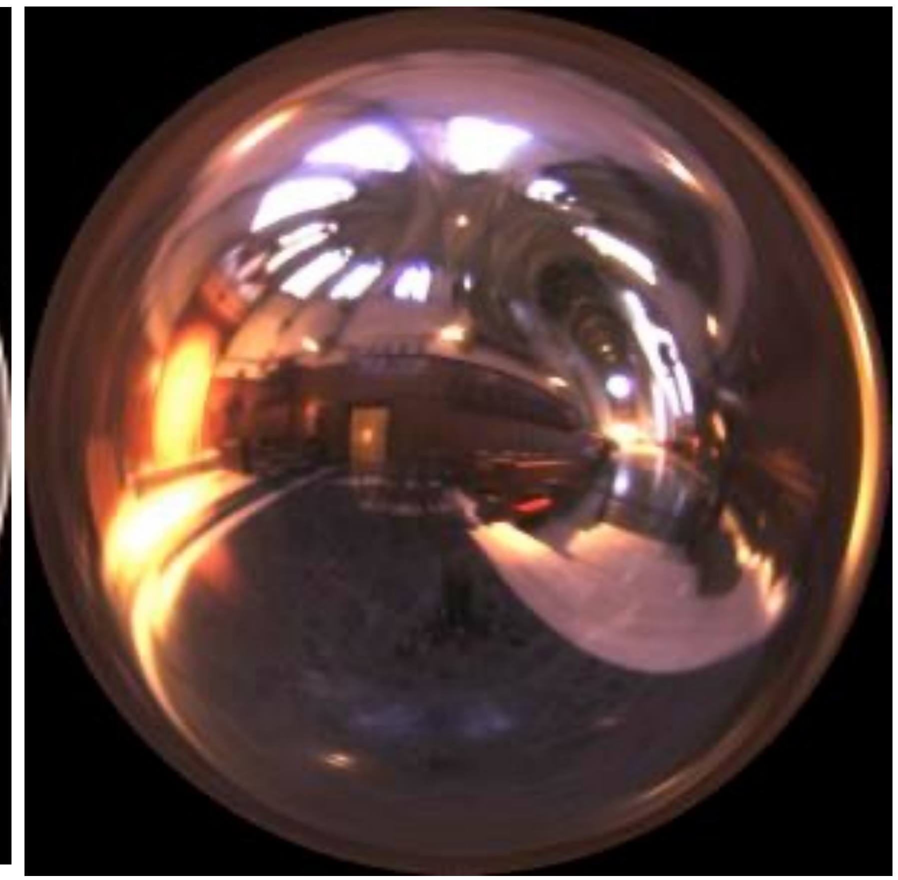




Hand with Reflecting Sphere. M. C. Escher, 1935. lithograph

Environment Maps

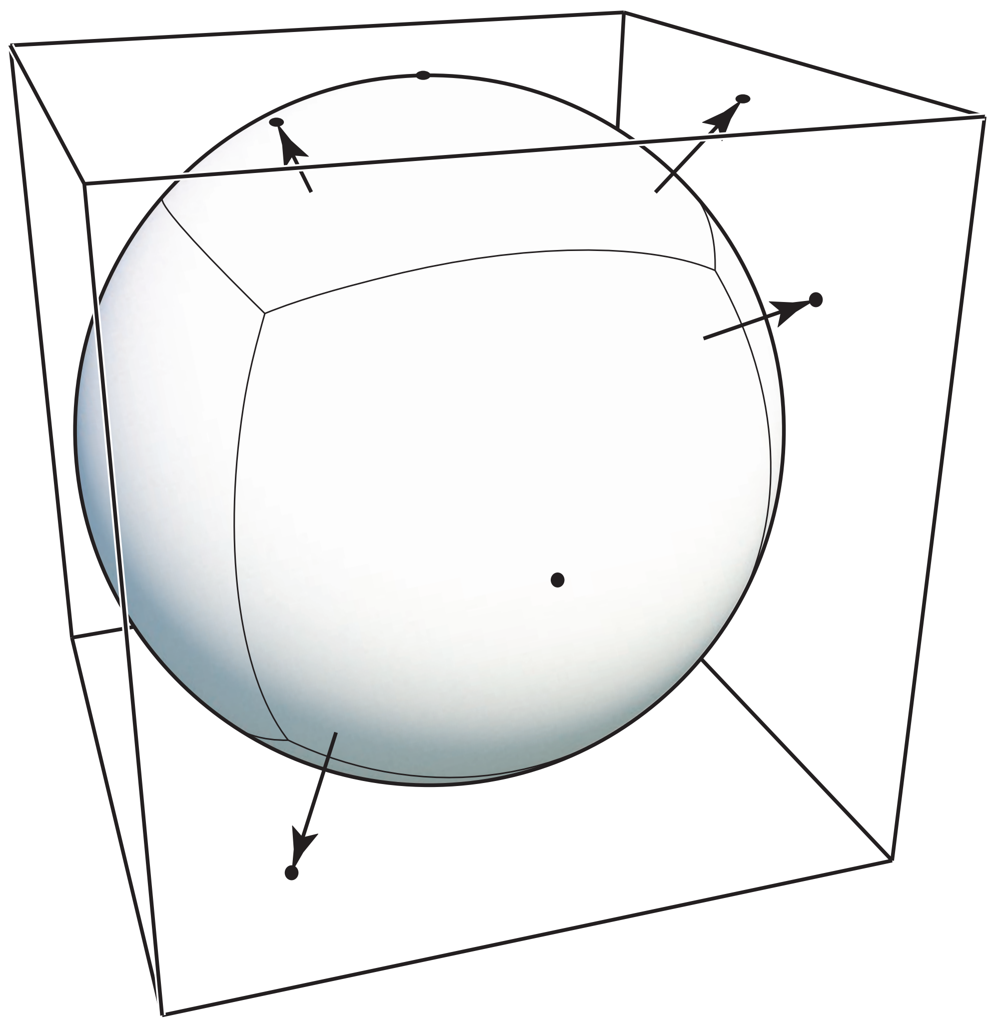


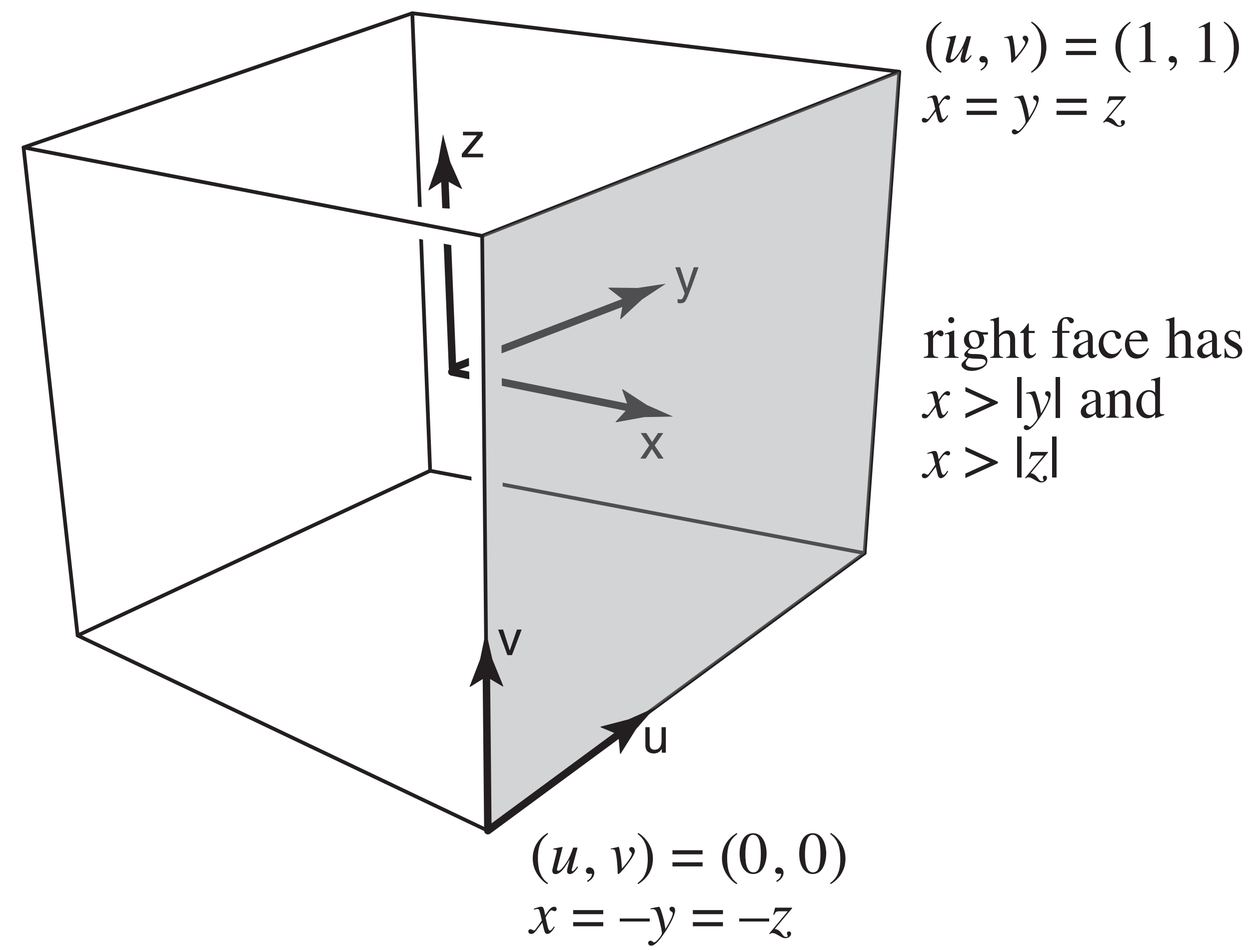


[Paul Debevec]

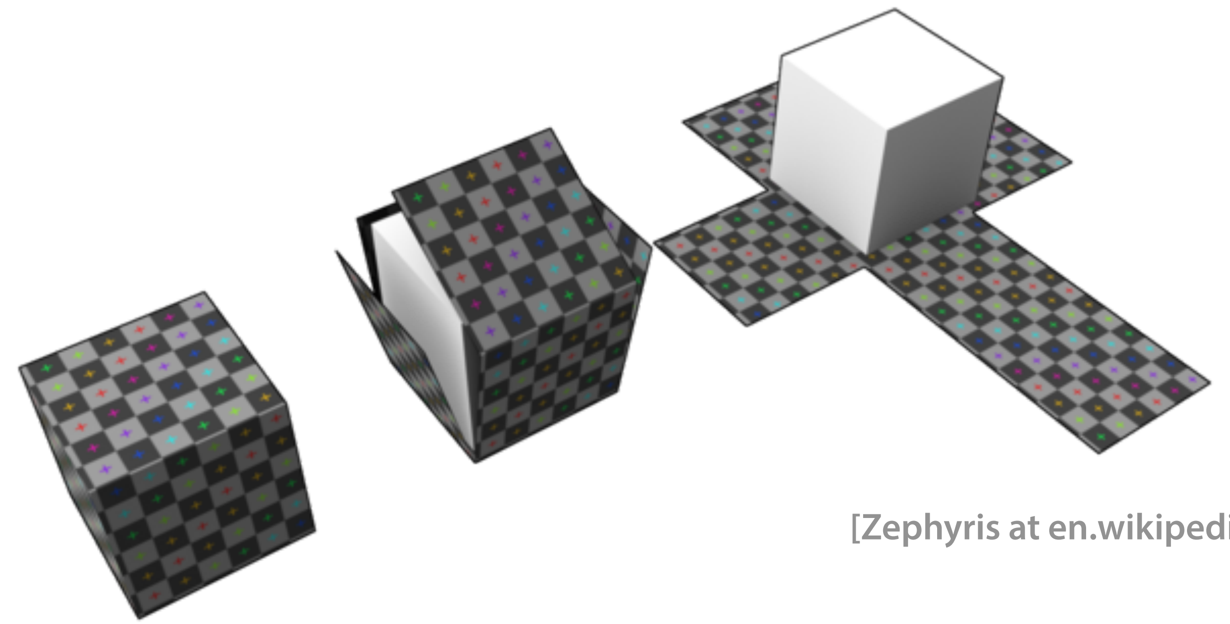
[CS467 slides]

Cube map





a direction vector maps to the point on the cube that is along that direction.
The cube is textured with 6 square texture maps.

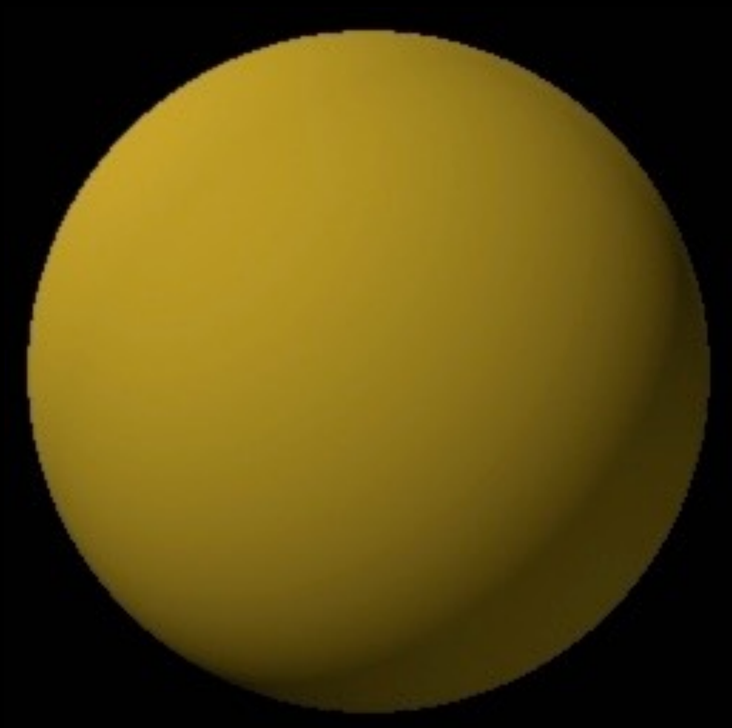


[Zephyris at en.wikipedia]

[Emil Persson]

Reflection mapping in GLSL

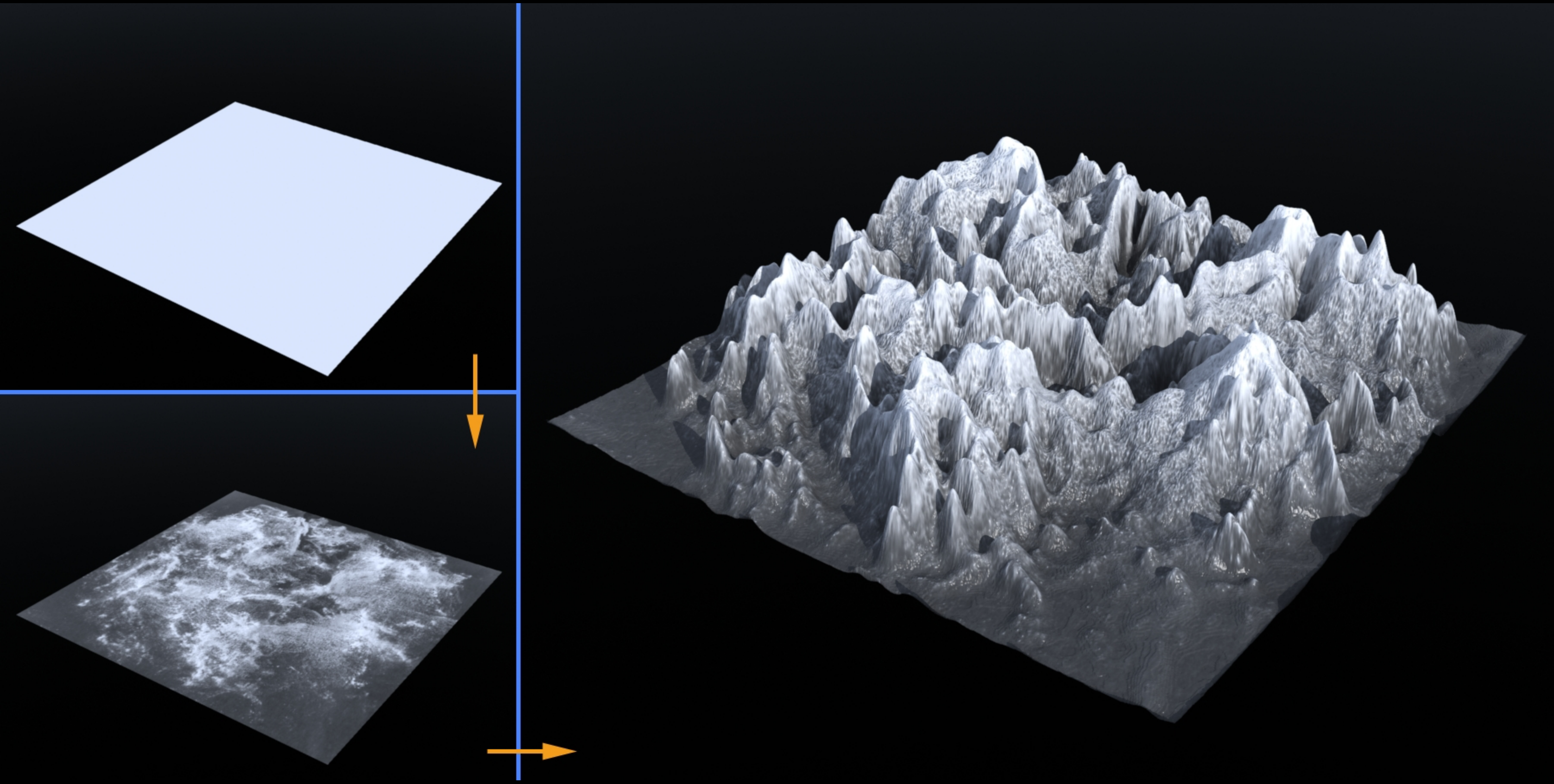
- **A fragment operation**
  - requires surface normal and a way to get the view direction
- **GLSL handles cubemaps by itself**
  - you just give it the reflection vector and it figures out where to sample and on which face
  - sample using `textureCube()`
- **Don't overlook built-in functions**
  - e.g. `reflect()`



Geometry

Displacement mapping

[CS467 slides]



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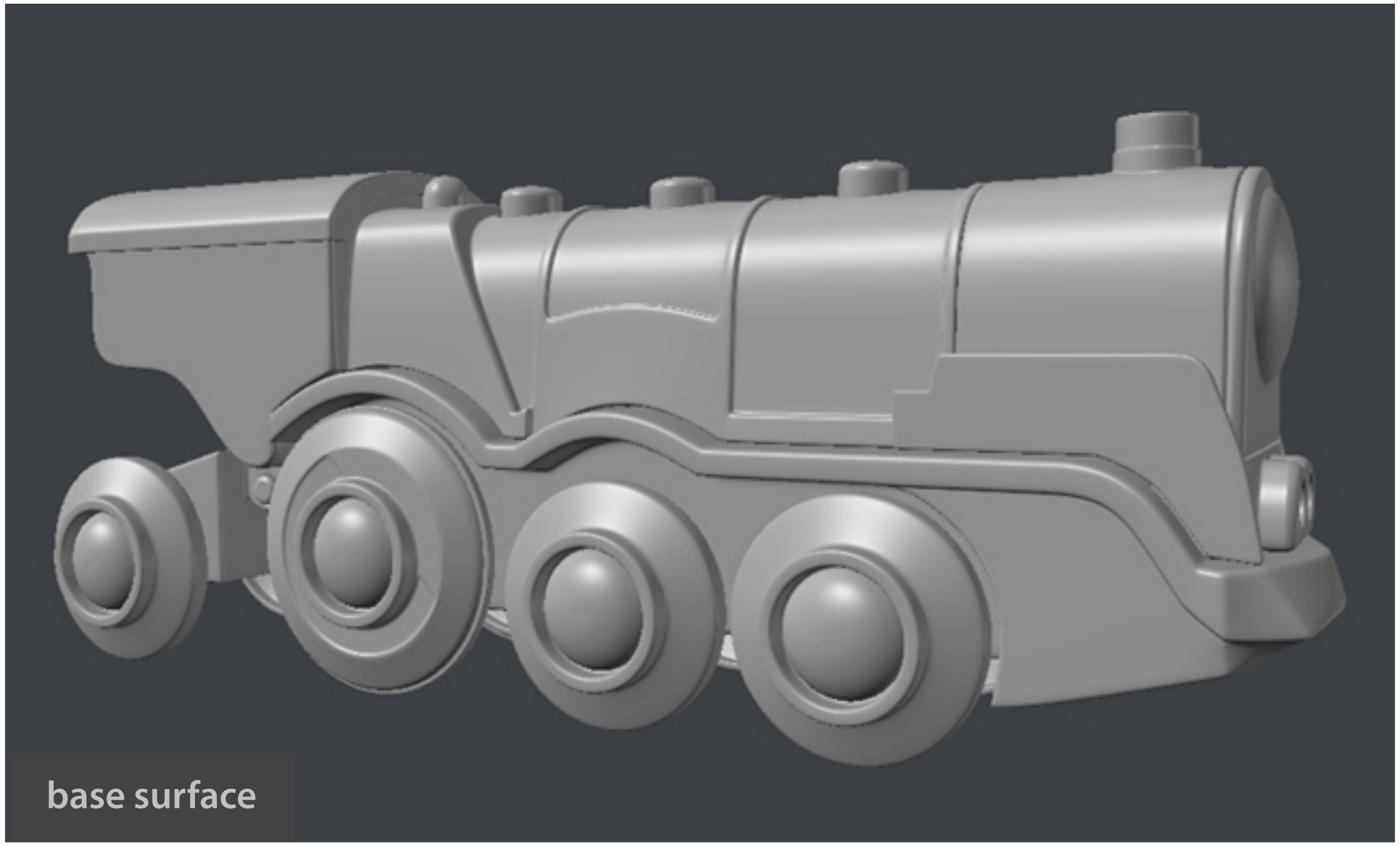
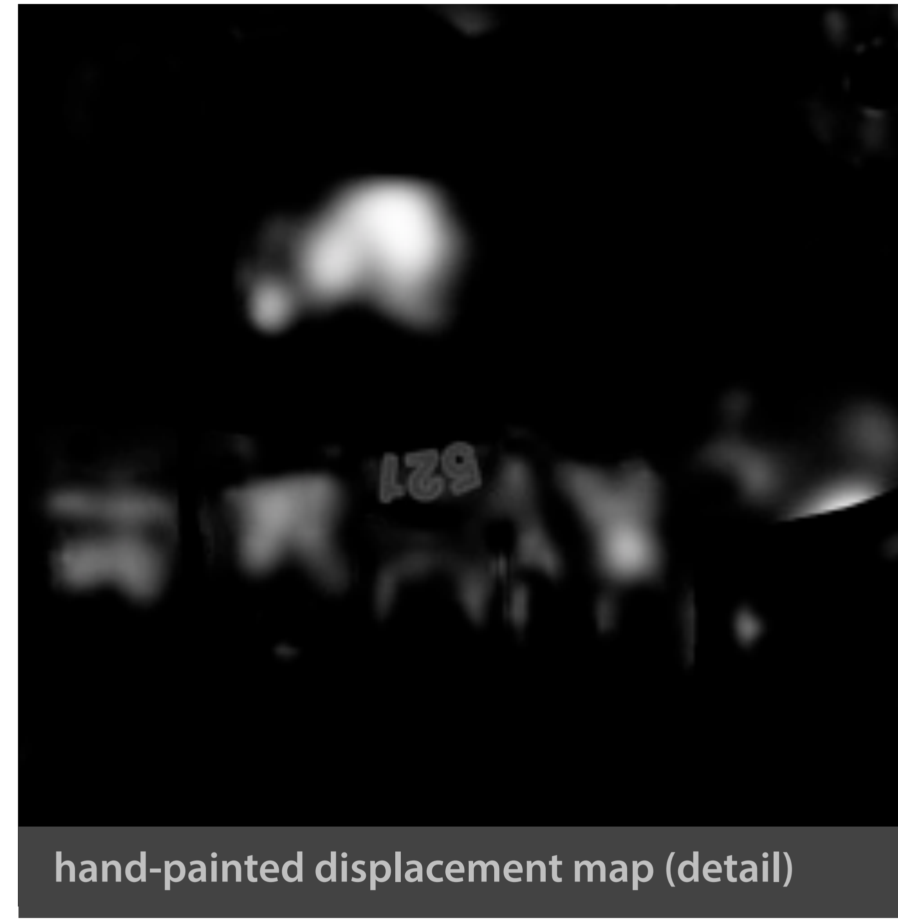
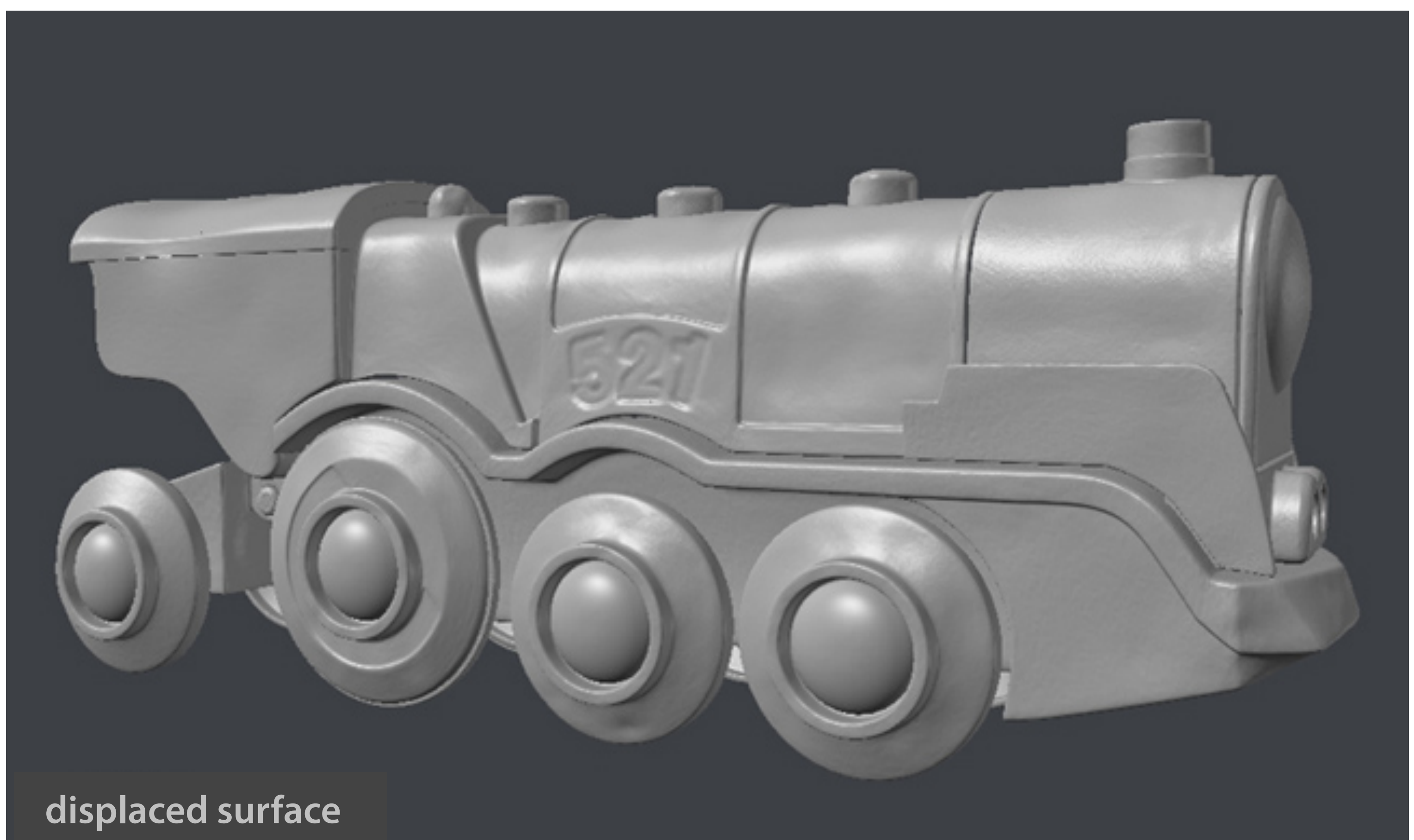


base surface



hand-painted displacement map (detail)



displaced surface

Paweł Filip
tolas.wordpress.com

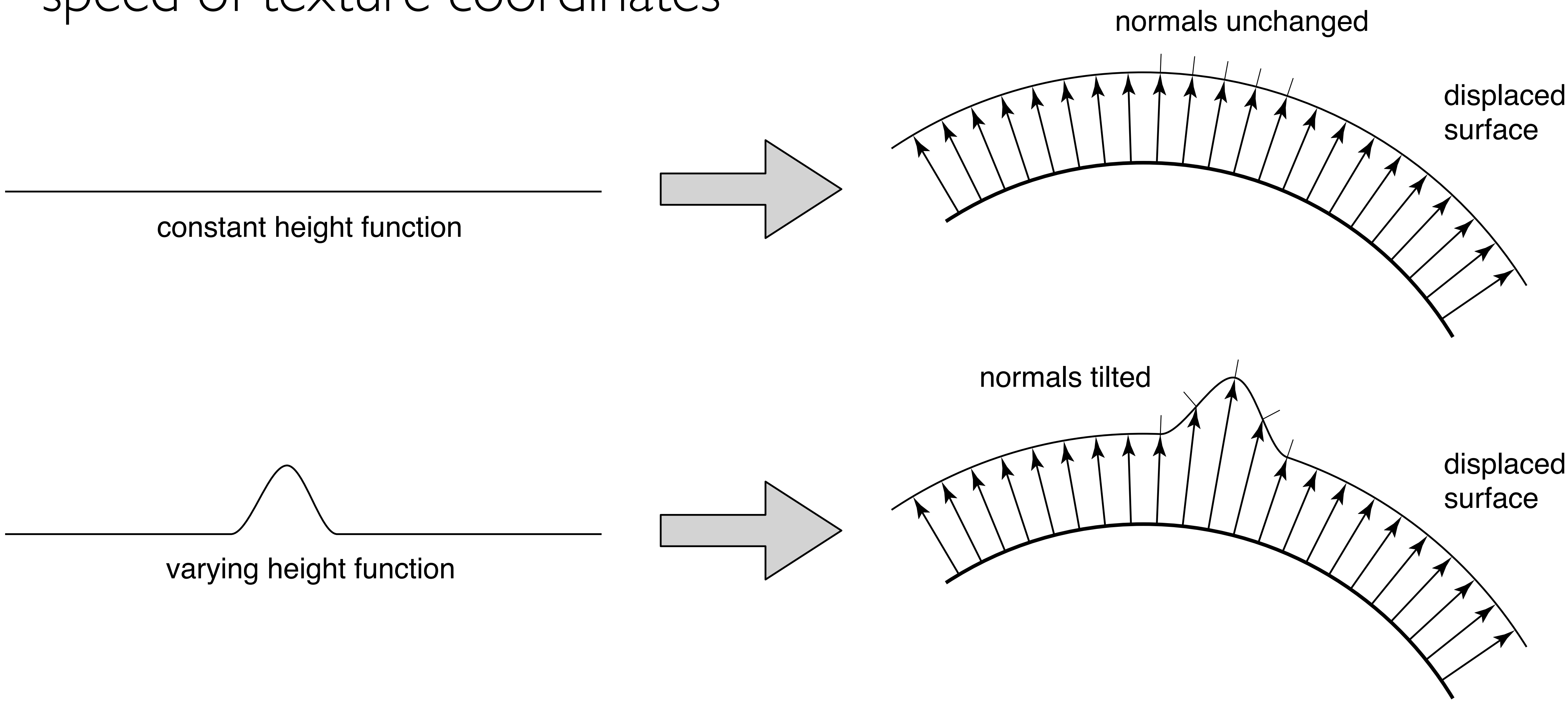

521
fryrender
physically-based render engine
©2007 Paweł Filip

Displacement mapping

- **A powerful tool for modeling detail**
  – used heavily in film production
- **Geometric prerequisites**
  – texture map representing height field
  – smooth normals
  – texture coordinates
  – dense triangulation
- **In GLSL**
  – a vertex operation (because it moves geometry)
  – displace vertices along normal vectors by a distance proportional to texture map value
  – compute new normal to displaced surface

Normals in displacement mapping

- **Displacement changes the surface normal, depending on:**
  - derivative of height function
  - orientation of texture coordinates
  - speed of texture coordinates



Normals in displacement mapping

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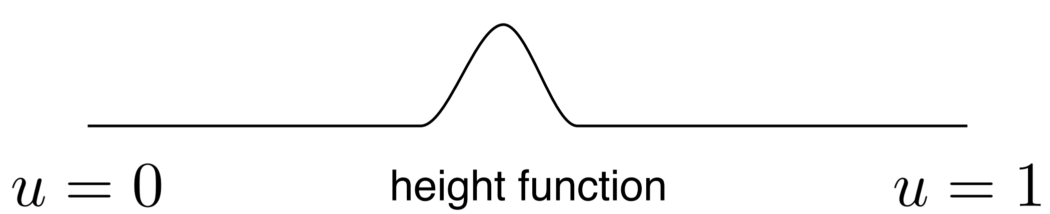
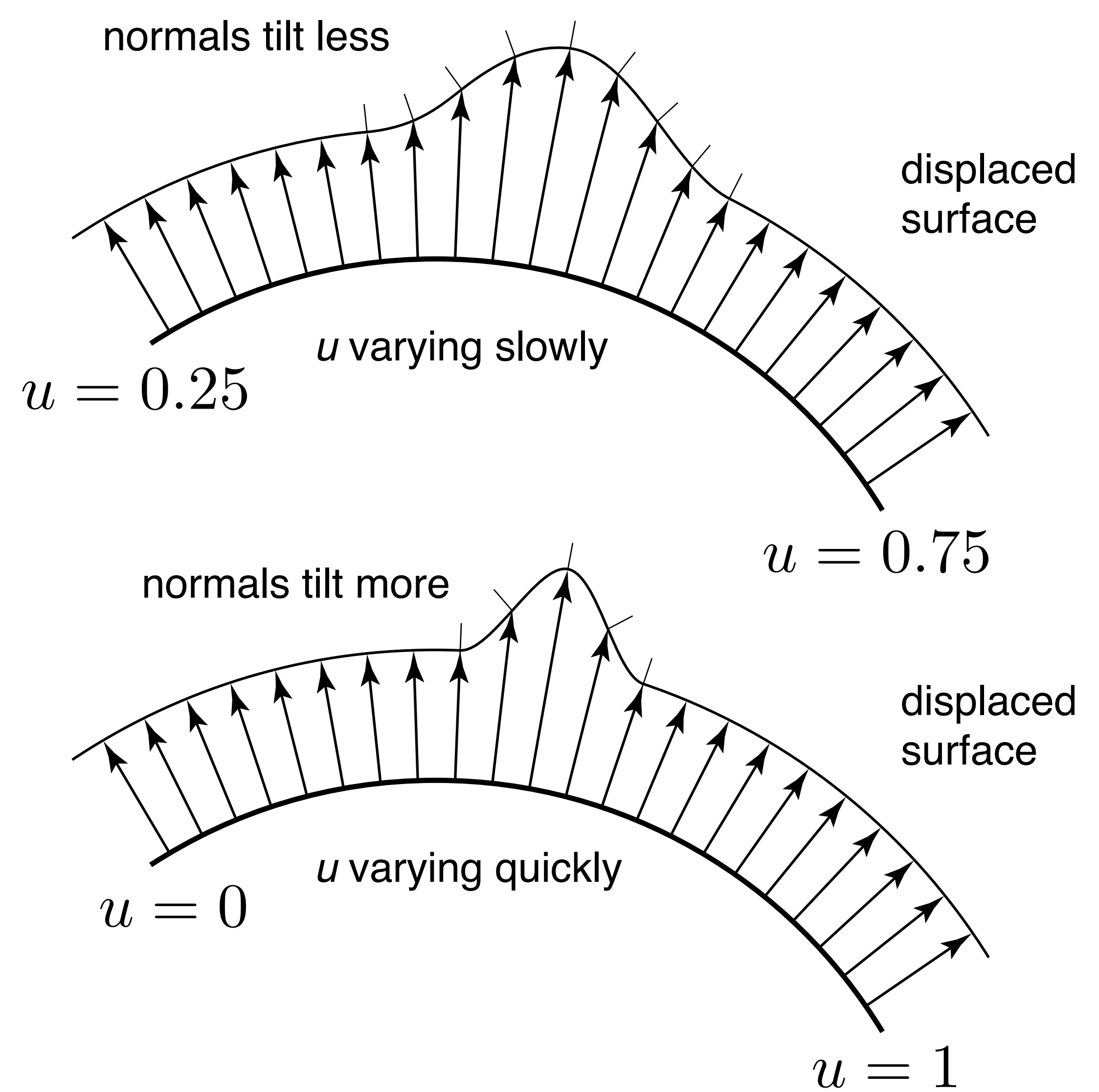




Displacement mapping math

- **Start with a parametric surface and a height function**

$$\mathbf{p}(u, v) : \mathbb{R}^2 \to \mathbb{R}^3 \qquad h(u, v) : \mathbb{R}^2 \to \mathbb{R}$$

  – Recall the tangent vectors are the partial derivatives of p

$$\mathbf{t}_u(u, v) = \frac{\partial \mathbf{p}}{\partial u}(u, v) \qquad \mathbf{t}_v(u, v) = \frac{\partial \mathbf{p}}{\partial v}(u, v)$$

  – …and the normal vector is the cross product of the two tangents.

$$\mathbf{n}(u, v) = \mathbf{t}_u(u, v) \times \mathbf{t}_v(u, v)$$

  – We normalize to make unit tangents and normals, when needed

$$\hat{\mathbf{t}_u} = \frac{\mathbf{t}_u}{\|\mathbf{t}_u\|} \qquad \hat{\mathbf{t}_v} = \frac{\mathbf{t}_v}{\|\mathbf{t}_v\|} \qquad \hat{\mathbf{n}} = \frac{\mathbf{n}}{\|\mathbf{n}\|} = \hat{\mathbf{t}}_u \times \hat{\mathbf{t}}_v$$

Displacement mapping math

- **Define displaced surface by adding an offset along the normal**

$$\mathbf{p}^d(u,v) = \mathbf{p}(u,v) + h(u,v)\hat{\mathbf{n}}(u,v)$$

(unit normal here because we want *h* to measure the displacement distance)

- **Tangents to the displaced surface**
  – start with tangent in the direction of the *u* texture coordinate

$$\frac{\partial \mathbf{p}^d}{\partial u}(u,v) = \frac{\partial \mathbf{p}}{\partial u}(u,v) + \frac{\partial h}{\partial u}(u,v)\hat{\mathbf{n}}(u,v) + h(u,v)\frac{\partial \hat{\mathbf{n}}}{\partial u}(u,v)$$

  – last term gets messy but only matters for large displacements relative to surface curvature; throw it out. Then the tangents are

$$\mathbf{t}_u^d(u,v) = \mathbf{t}_u(u,v) + \frac{\partial h}{\partial u}(u,v)\,\hat{\mathbf{n}}(u,v)$$

$$\mathbf{t}_v^d(u,v) = \mathbf{t}_v(u,v) + \frac{\partial h}{\partial v}(u,v)\,\hat{\mathbf{n}}(u,v)$$

(non-unit tangents here because the correct result depends on their length)

Displacement mapping math

- **Last step is to compute the normal to the displaced surface**

$$\mathbf{n}^d = \mathbf{t}_u^d \times \mathbf{t}_v^d$$

$$\hat{\mathbf{n}}^d = \frac{\mathbf{n}^d}{\|\mathbf{n}^d\|}$$

Geometry for displacement

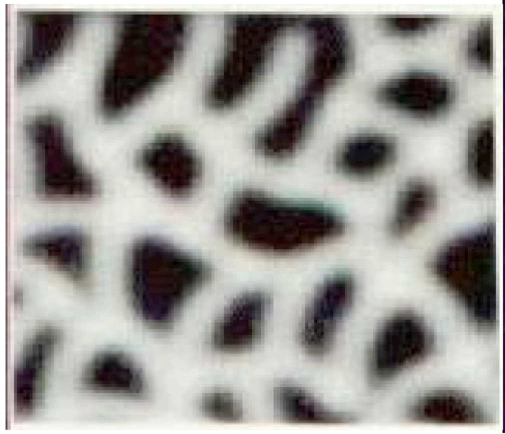
- **geometric inputs**
  - *u* derivative (unnormalized tangent) as vertex attribute
  - *v* derivative (unnormalized tangent) as vertex attribute
  - height field as a texture
- **vertex stage**
  - compute displaced vertex position
    - look up displacement value from texture
  - compute normal to displaced surface
    - compute derivatives of height by finite differences
    - add offset to the base surface tangents
    - normalized cross product is the shading normal
- **fragment stage: just compute shading**

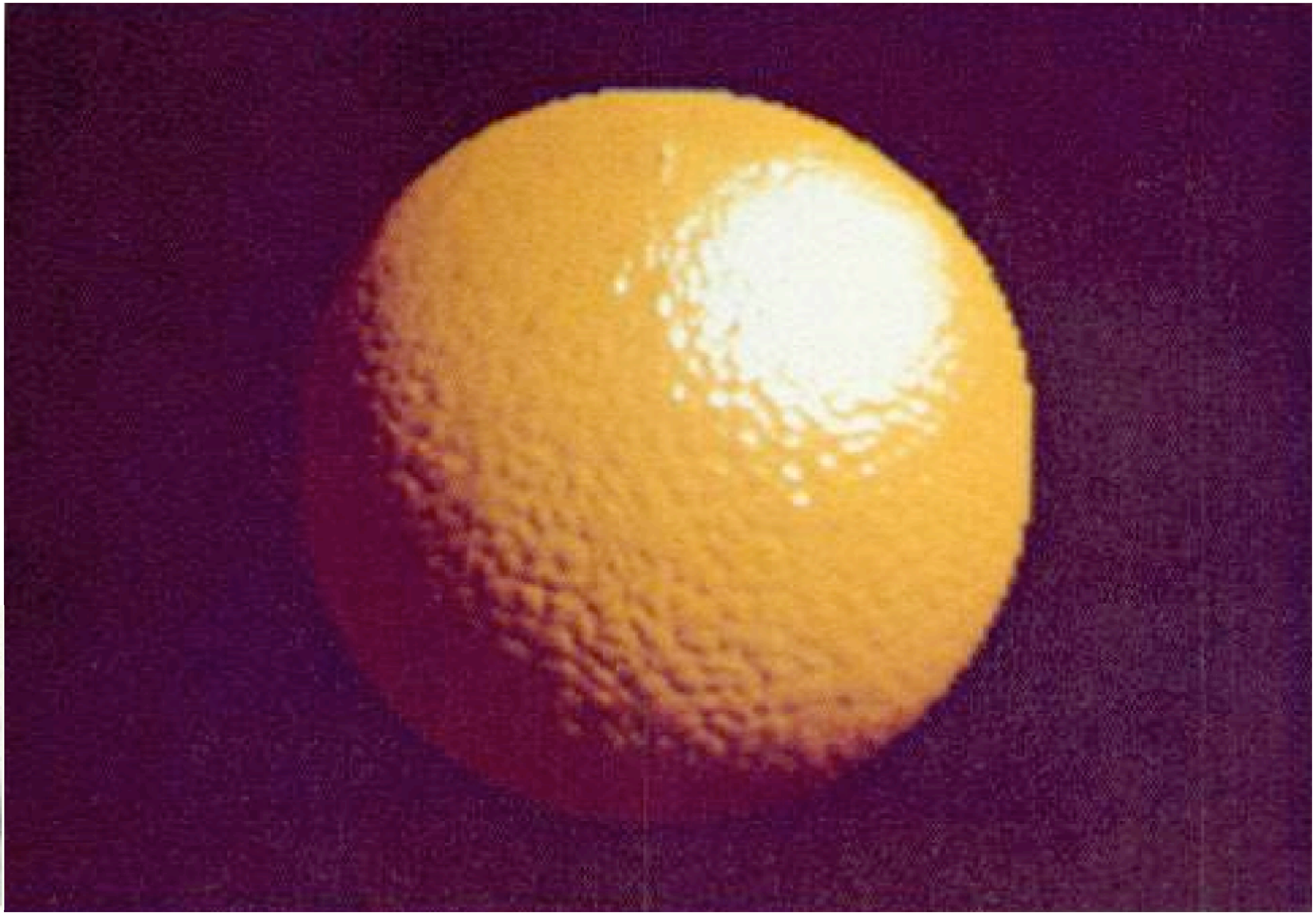
(or compute them ahead of time and store height and derivatives in a 3-channel texture)

Computing tangent vectors

- **How do we get these tangent vectors?**
  - they need to be stored at vertices on the mesh, like normals
- **For a triangle, there's a unique linear map from (u,v) to (x,y,z)**
  - the derivatives of that map are the (non-unit) tangents
  - can be computed by solving three 2x2 linear systems
  - math resembles triangle setup for rasterization; details here
- **For displacement mapping you want to leave the tangents unnormalized and non-orthogonal**
- **For other uses it's often handy to make the two tangents and the normal into an ONB**
  - use exactly the basis-from-two math that we have used for cameras and manipulators

Bump mapping

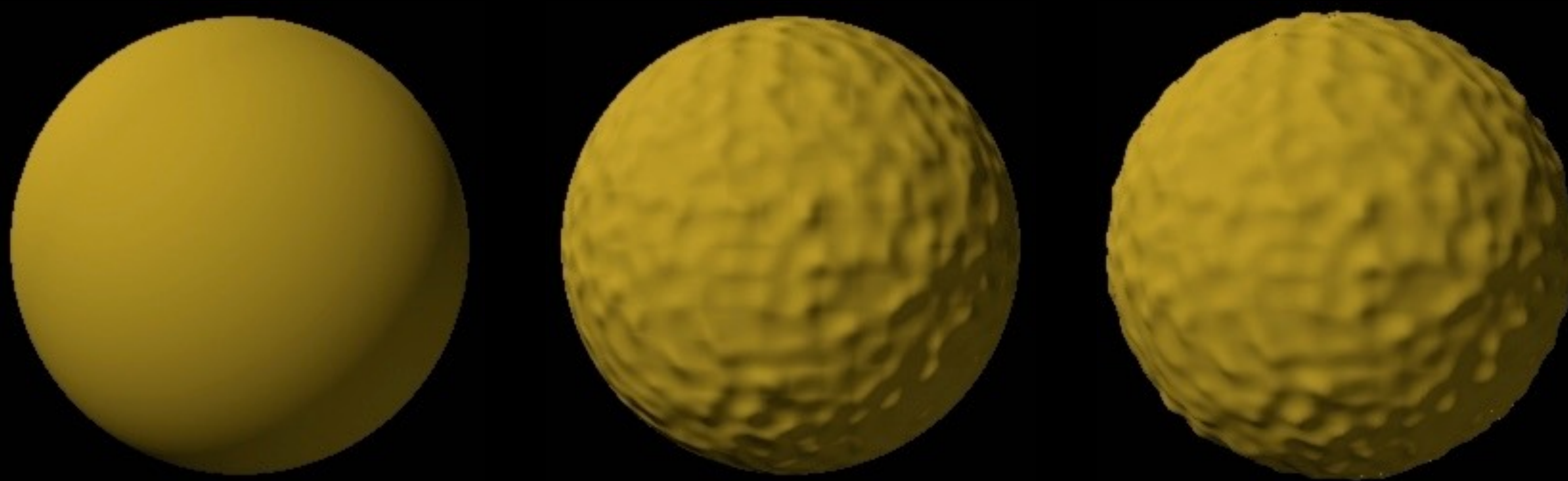




[Blinn 1978]

Bump mapping

- **Displacement mapping is expensive**
  - requires densely tessellated geometry
  - many triangles to rasterize
- **For small displacements, the most important effect is on the normal**
  - so just do that part; don't displace the surface
- **Bump mapping is then a fragment operation**
  - doesn't require dense tessellation
  - doesn't actually displace the surface
  - gives shading that looks just like displaced surface



Geometry

Bump mapping

Displacement mapping

[CS467 slides]

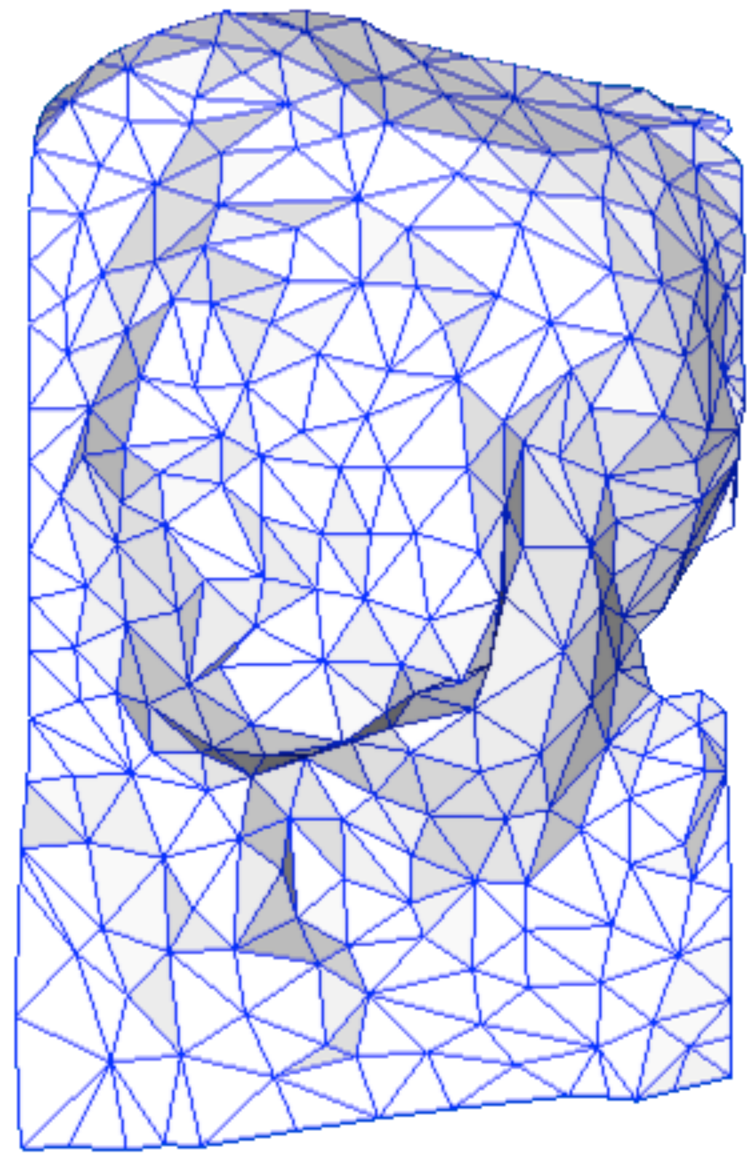
Bump mapping

- **Geometric inputs**
  - derivative vectors (unnormalized tangents) as vertex attributes
  - height field as a texture
  - no dense triangulation needed
- **Vertex phase**
  - simply transform and pass through the position and tangents
- **Fragment phase**
  - compute normal to displaced surface
    - compute derivatives of height by finite differences
    - add offset to the base surface tangents
    - normalized cross product is the shading normal
  - compute shading using displaced normal

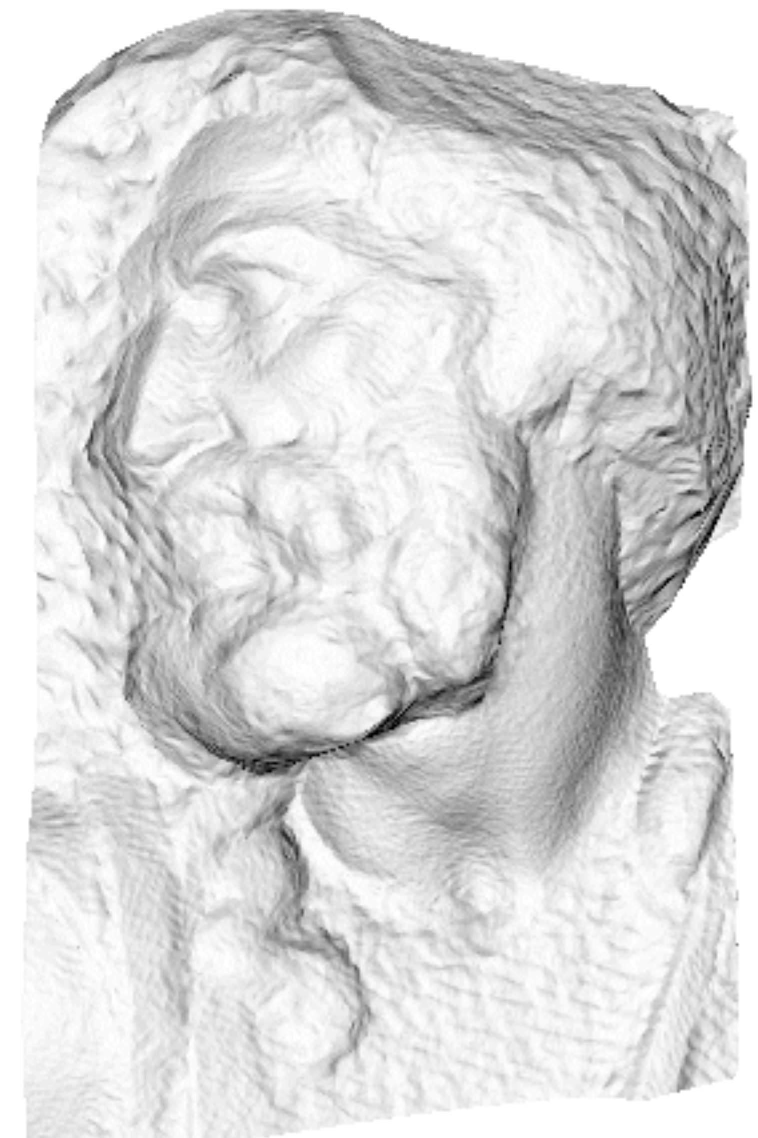
(or compute them ahead of time and store in a 2-channel texture)

Normal mapping

original mesh
4M triangles



simplified mesh
500 triangles



simplified mesh
and normal mapping
500 triangles

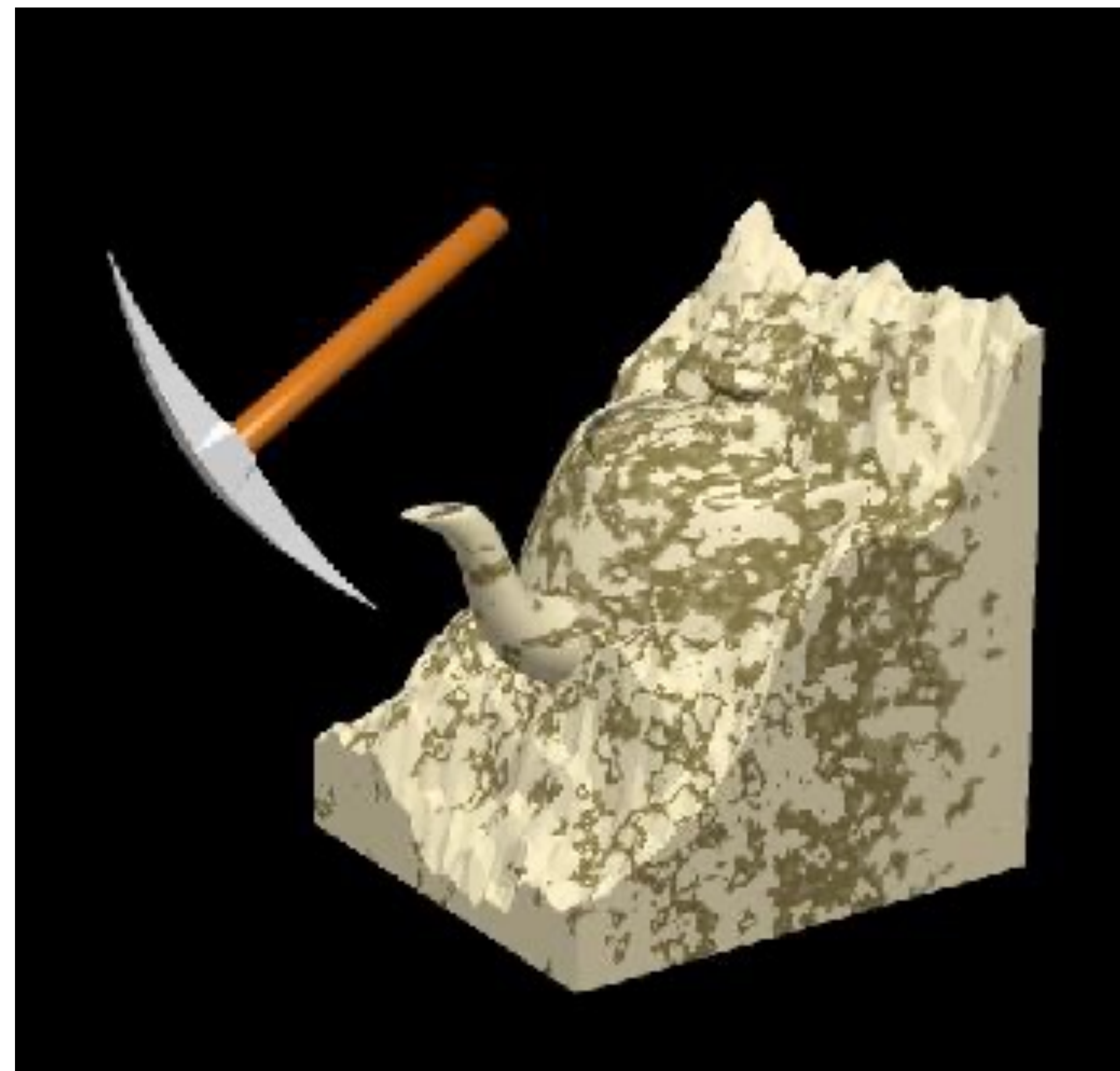
[Paolo Cignoni]

Normal mapping

- **Geometric prerequisites**
  - Texture map (3 channels) representing normal field
    - single lookups into normal map required
  - Smooth normals
  - Unit tangent vectors (normalized, orthogonal)
  - No dense triangulation needed
  - No finite differencing needed
- **Geometric logic**
  - look up normal from map
  - transform into (tangent-u, tangent-v, normal) space

3D textures

- **Texture is a function of (*u*, *v*, *w*)**
  – can just evaluate texture at 3D surface point
  – good for solid materials
  – often defined procedurally
  – see book for more!



[Wolfe / SG97 Slide set]

