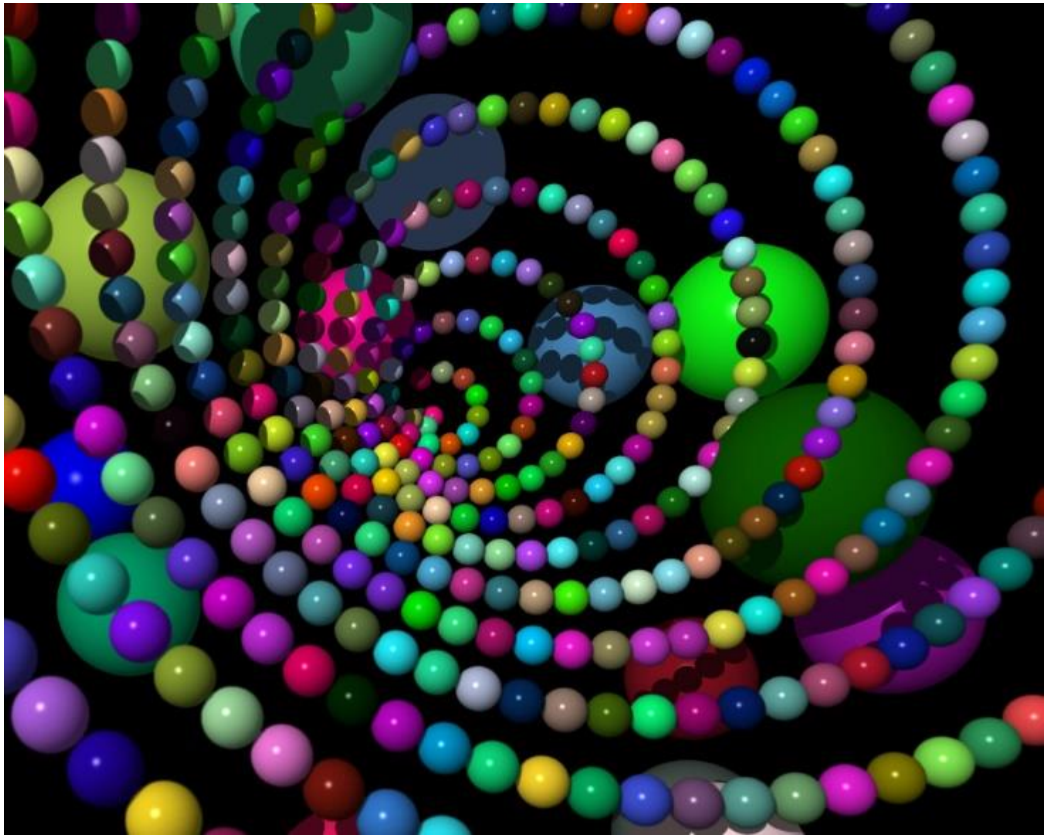
Computer Graphics

Texture Mapping

Introduction and Motivation

- so far: detail through polygons & materials
- images look very “plasticy”



[image: Marijn Stollenga]

Introduction and Motivation

- example: brick wall
- problem: extremely many polygons & materials needed for detailed structures
  $\rightarrow$ inefficient for memory and processing
- new approach necessary: texture mapping
- introduced by Ed Catmull (1974), extended by Jim Blinn (1976)

Introduction and Motivation

- several properties can be modified
  - color: diffuse component of surface
  - reflection: specular component of surface to simulate reflection (environment mapping)
  - normal vector: simulate 3D surface structure (bump mapping)
  - actual surface: raise/lower points to actually modify surface (displacement mapping)
  - transparency: make parts of a surface entirely or to a certain degree transparent

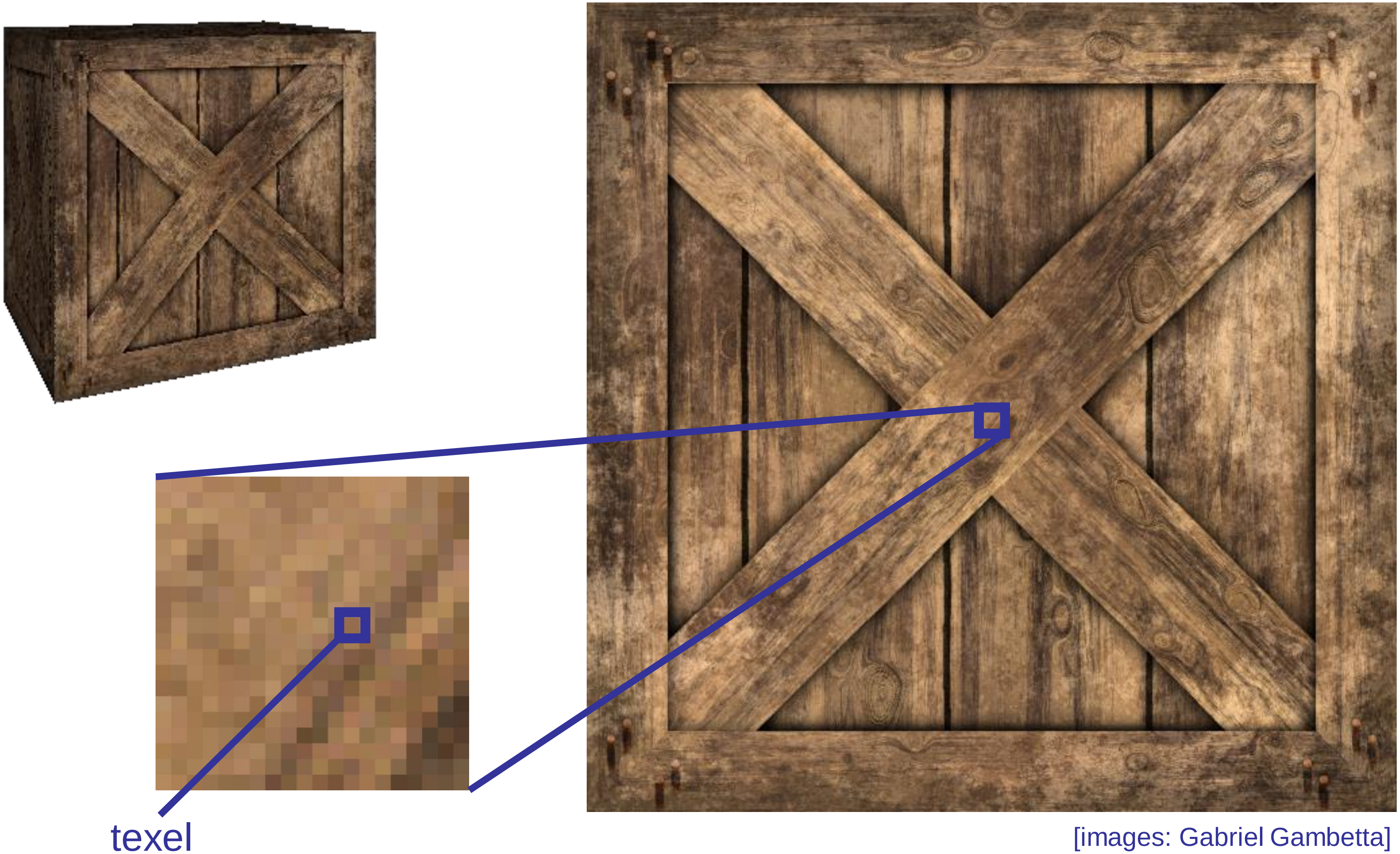
Texture Mapping

General Approach

Texture Mapping

- **texture**: typically 2D pixel image
- **texel**: pixel in a texture
- determines the appearance of a surface
- procedure to map the texture onto the surface needed
  - easy for single triangle
  - complex for arbitrary 3D surface
- goal: find easy way to do this mapping

Texture Mapping



[images: Gabriel Gambetta]

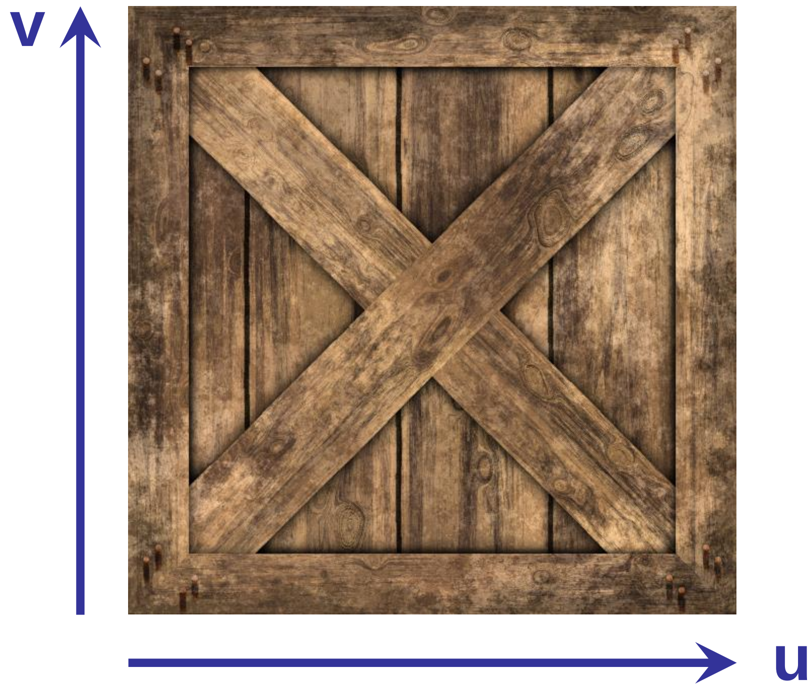
Texture Mapping

- rendering pipeline slightly modified to use new texture mapping function

- algorithm: for each pixel to be rendered
  - find depicted surface point
  - find point in texture (texel) that corresponds to surface point
  - use texel color to modify the pixel’s shading

Texture Mapping: Definitions

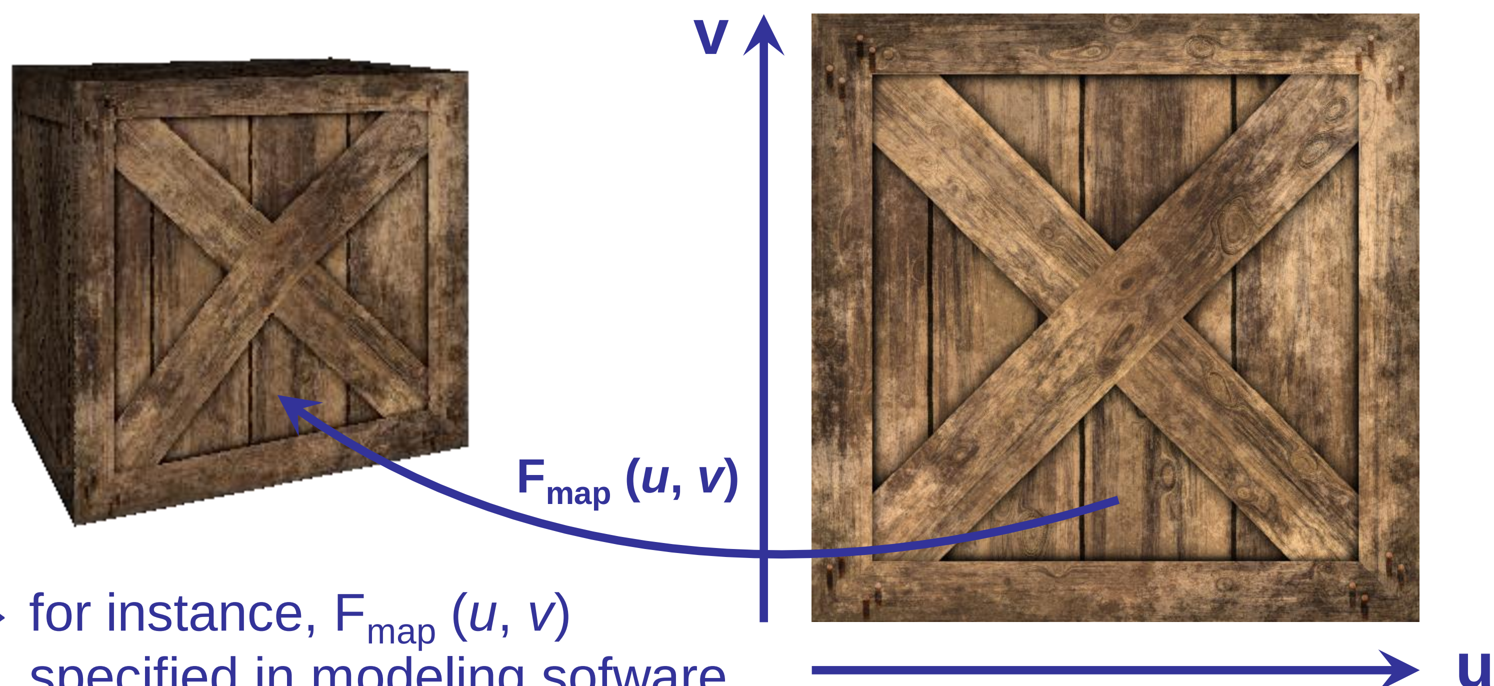
- 2D texture: function that maps points on the (u, v) plane to (r, g, b) values: $(r, g, b) = c_{tex}(u, v)$



[image: Gabriel Gambetta]

Texture Mapping: Definitions

- texture mapping function maps (u, v) values to (x, y, z) positions on objects: (x, y, z) = F_{map} (u, v)

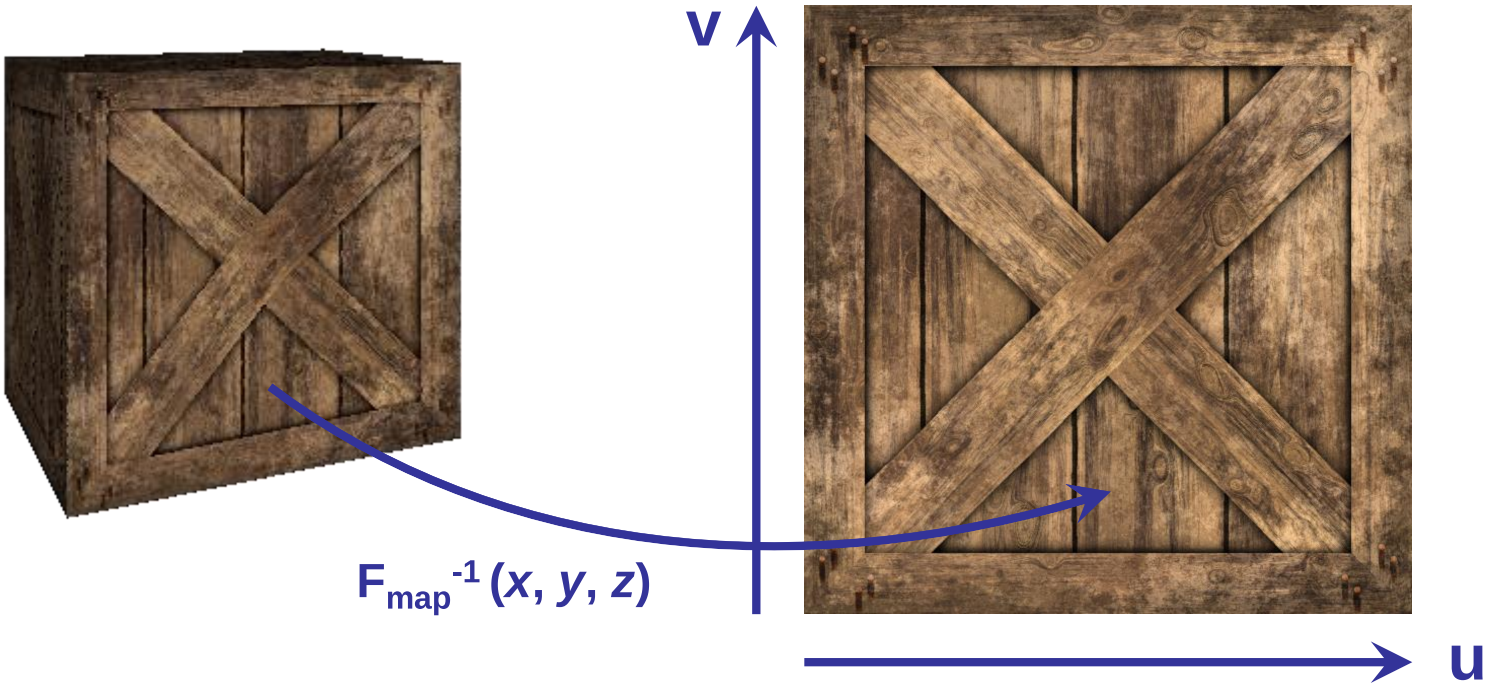


→ for instance, F_{map} (u, v) specified in modeling sofware

[images: Gabriel Gambetta]

Texture Mapping: Definitions

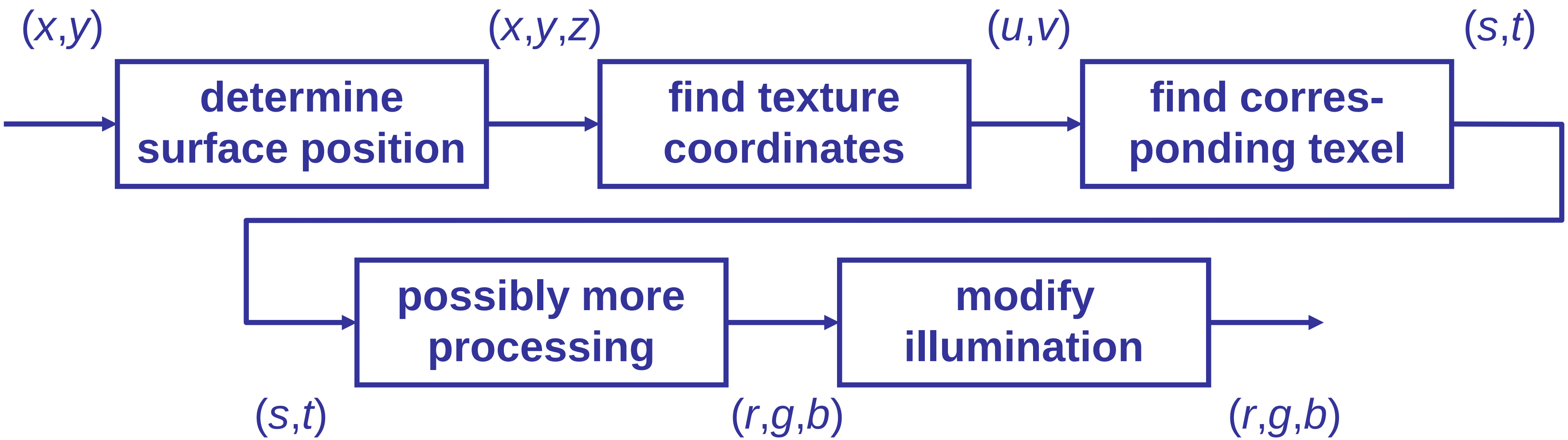
- for rendering, we need to solve the inverse function: find (u, v) for a (x, y, z) position: $(u, v) = F_{map}^{-1}(x, y, z)$



[images: Gabriel Gambetta]

Texture Mapping: General Procedure

- general texture mapping pipeline:



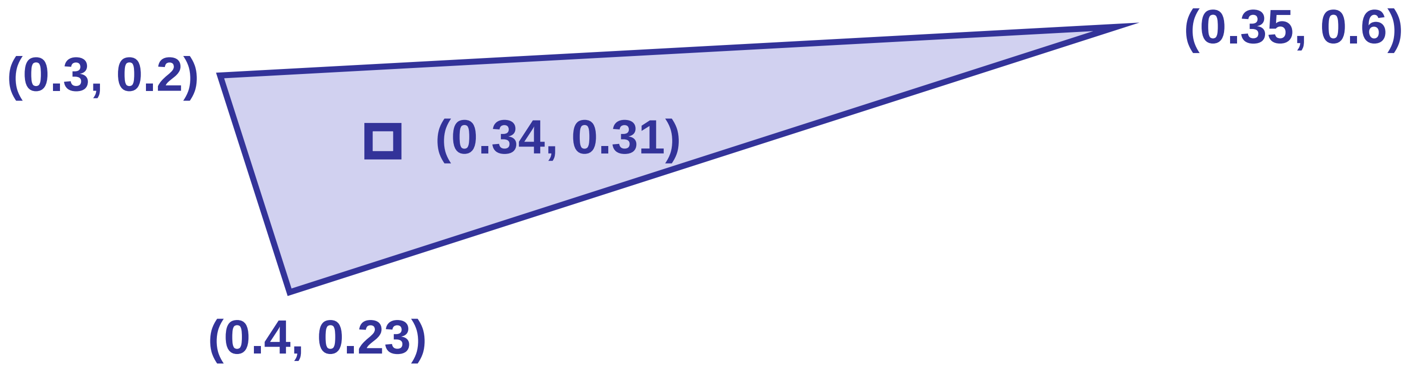
1. compute texture color for surface point
2. use to modify parameters in Phong illumination

u,v-Coordinates: Projector Functions

- goal: derive u, v texture coordinates from a given 3D point that is being rendered
- $F_{map}^{-1}: \Re^3 \rightarrow \Re^2$, so $F_{map}^{-1}(x, y, z) = (u, v)$
- several typical possibilities
  - (manual) parameterization of the surface
  - use of inherent (u, v) coordinates (e.g., freeform surfaces or primitive shapes)
  - two step technique

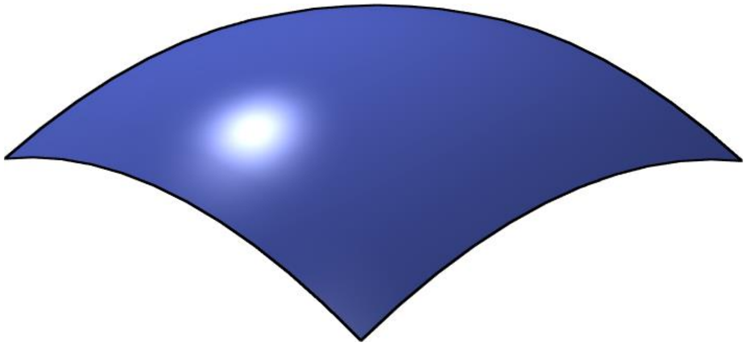
(Manual) Surface Parameterization

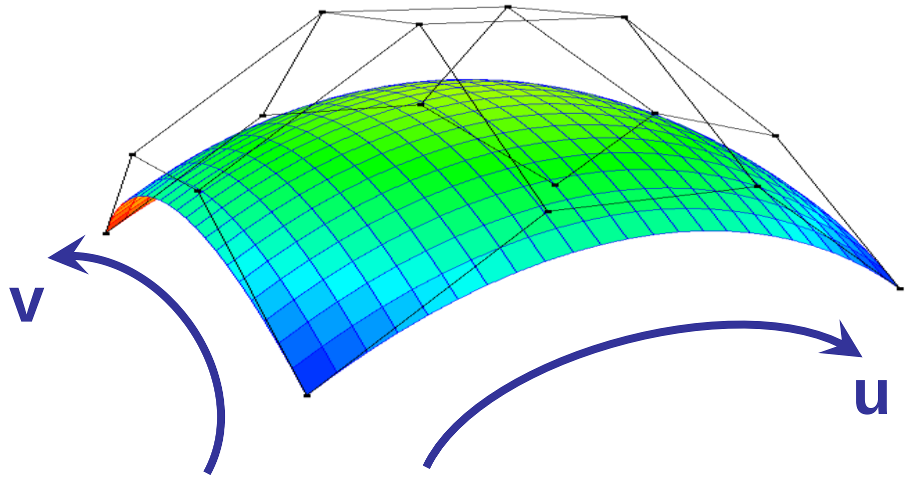
- simplest technique: specification of (u, v) texture coordinates during modeling for all vertices of a polygon
- interpolation between these values for points inside the polygon (e.g., barycentric interpolation for triangles)



Inherent (*u*, *v*) Coordinates

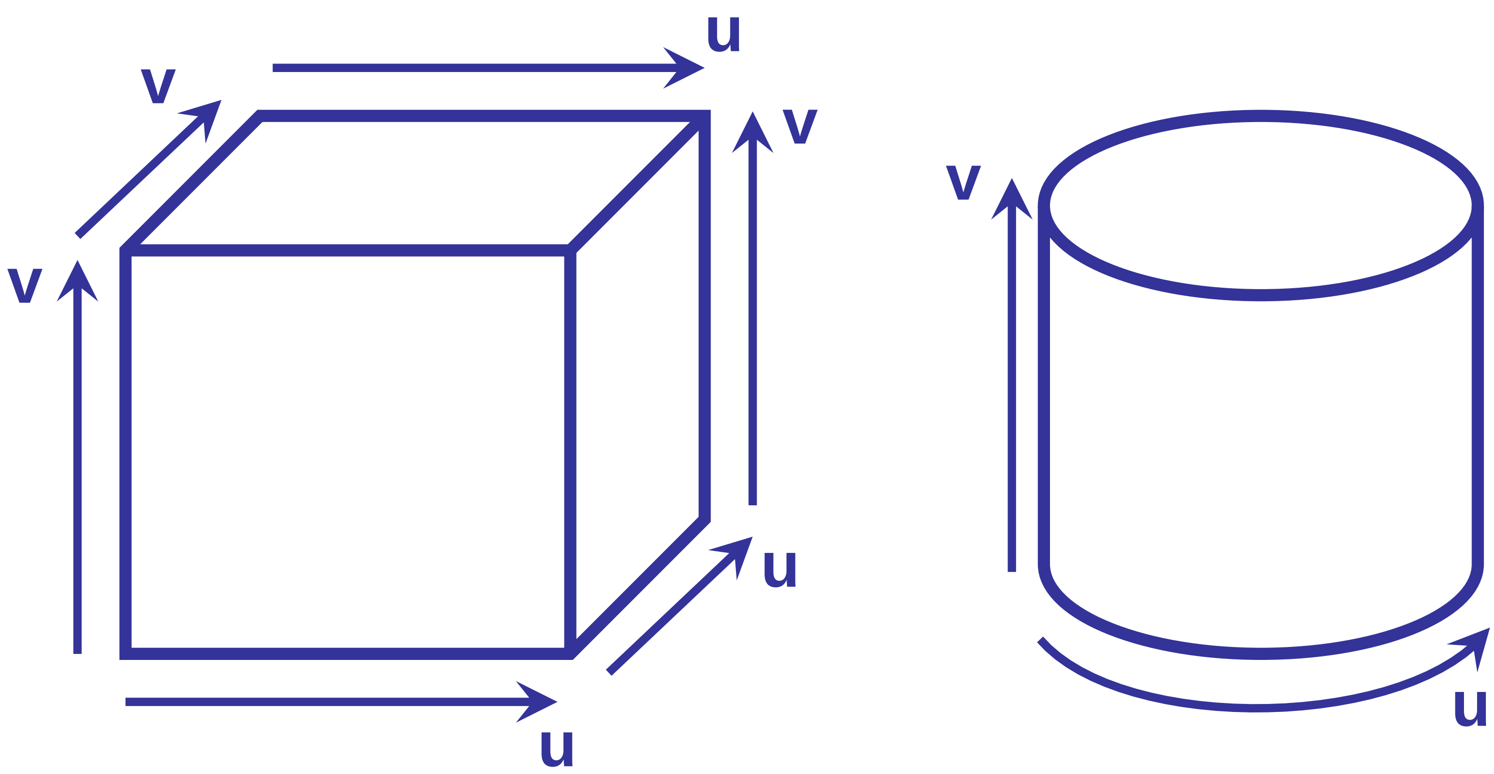
- (*u*, *v*) coordinates derived from parameter directions of surface patches
(e.g., Bézier and spline patches)





Inherent (*u*, *v*) Coordinates

- obvious (*u*, *v*) coordinates derived for primitive shapes (e.g., boxes, spheres, cones, cylinders, etc.)



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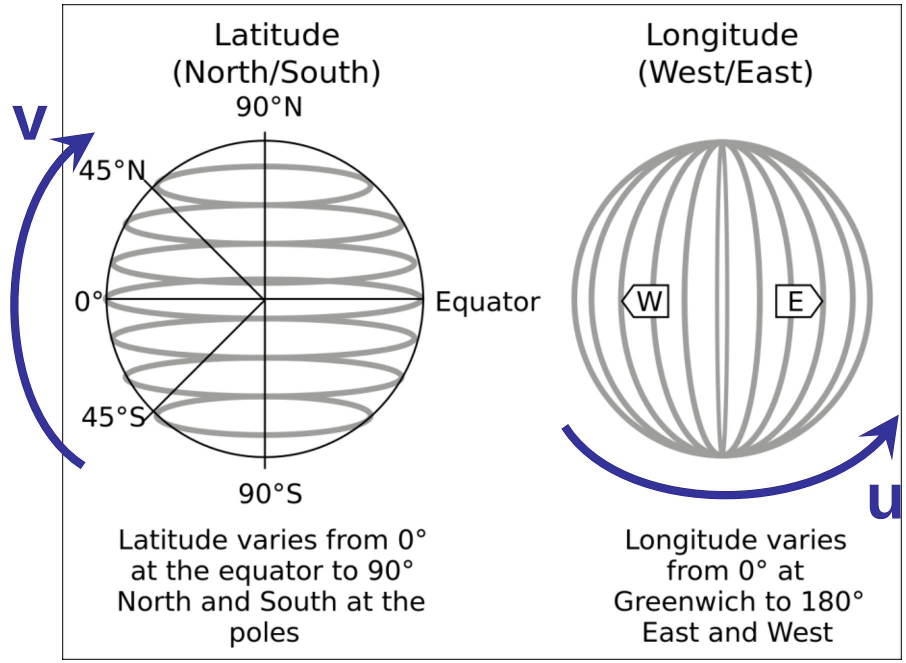
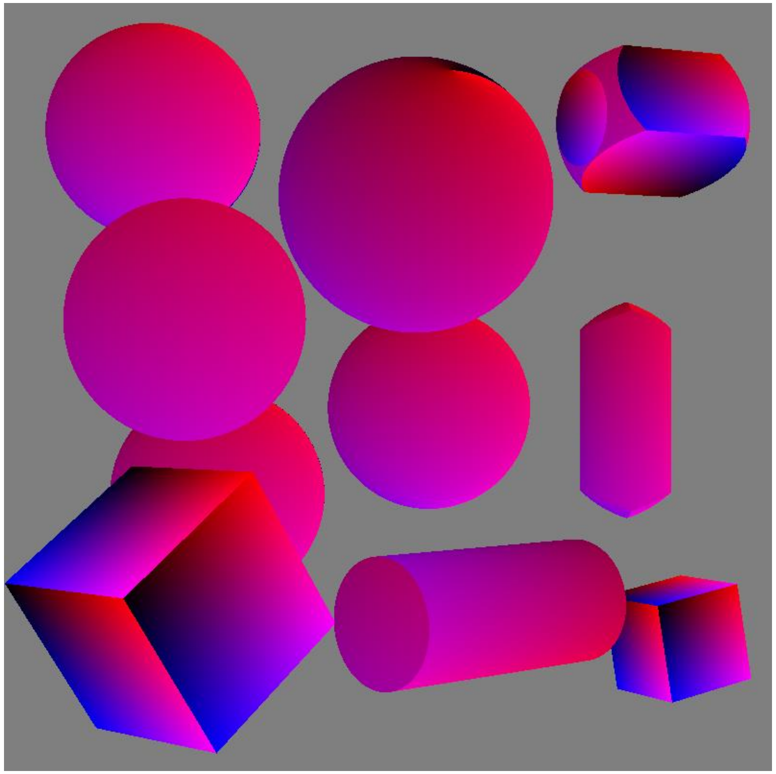
[image: Flickr Kevin Gill]



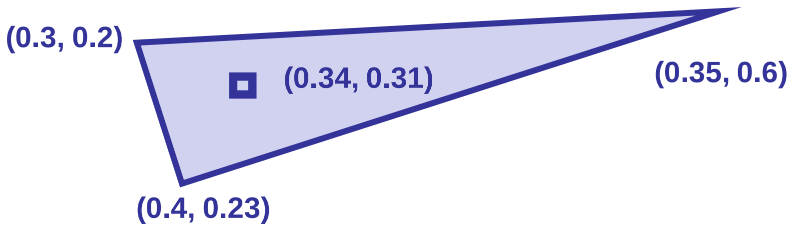
Inherent (*u*, *v*) Coordinates

- examples for simple shapes, with (u, v) coordinates mapped to red-blue color

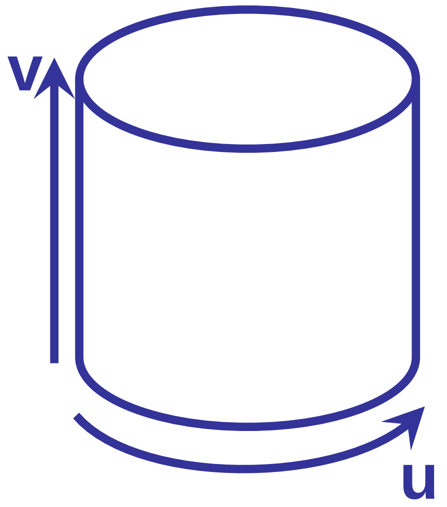


u,v-Coordinates: Projector Functions

- manual specification:
  → flexible, but tedious
  and inconvenient



- inherent (*u*, *v*) coordinates:
  → inflexible (relies on
  a few simple shapes)
  but easy to compute



- combination of both that is flexible and easy to compute? → two-step approach

Texture Mapping

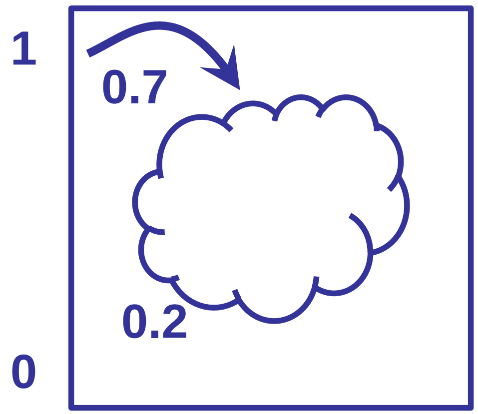
Two-Step Approach

Two Step Approach

- problem with previous techniques:
  - not flexible enough (inherent coordinates)
  - too tedious (manual parameterization)
- new idea:
  - texture mapped on simple intermediate surface that has inherent coordinates
  - then transfer onto complex objects
- common intermediate surfaces: cylinder, sphere, plane, box

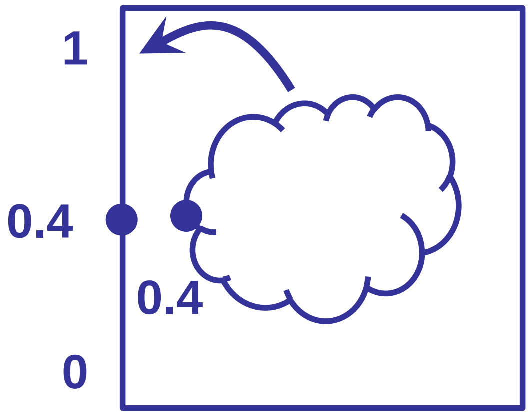
Two Step Approach

- two steps:
  – mapping of 2D texture coordinates onto simple 3D surface (s-mapping)
  – mapping of the now 3D texture pattern onto complex object (o-mapping)



Two Step Approach

- in practice – inverse approach:
  - mapping of object point onto simple surface
    O: $f(x_o, y_o, z_o) = (x_i, y_i, z_i)$
  - mapping of surface point onto texture
    S: $f(x_i, y_i, z_i) = (u, v)$

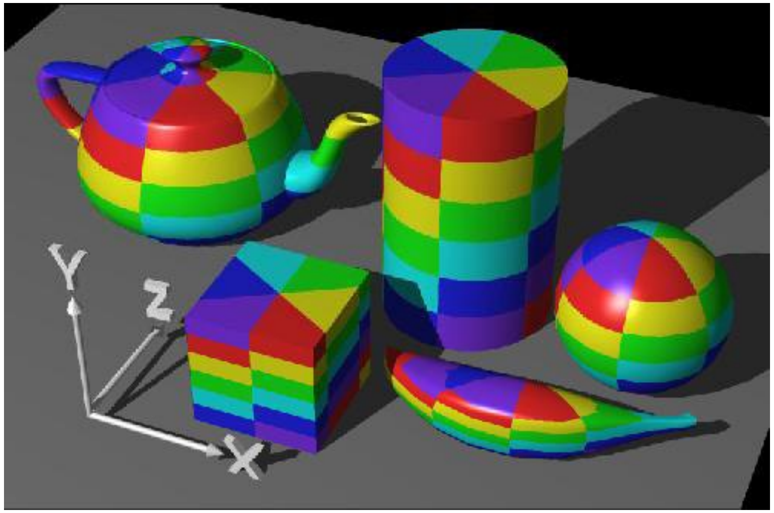


Cylindrical Mapping

- mapping onto cylinder surface given by height h_0 and angle θ_0

$$S : (\theta, h) \to (u, v) = \left(\frac{r}{c}(\theta - \theta_0), \frac{1}{d}(h - h_0) \right)$$

  using scaling factors c, d, and the radius r
- discontinuity along one line parallel to center axis



from R. Wolfe: *Teaching Texture Mapping*

Examples of Cylindrical Maps

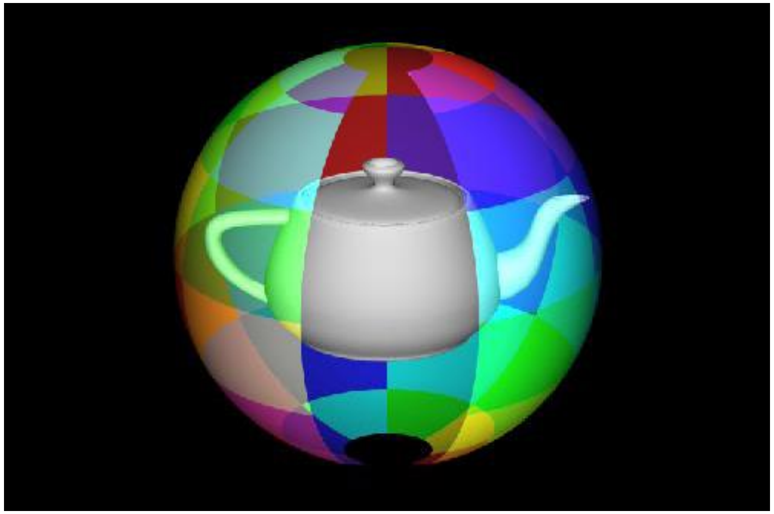
Examples of Cylindrical Maps

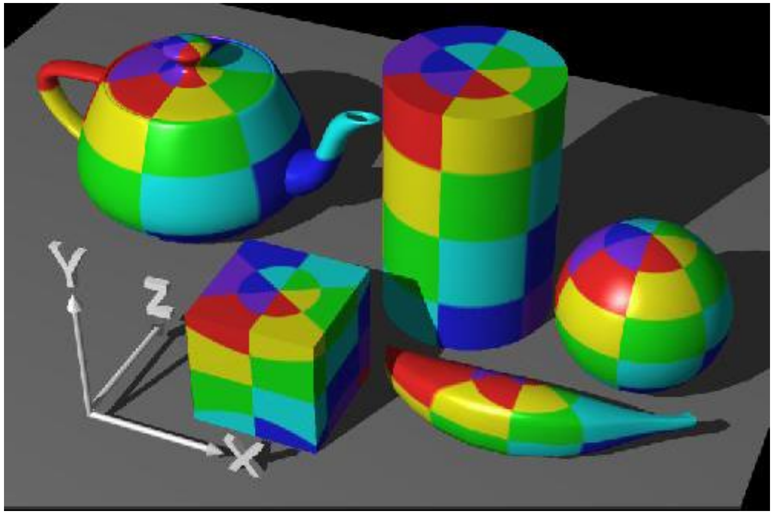
Spherical Mapping

- mapping onto surface of a sphere given by spherical coordinates

$$S : (r, \phi, \theta) \rightarrow (u, v) = \left(\frac{\theta}{2\pi}, \frac{(\pi / 2) + \phi}{\pi} \right)$$

- no non-distorting mapping possible between plane and sphere surface





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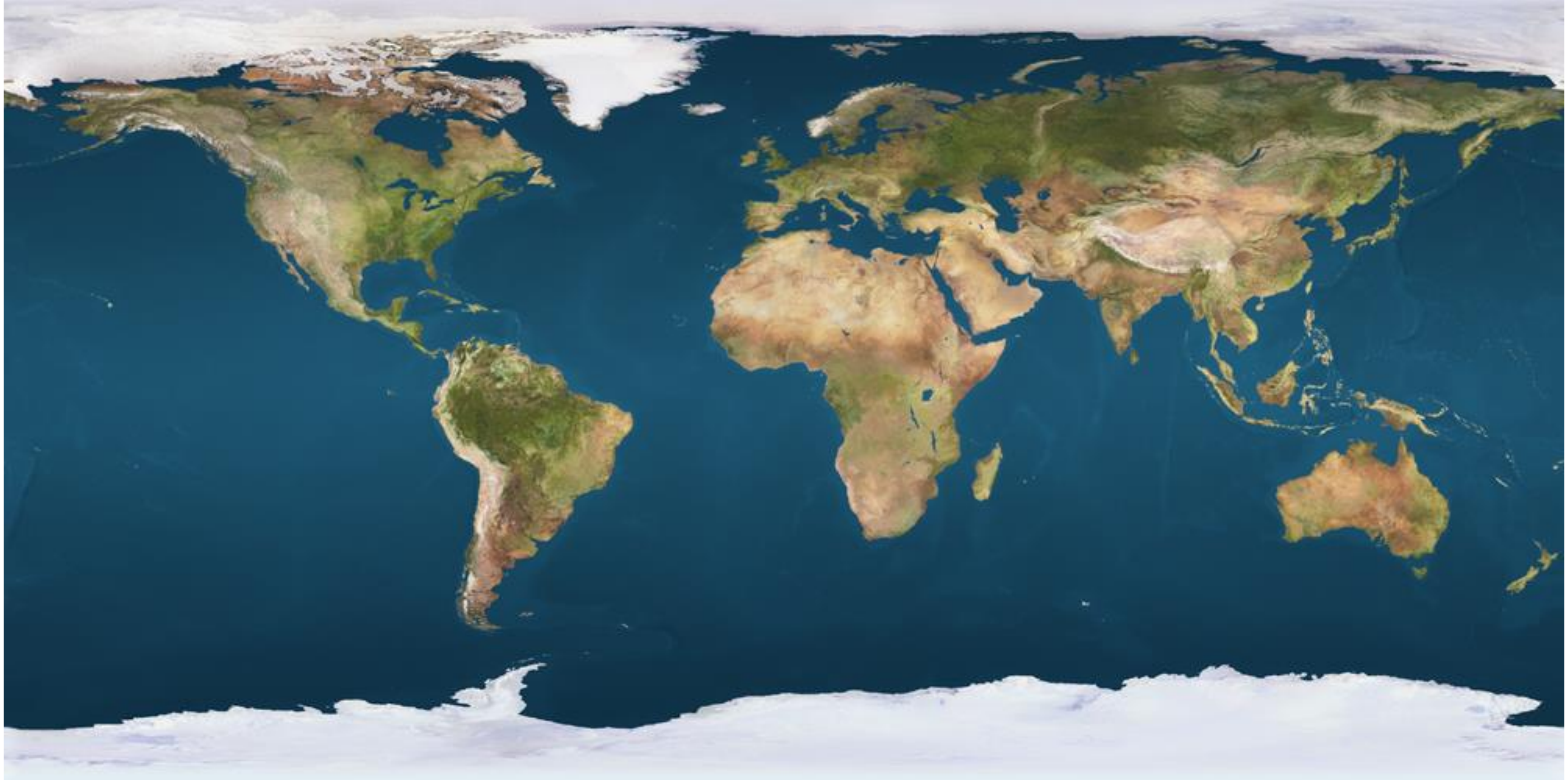
Examples for Spherical Maps



- **spherical** texture map = **cylindrical** map projection!
  the latter does not use cylindrical but **spherical textures**
- notice the distortion at the polar regions

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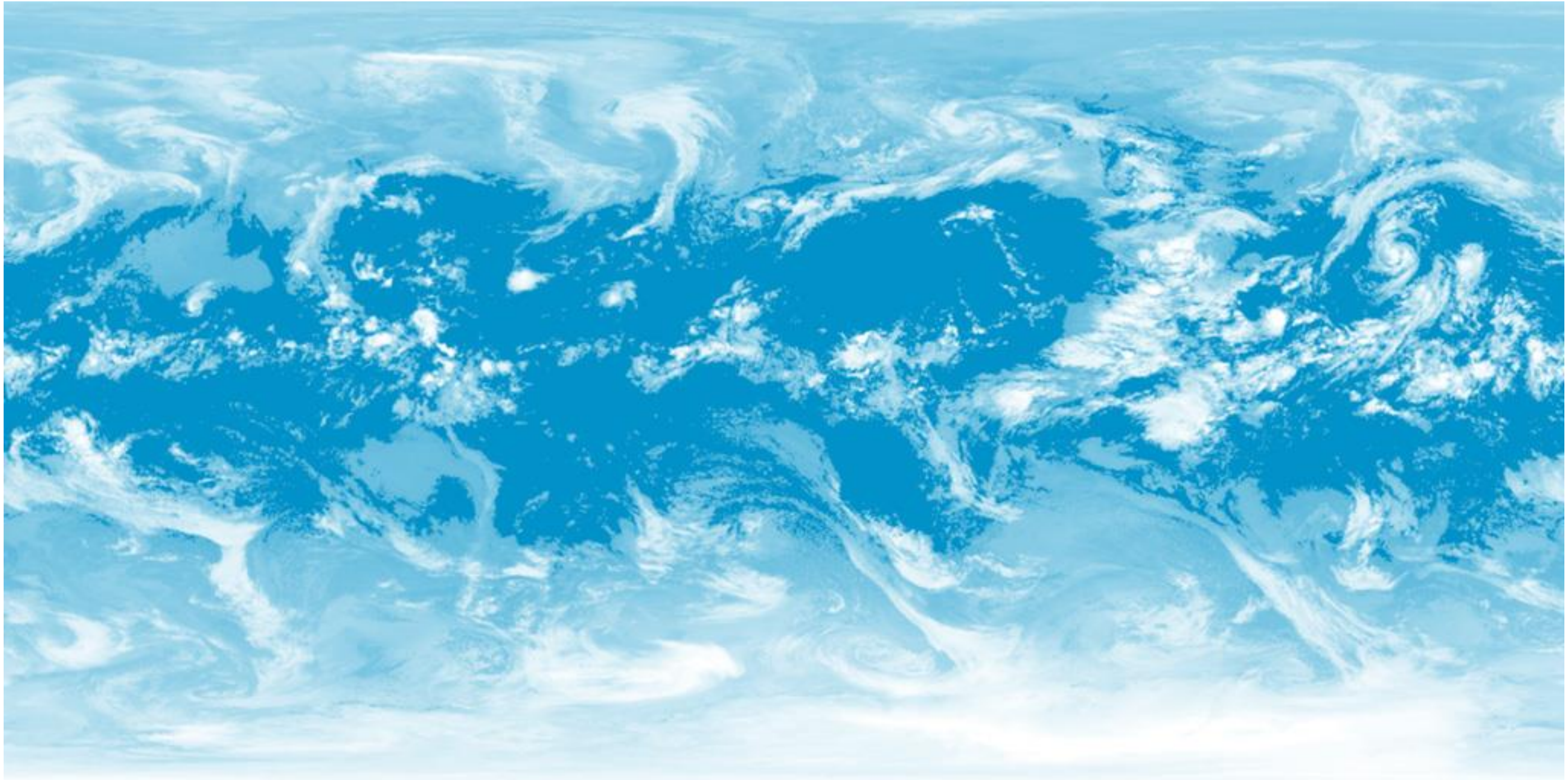

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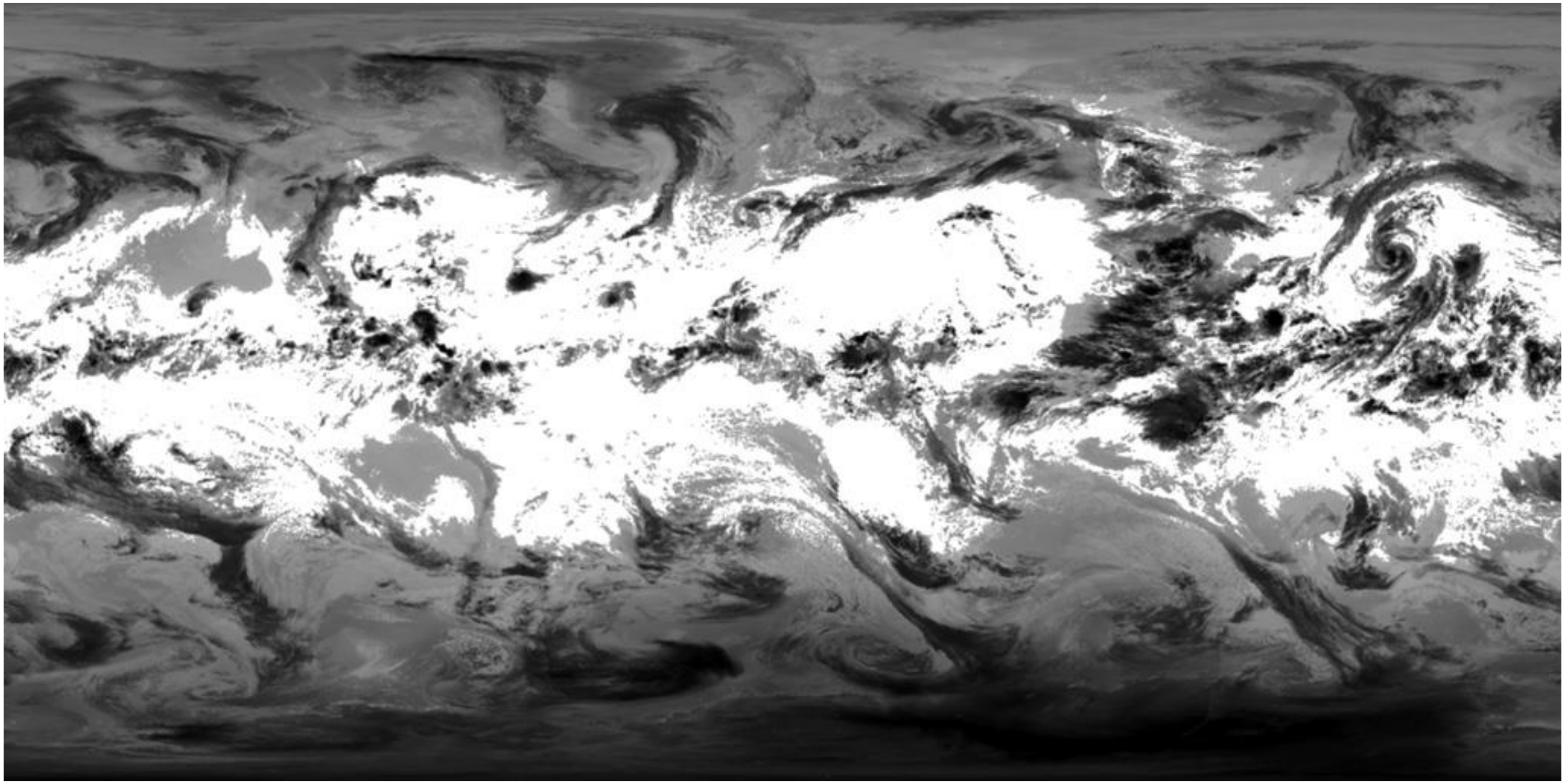

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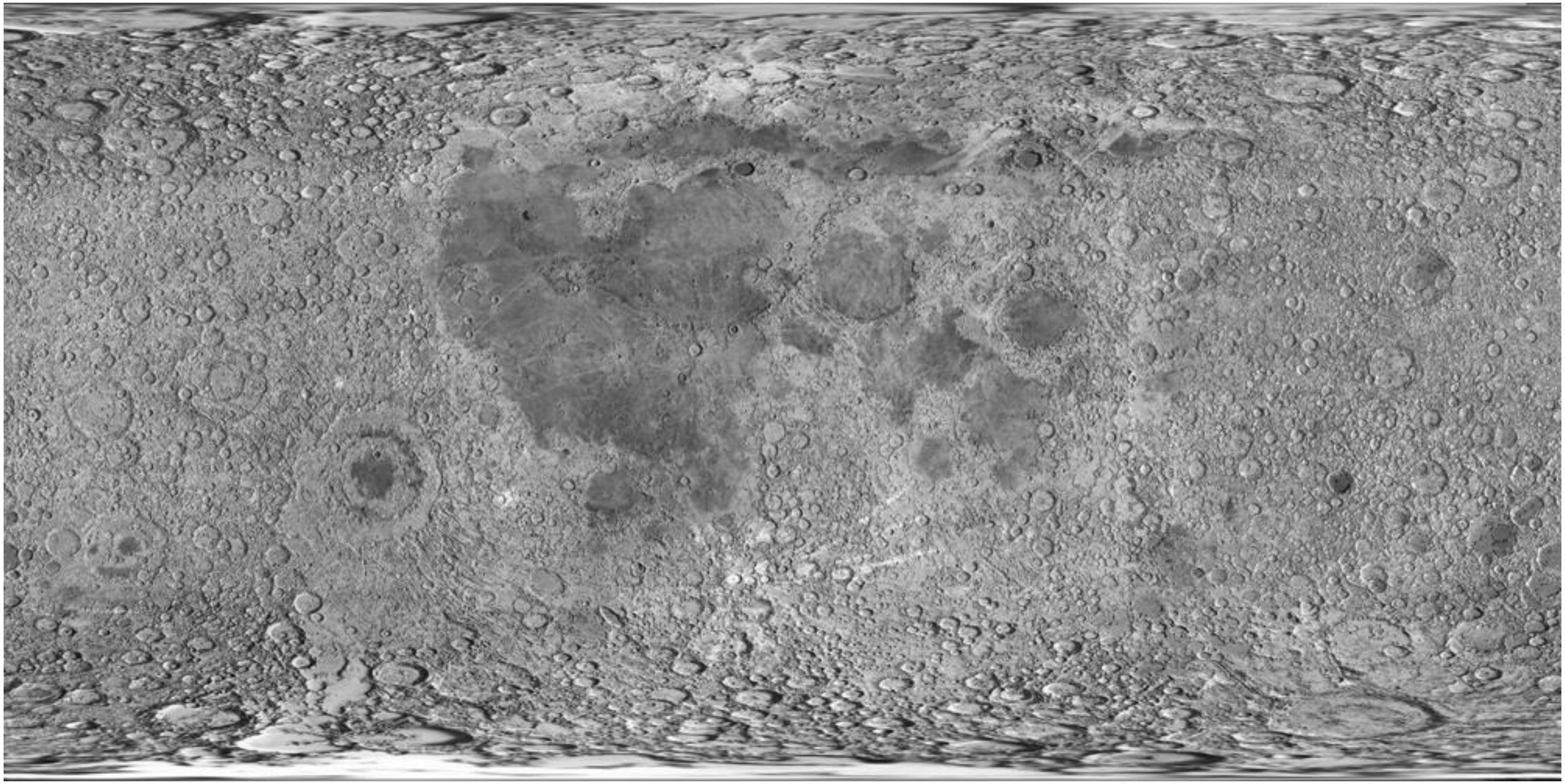

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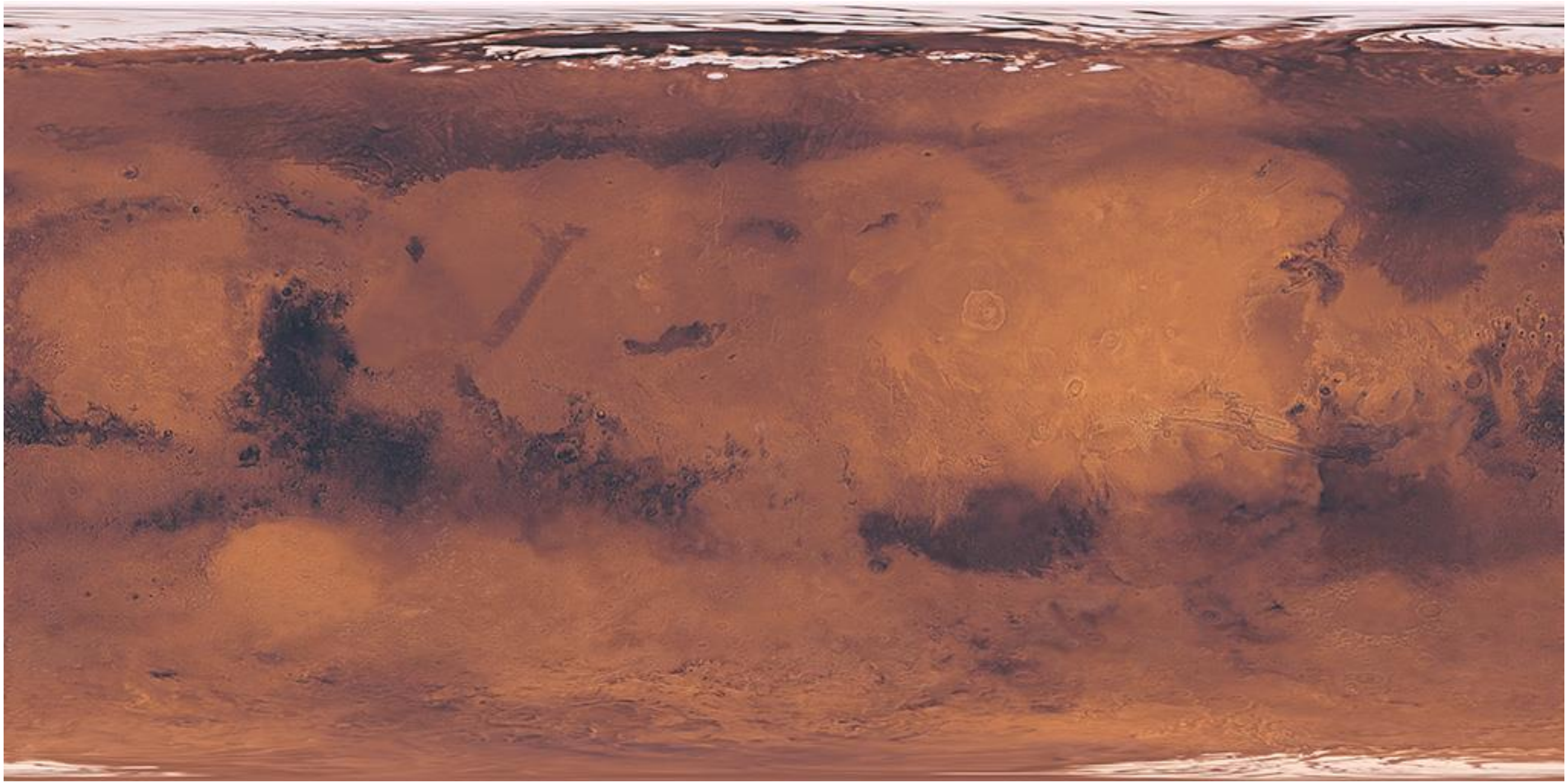

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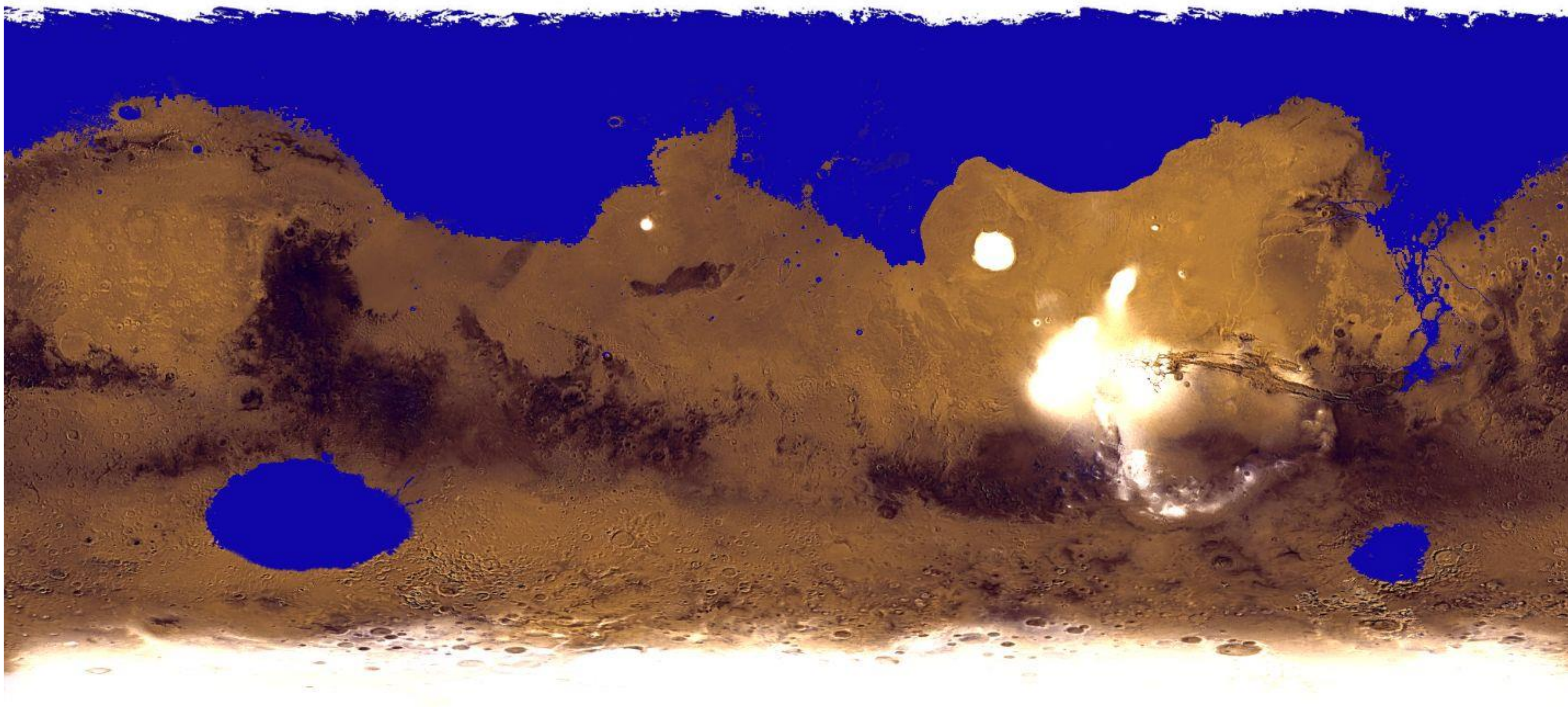

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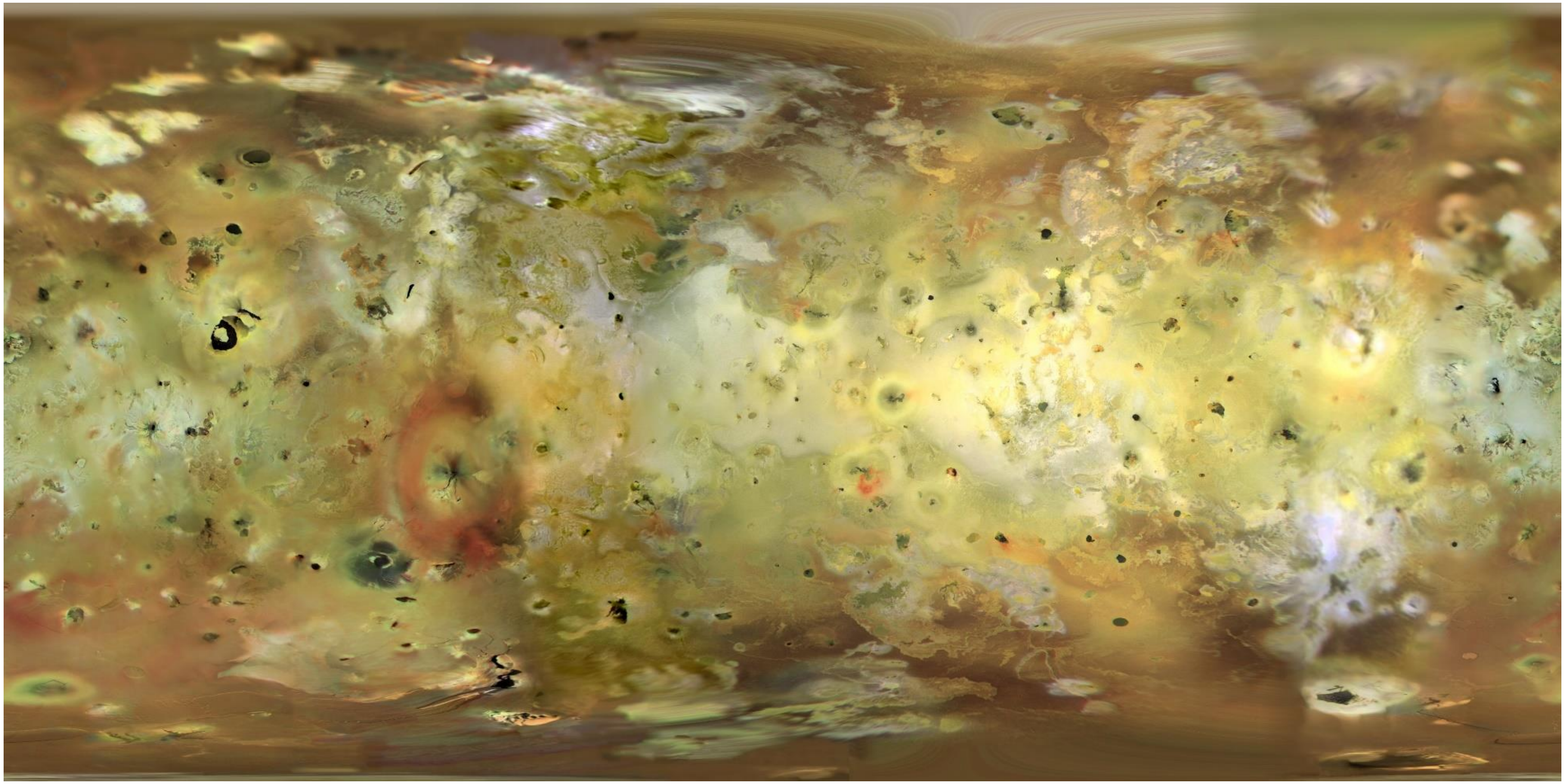

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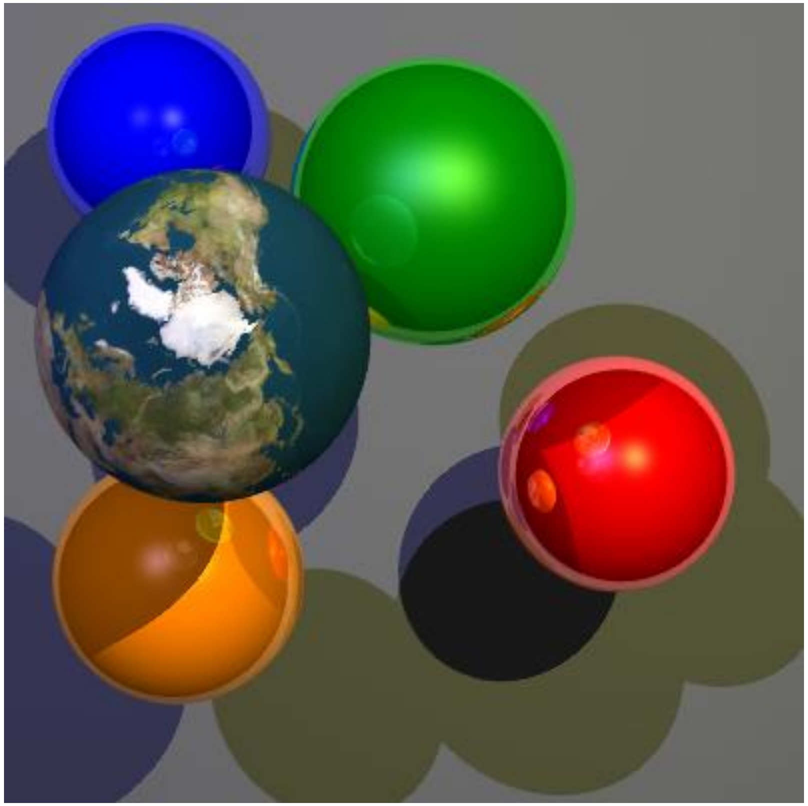
Examples for Spherical Maps

- but this distortion disappears if the spherical map is applied to a sphere

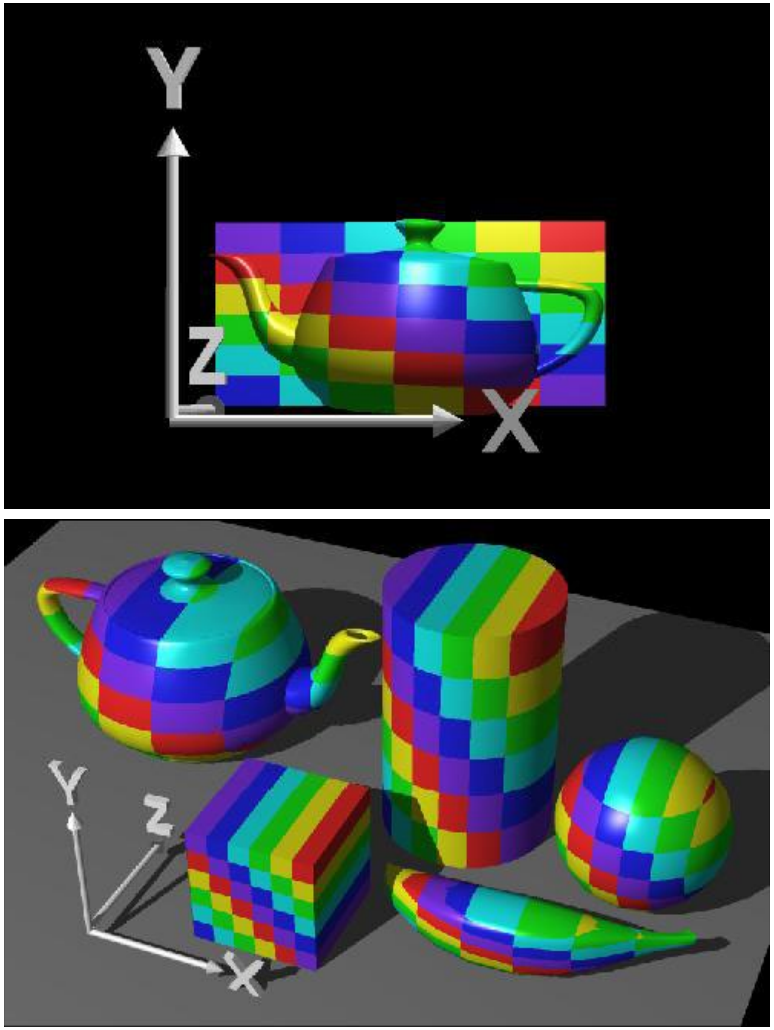


Planar Mapping

- mapping onto planar surface given by position vector $\vec{v}_0$ and two vectors $\vec{s}$ and $\vec{t}$

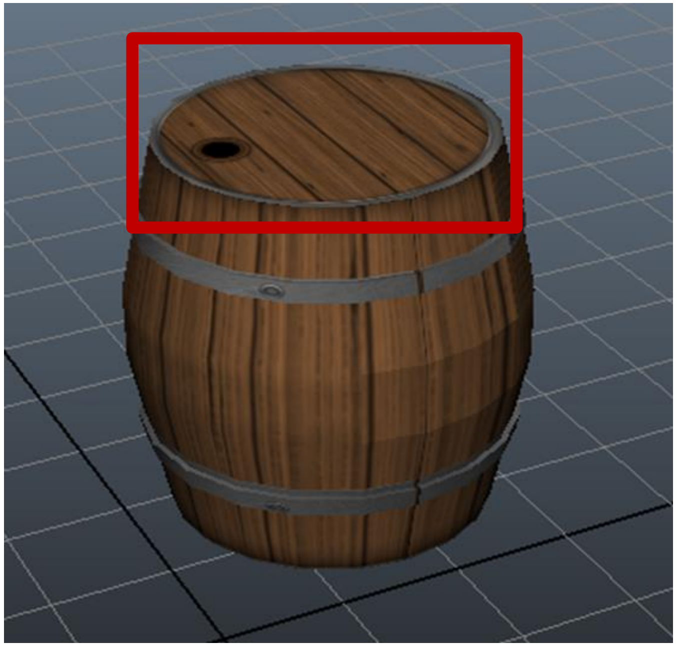
$$S : (x, y, z) \rightarrow (u, v) = \left(\frac{\vec{v} \cdot \vec{s}}{k}, \frac{\vec{v} \cdot \vec{t}}{k} \right)$$

- scaling factor k and $\vec{v} = \vec{P}_i - \vec{v}_0$ (describes point position w.r.t. the origin of the plane)



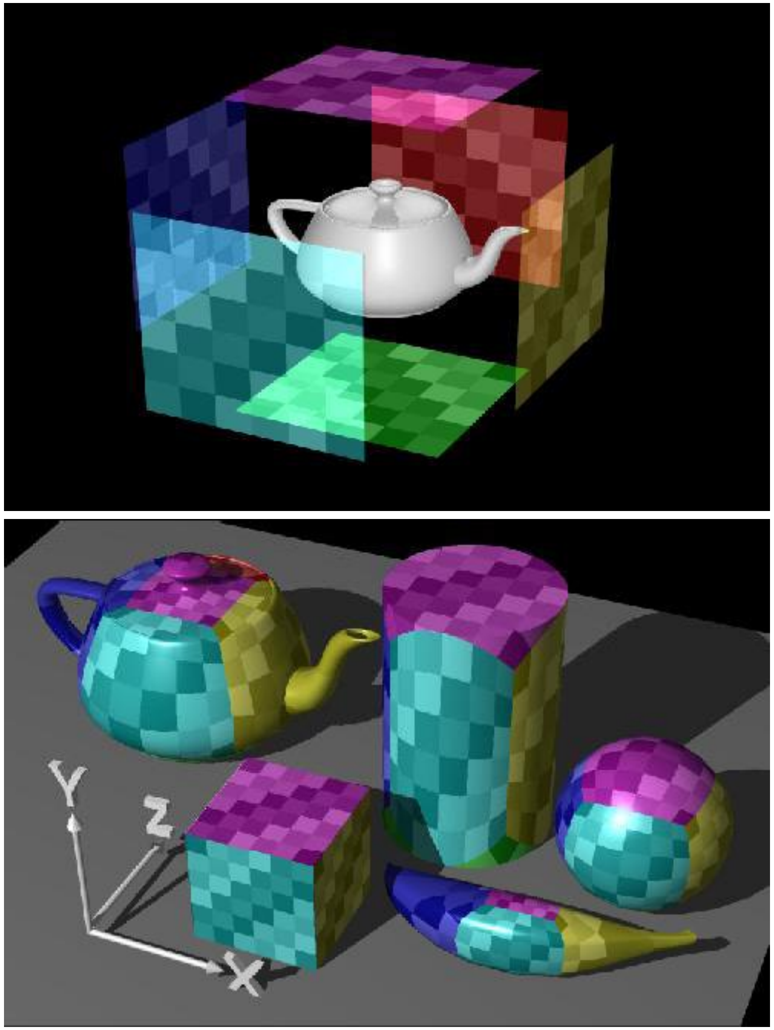
from R. Wolfe: *Teaching Texture Mapping*

Example of Planar Mapping



Box Mapping

- enclosing box is usually axis-parallel bounding box of object
- six rectangles onto which the texture is mapped
- similar to planar mapping



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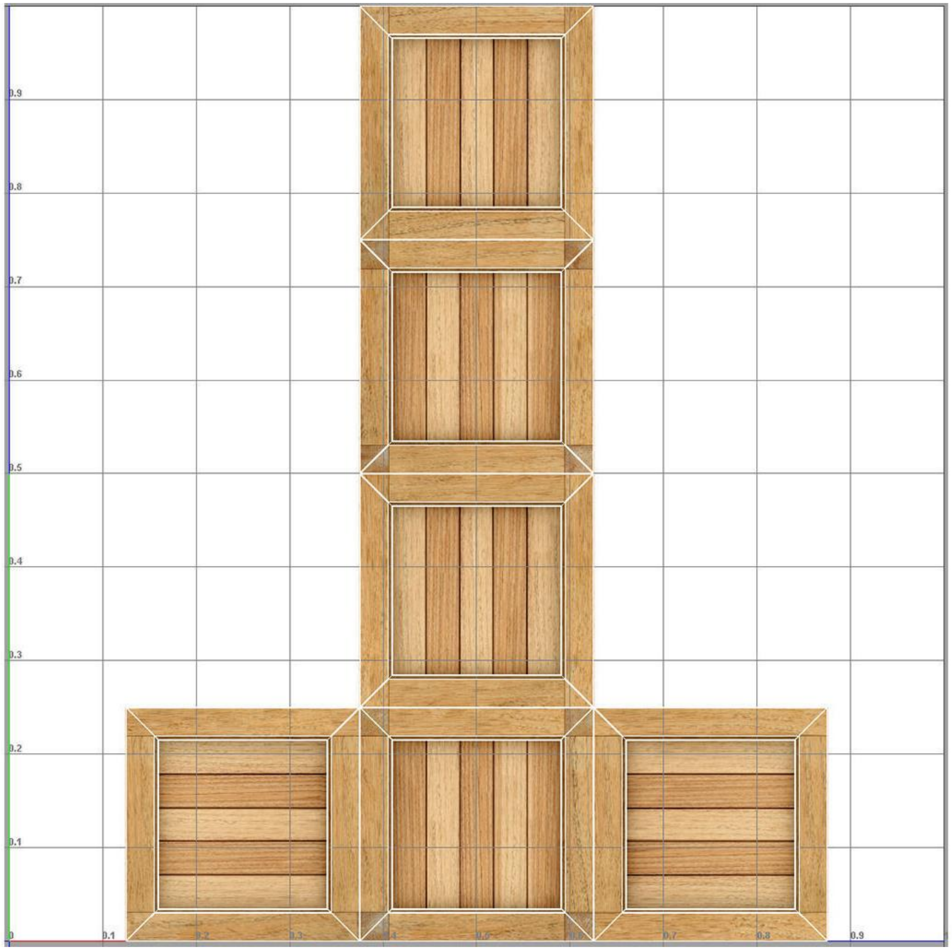
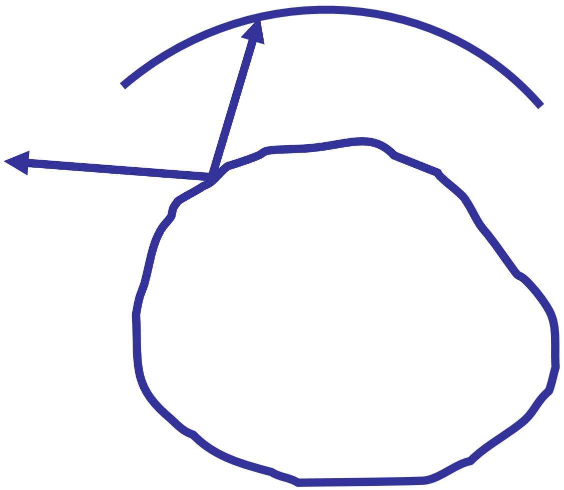
Example of Box Mapping



O Mapping: Object to Surface

- necessary for all named techniques
- four methods:
  reflected ray, *object normal*, *object center*, and *normal of intermediate surface*
  - ***reflected ray***:
    trace a ray from viewer to object and reflect it onto the intermediate surface



O Mapping: Object to Surface

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- four methods:
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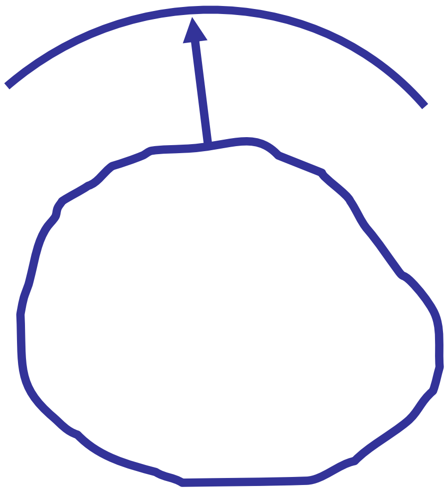
  - ***object normal***: intersection of normal vector of object with intermediate surface



O Mapping: Object to Surface

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- four methods:
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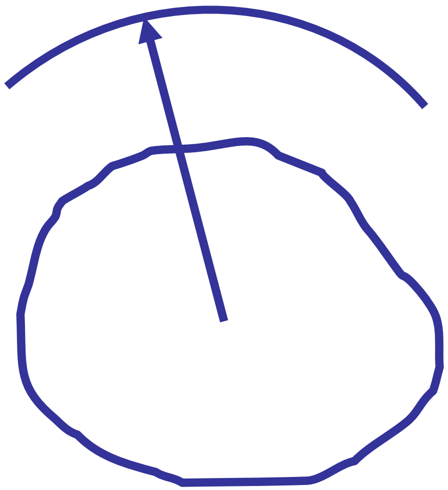
  - ***object center***: intersection of ray from object center through the object surface with the intermediate surface



O Mapping: Object to Surface

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- four methods:
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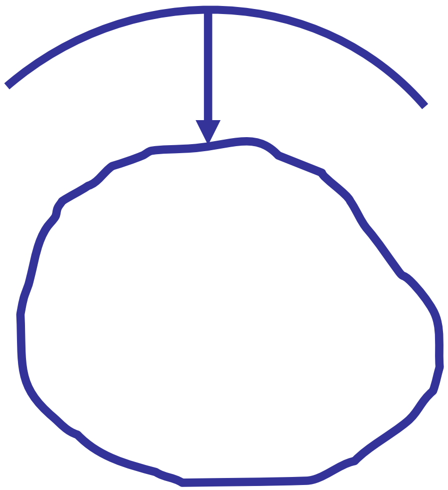
  - ***normal of intermediate surface***:
    trace this normal vector towards the object and determine intersection with it



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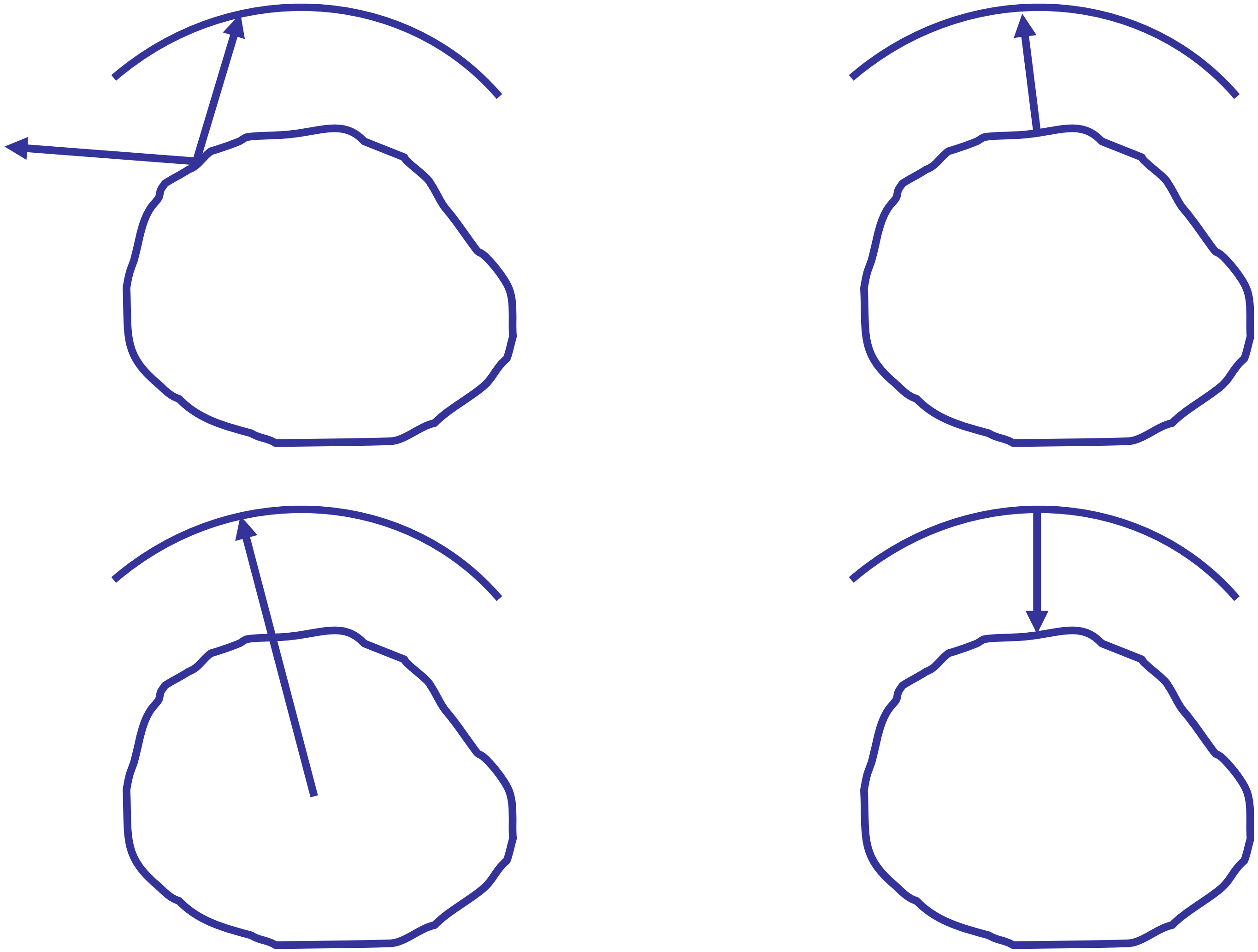
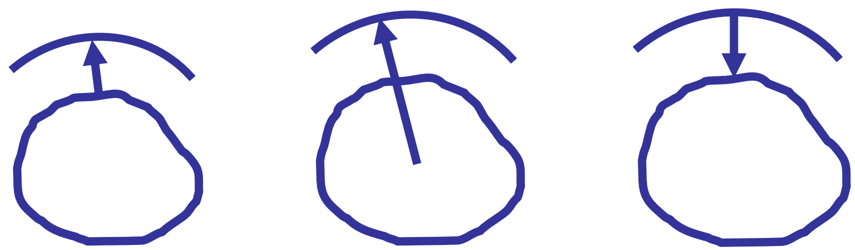


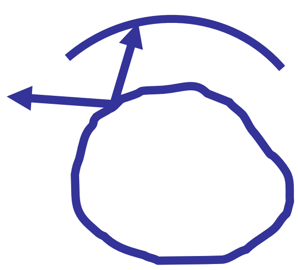
When to do the 2-step mapping?

- typically at model time, works for most schemes:



$\rightarrow$ uv coordinates stored with vertices/normals

- but reflection mapping depends on view direction, so needs to be computed at render time:

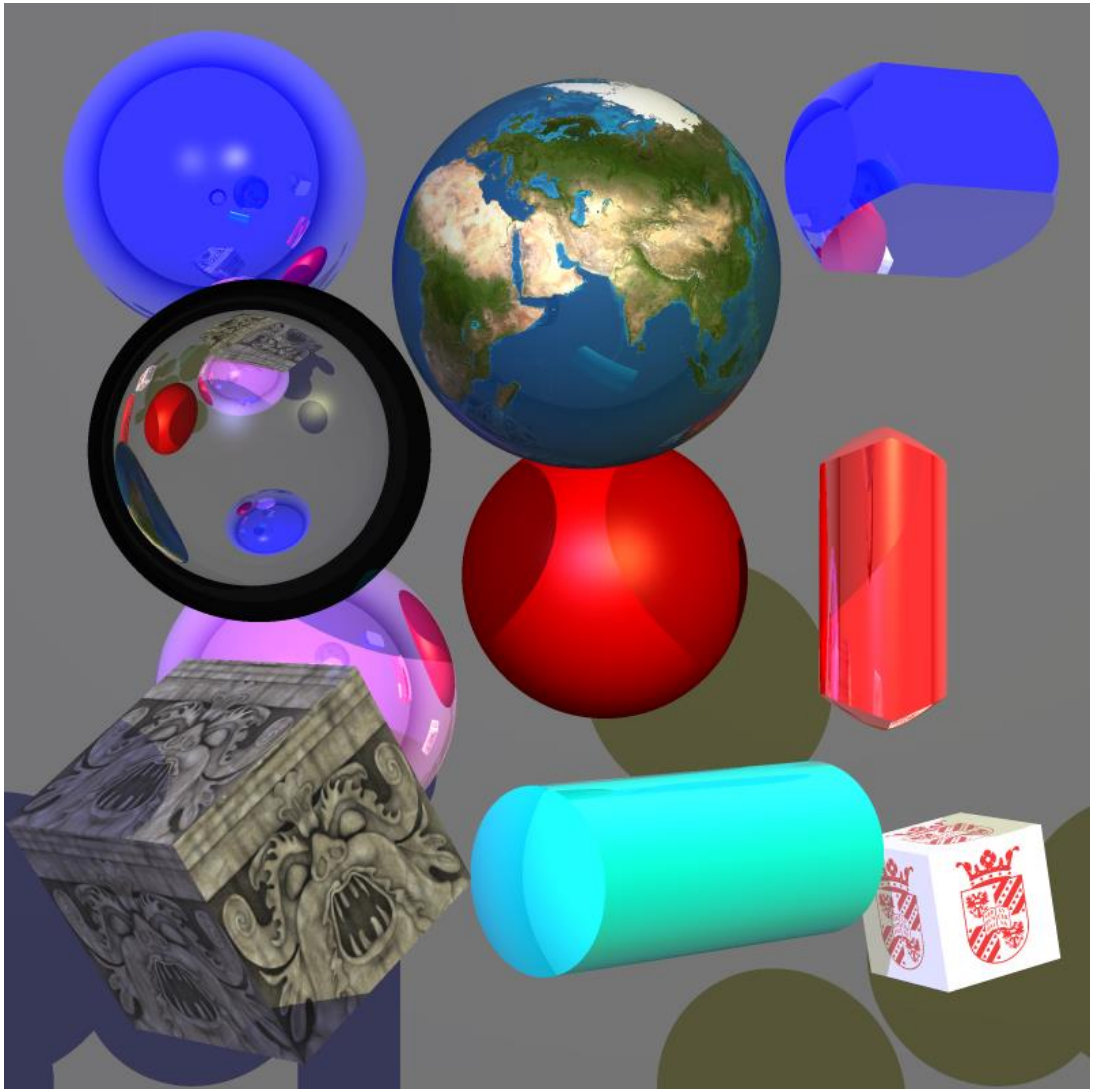


Application of Texture Values

- from an (x, y, z) position we derived an (r, g, b) color value from the texture, potentially with α transparence value
- is typically used to modify illumination
- methods:
  - replace: surface color value is replaced with texture color
  - decal: α blending of texture and original color
  - modulate: multiplication of original color value with texture color

Texture Mapping: Ambient & Diffuse

- done!
- well, almost ...



Texture Mapping

Affecting Other Properties

Texture Mapping: Bump Mapping

- recall: the brick wall
- texture captures visuals
- problem: illumination captured in the texture, conflicting visuals

- solution part 1: capture texture under diffuse light only – how?
- solution part 2: **bump mapping** → change illumination handling with texture

Texture Mapping: Bump Mapping

- bump maps: vector offsets to the normal vectors
- illumination computed as usual
- bump maps should match visual texture

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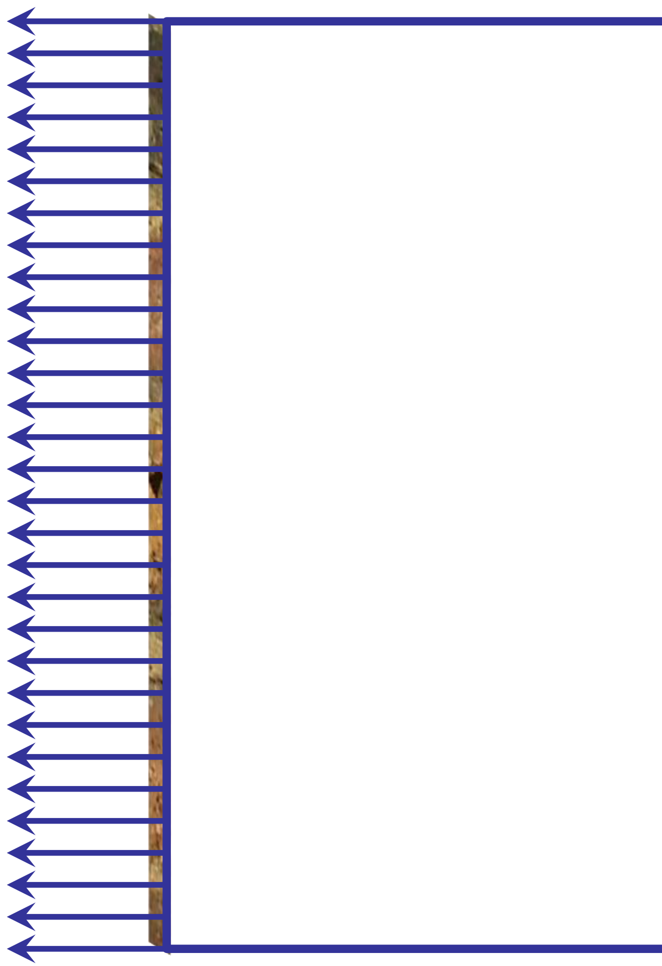

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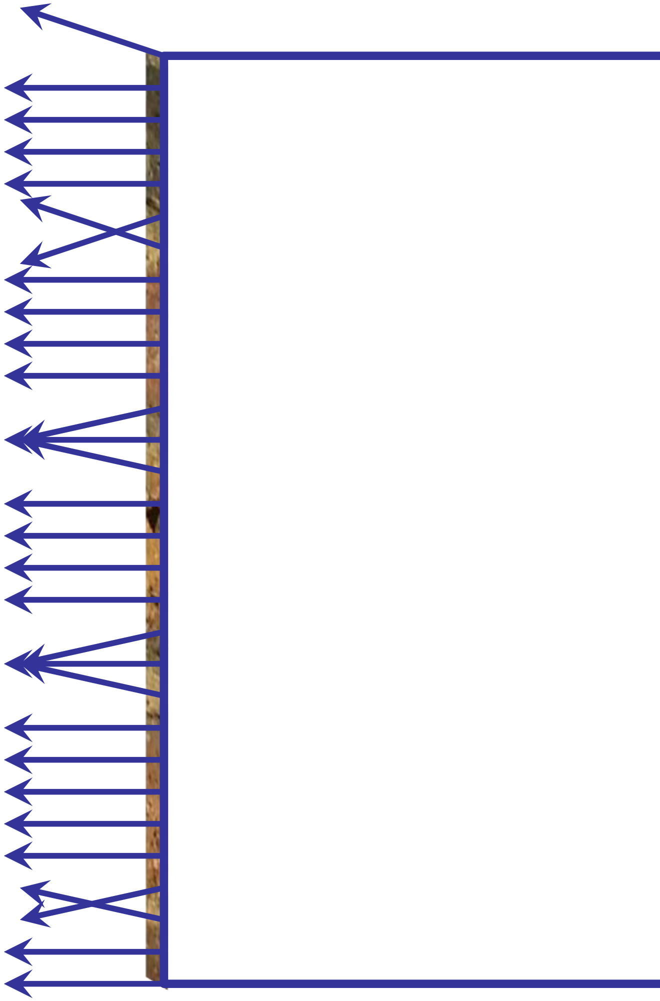

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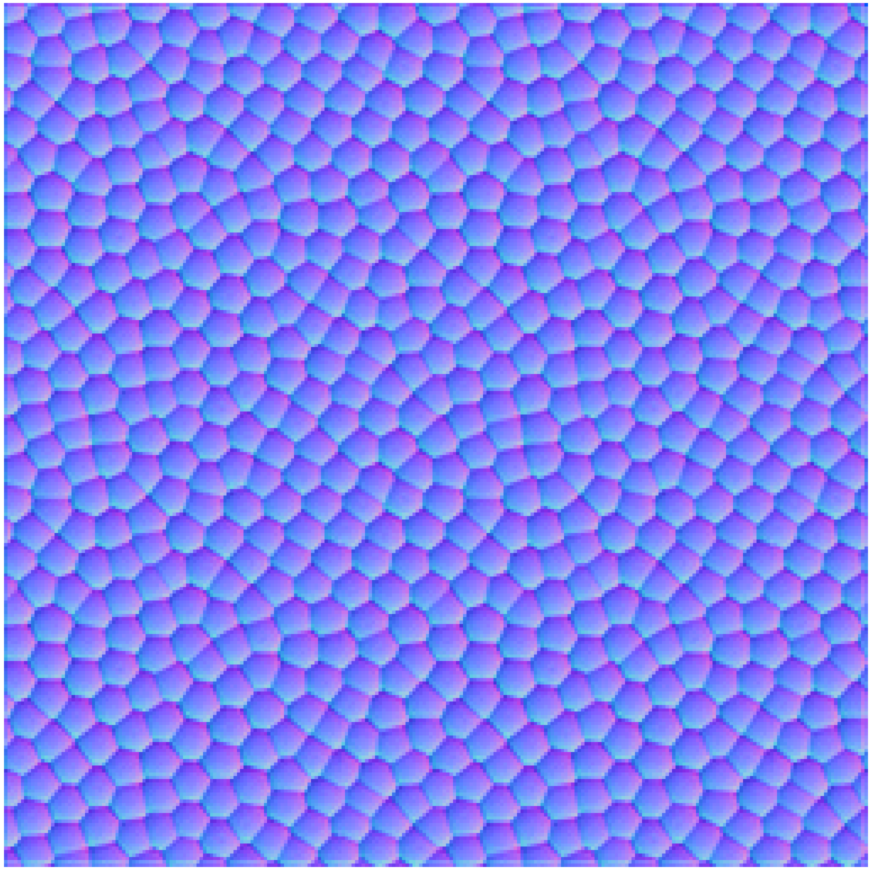

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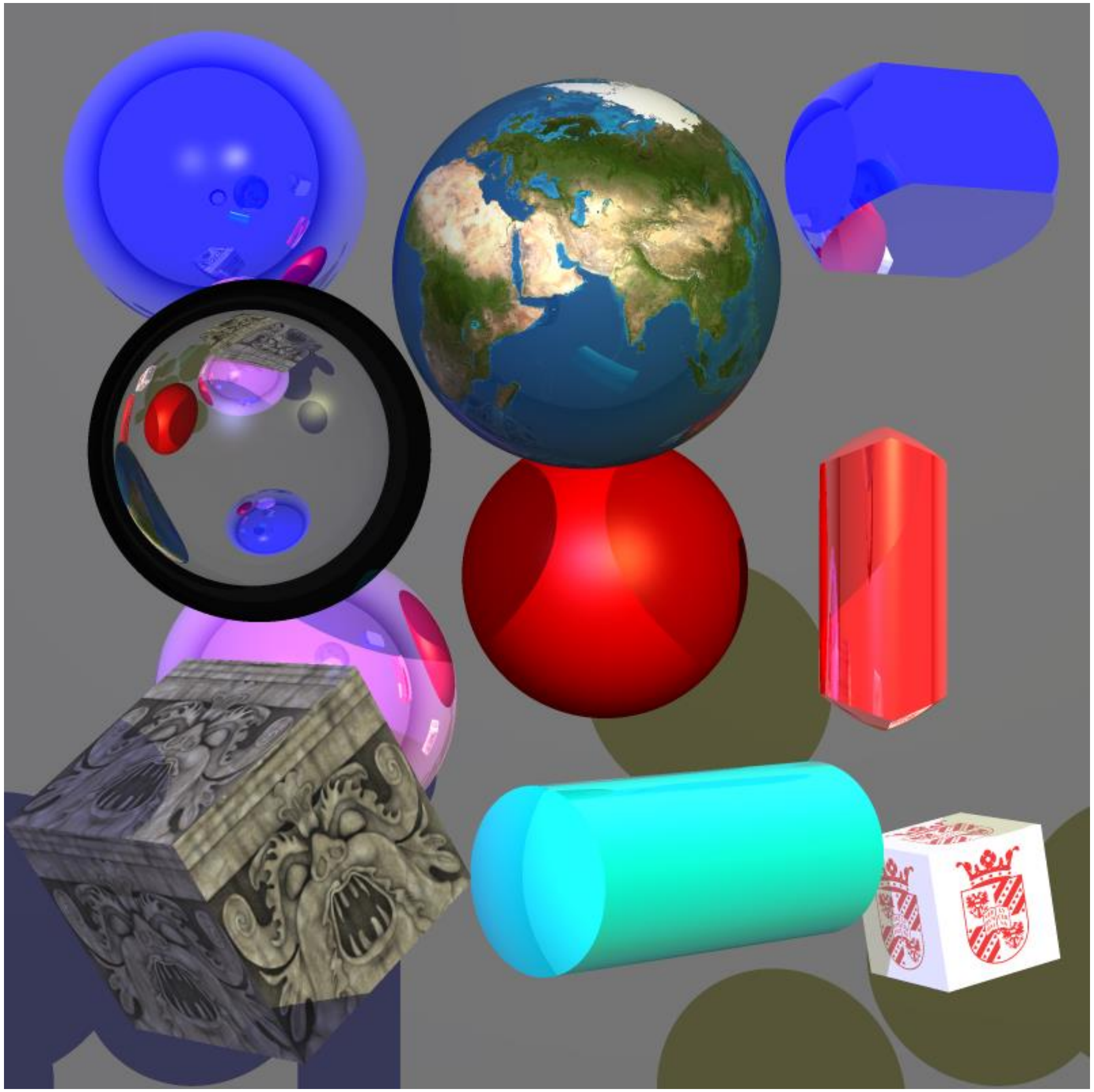

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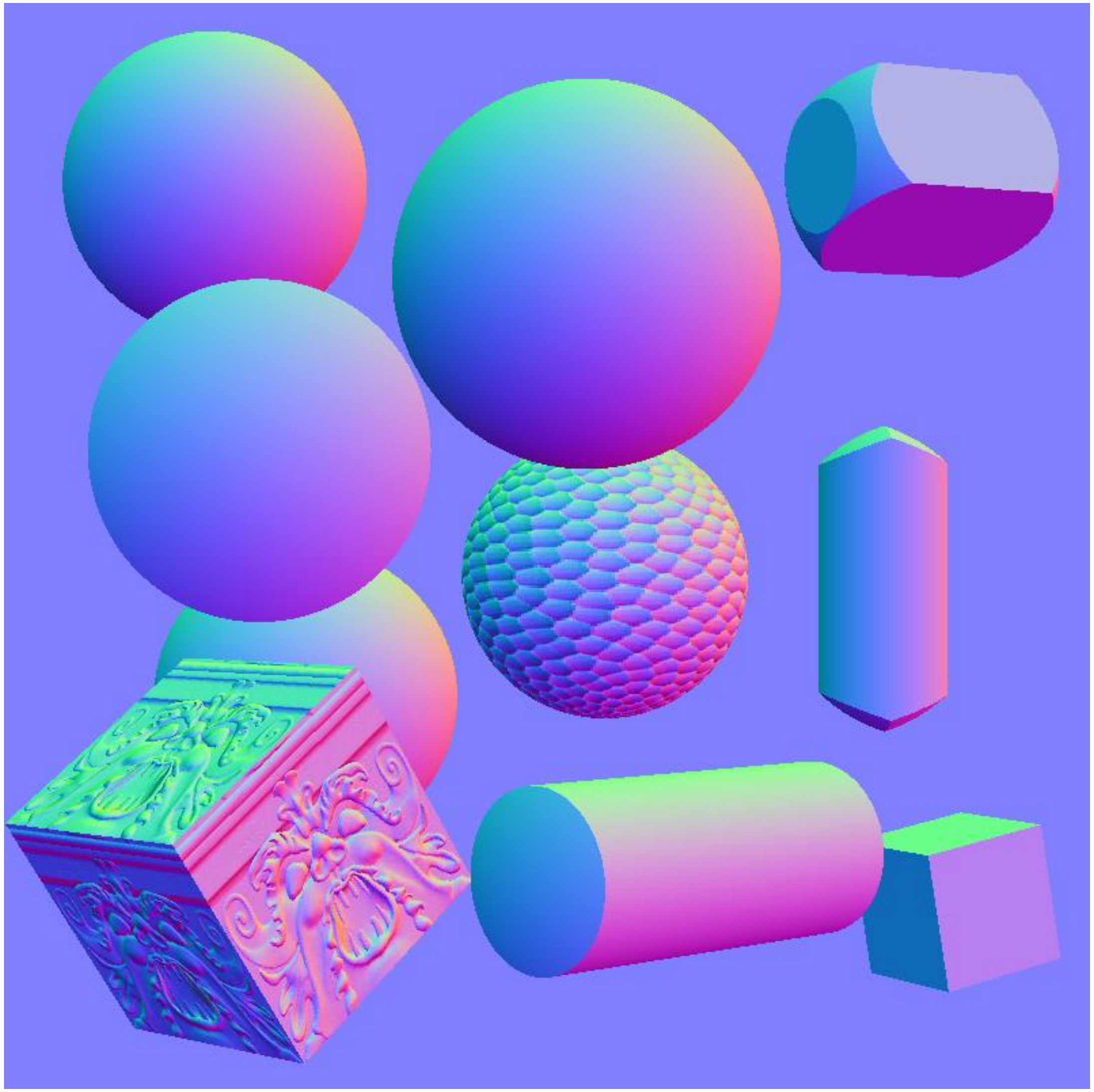

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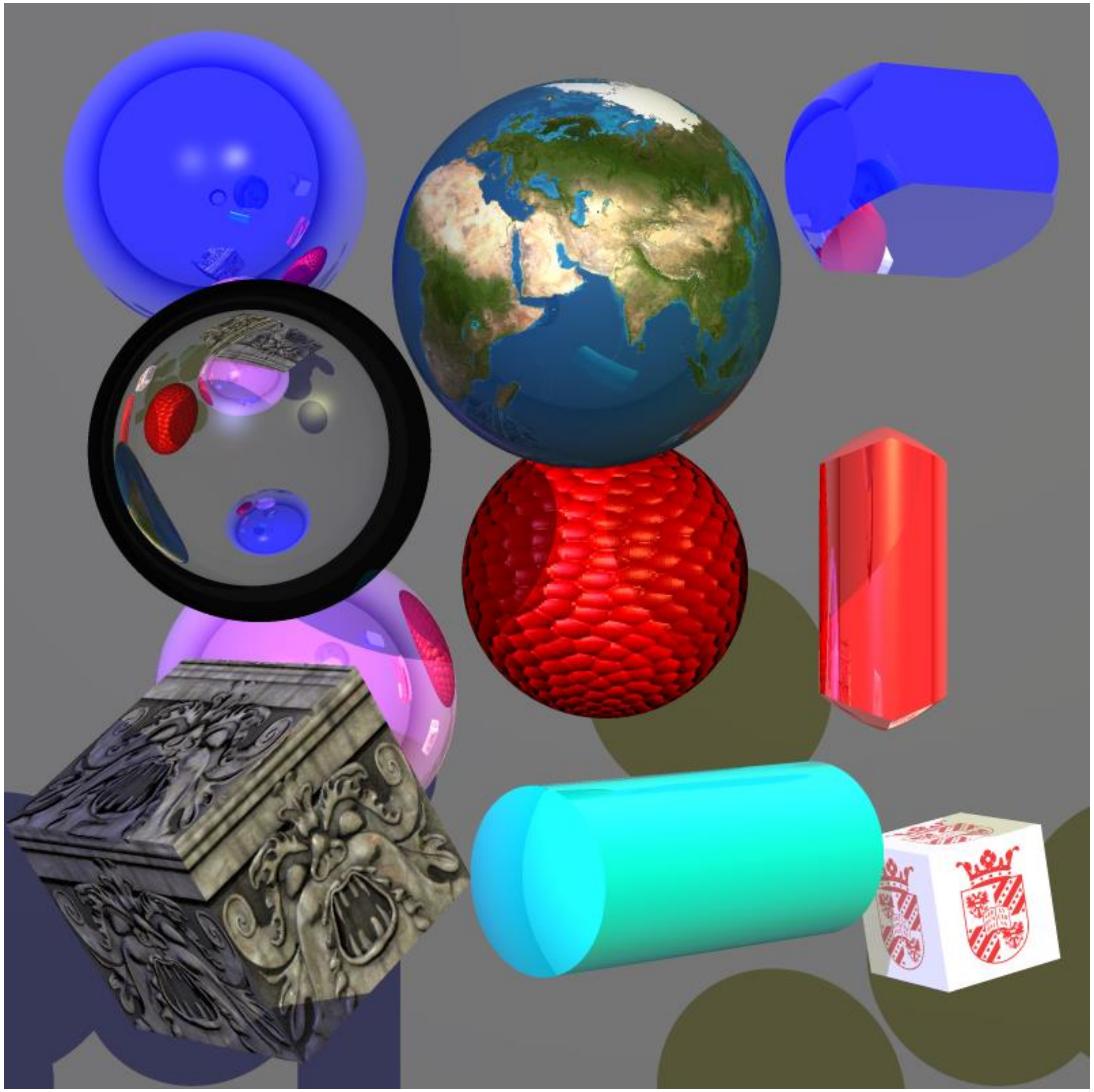

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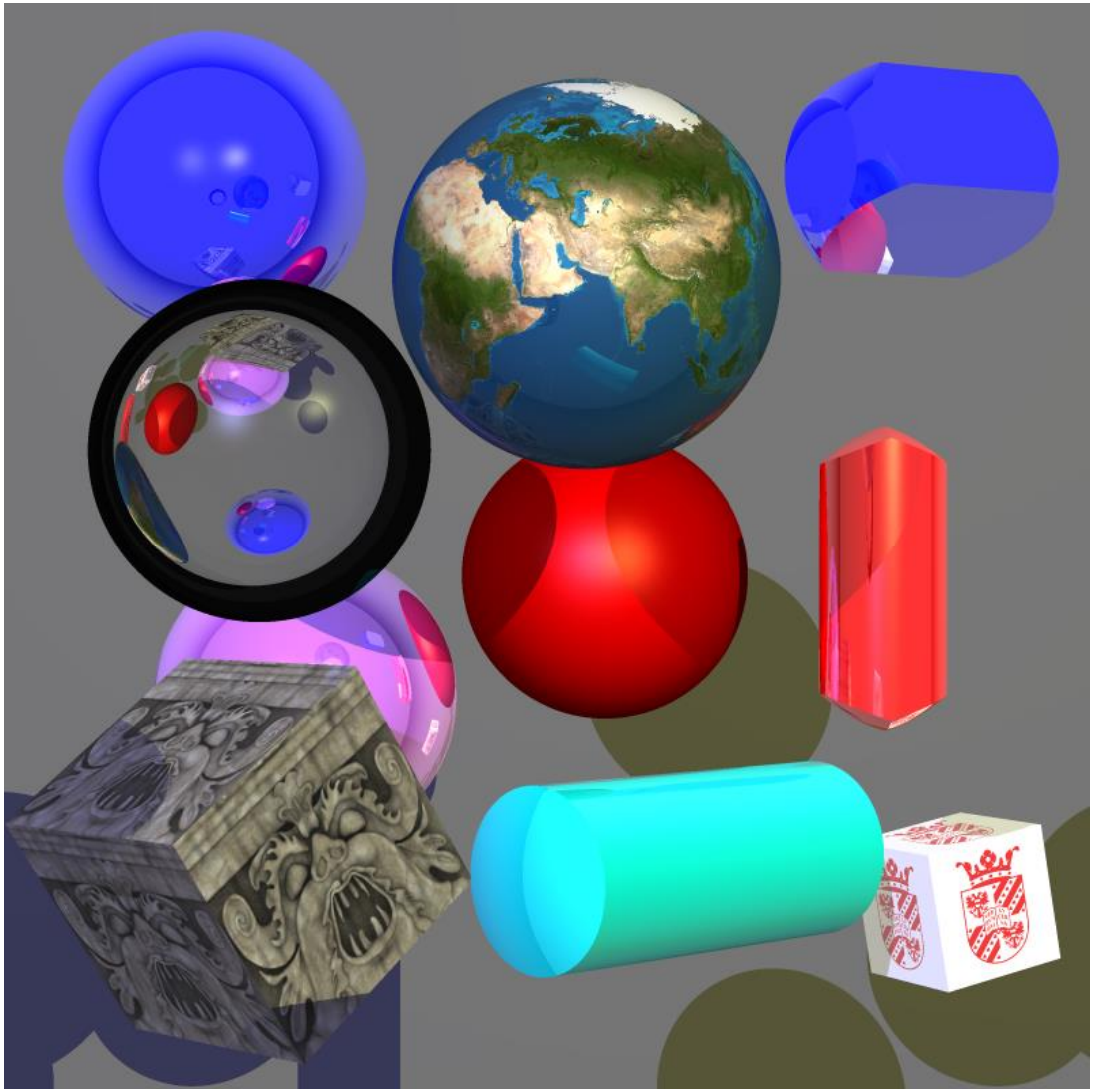

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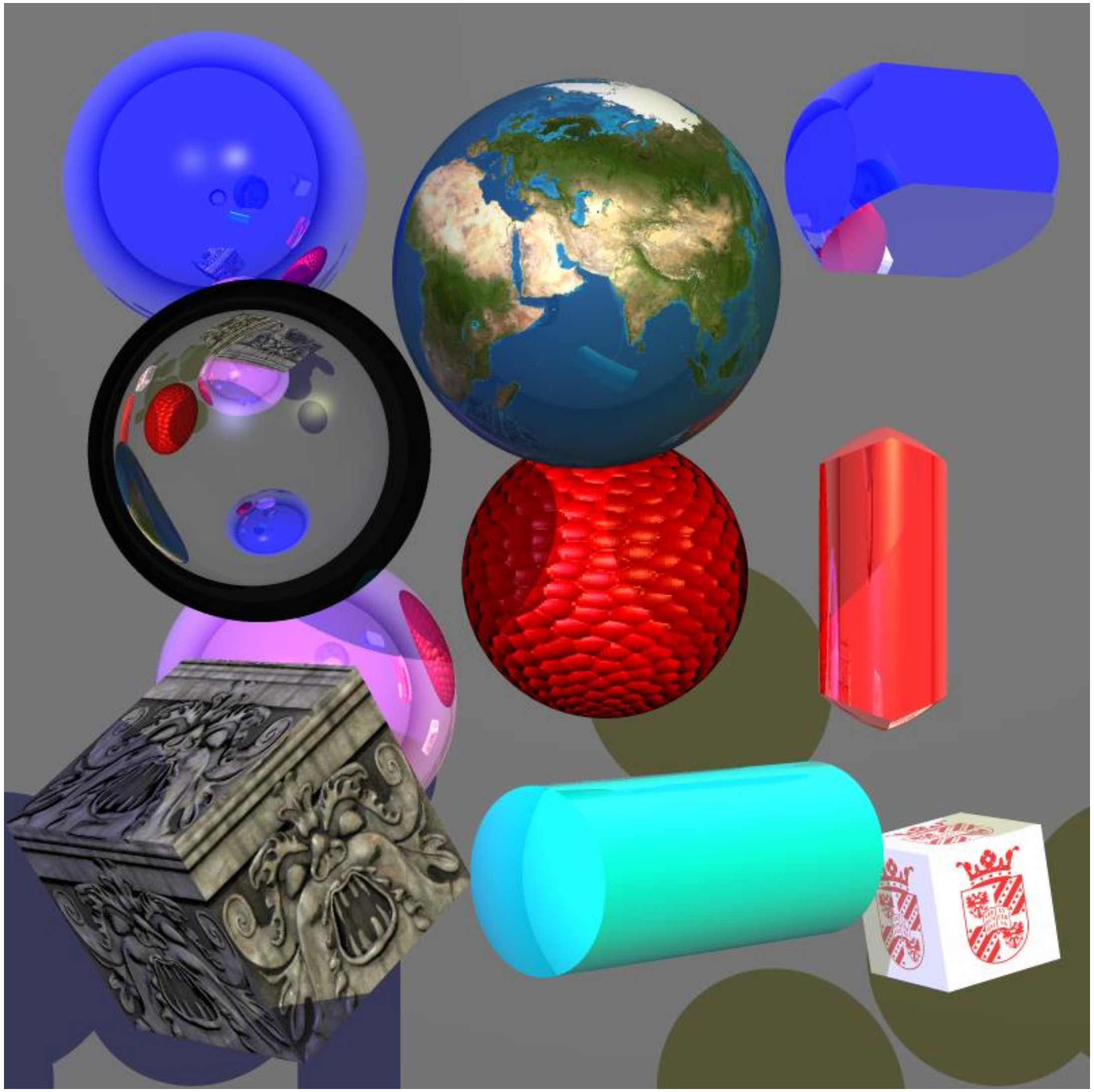
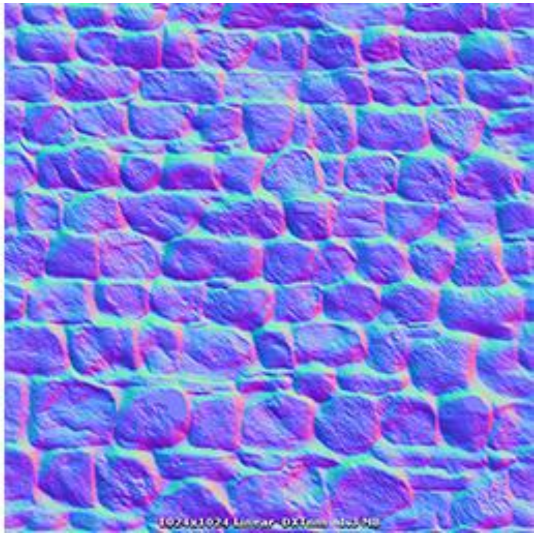


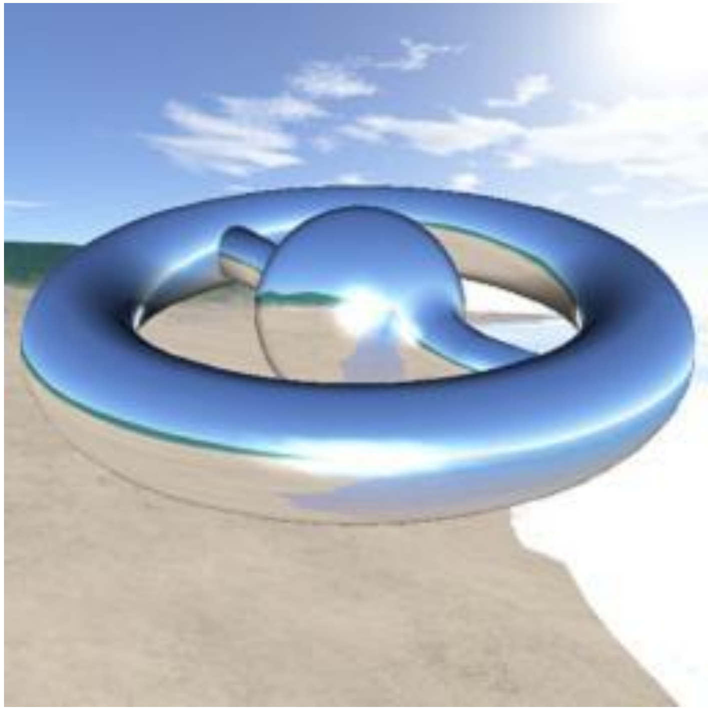
How to create bump maps?

1. Model/carve detailed object and “render” normals into a bump map.
2. Some image processing tools (e.g., Photoshop CC) allow one to create normal maps from regular images.

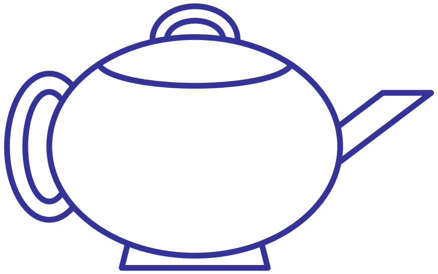


Affecting other Properties

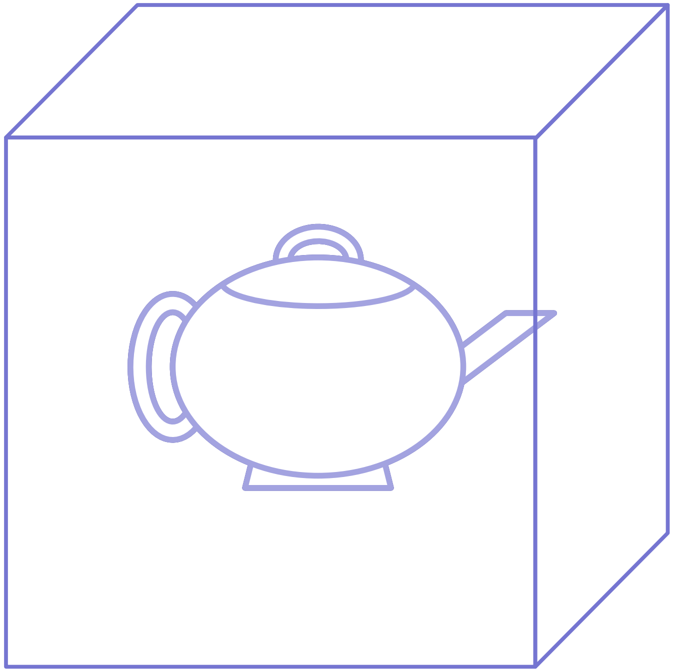
- actual surface positions (as opposed to normal vectors only): **displacement mapping**
- transparency
- simulation of reflection: **environment mapping**
- many more things with GPU processing



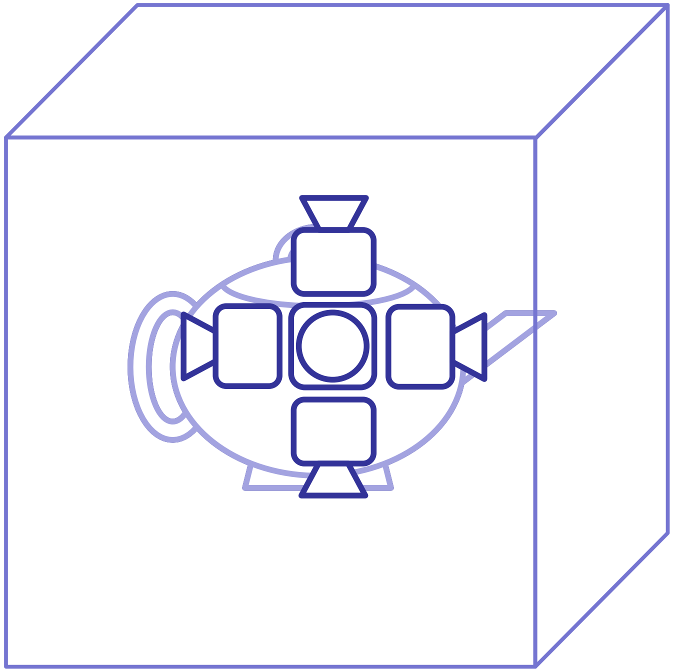
Environment Mapping



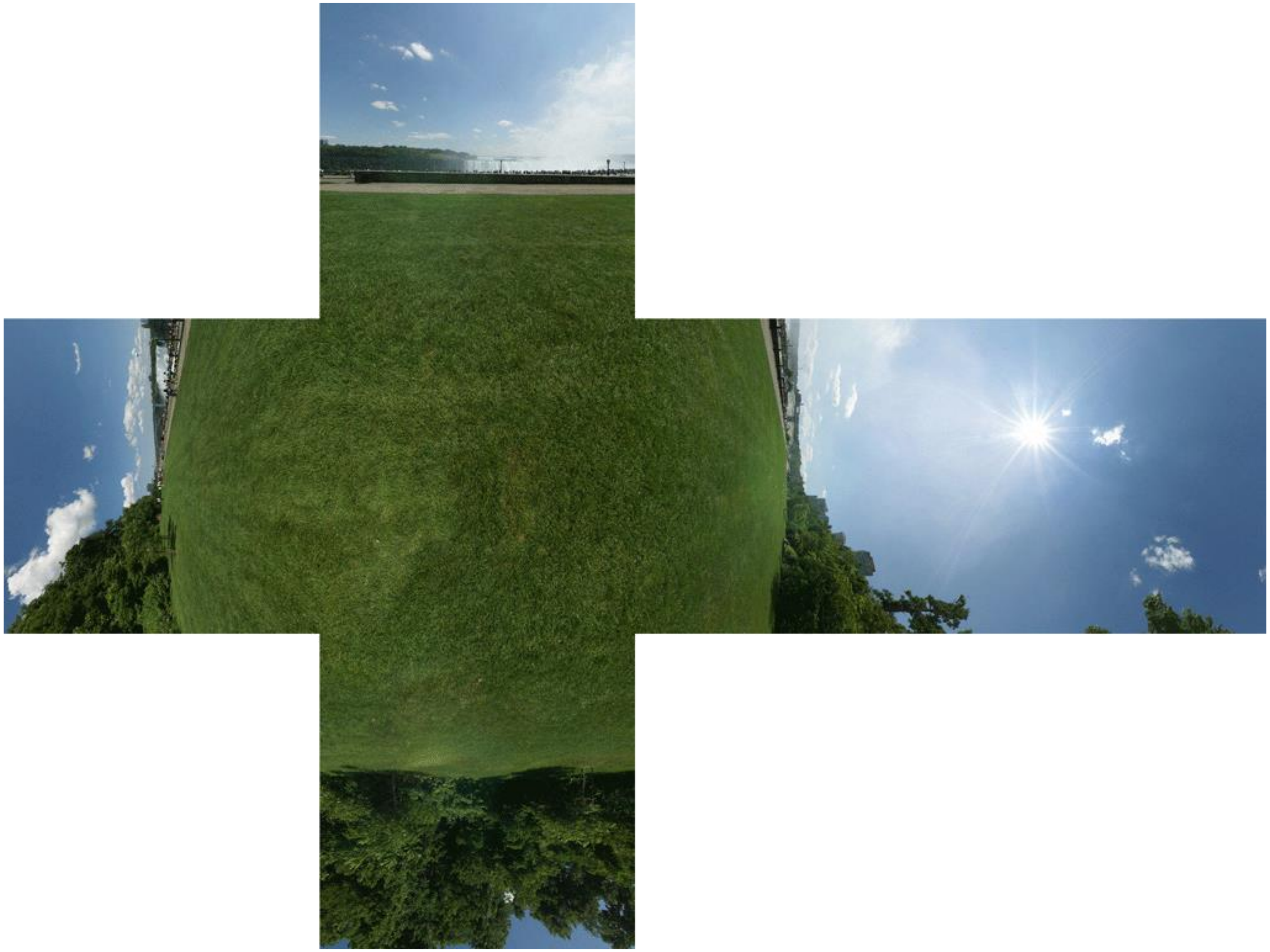
Environment Mapping



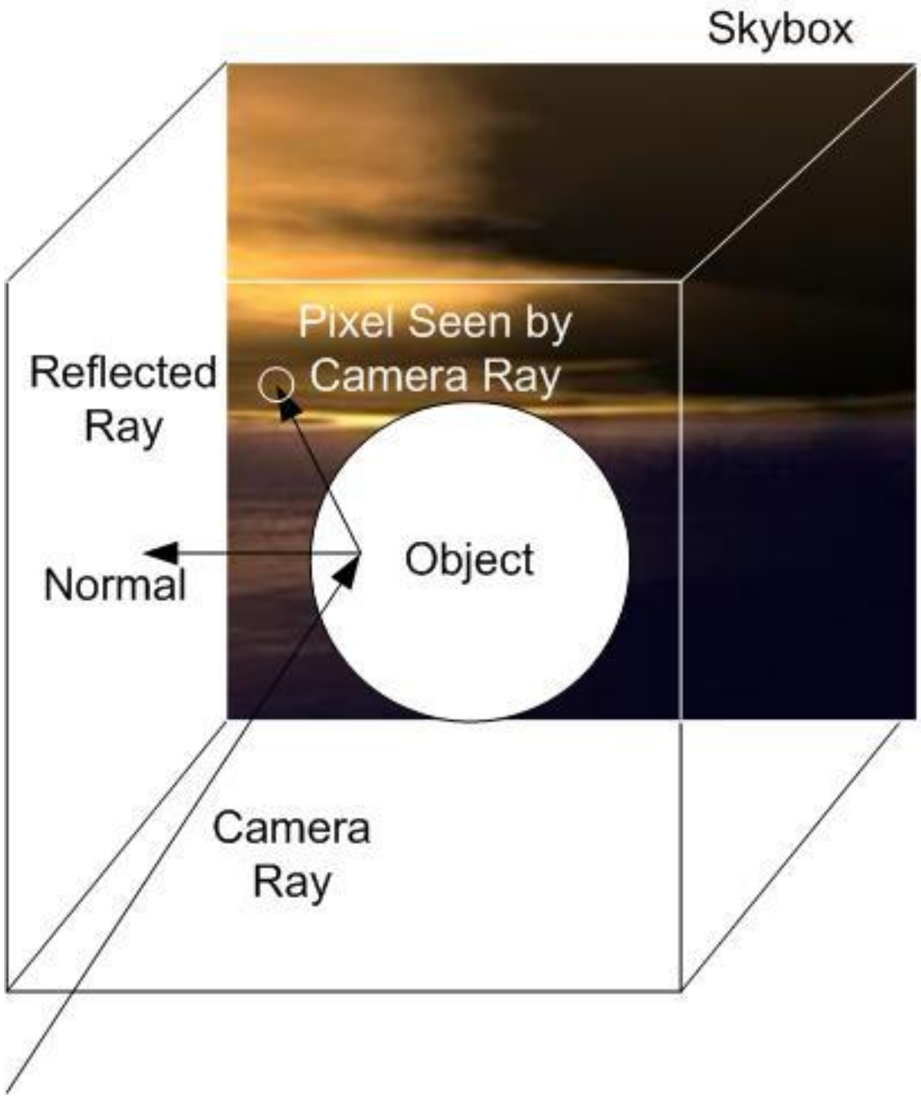
Environment Mapping

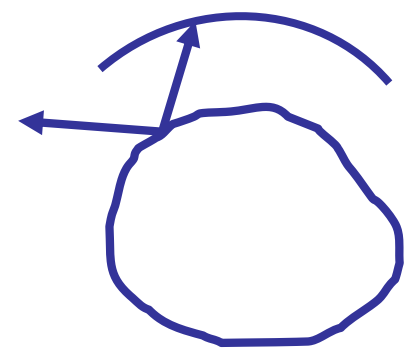


Environment Mapping

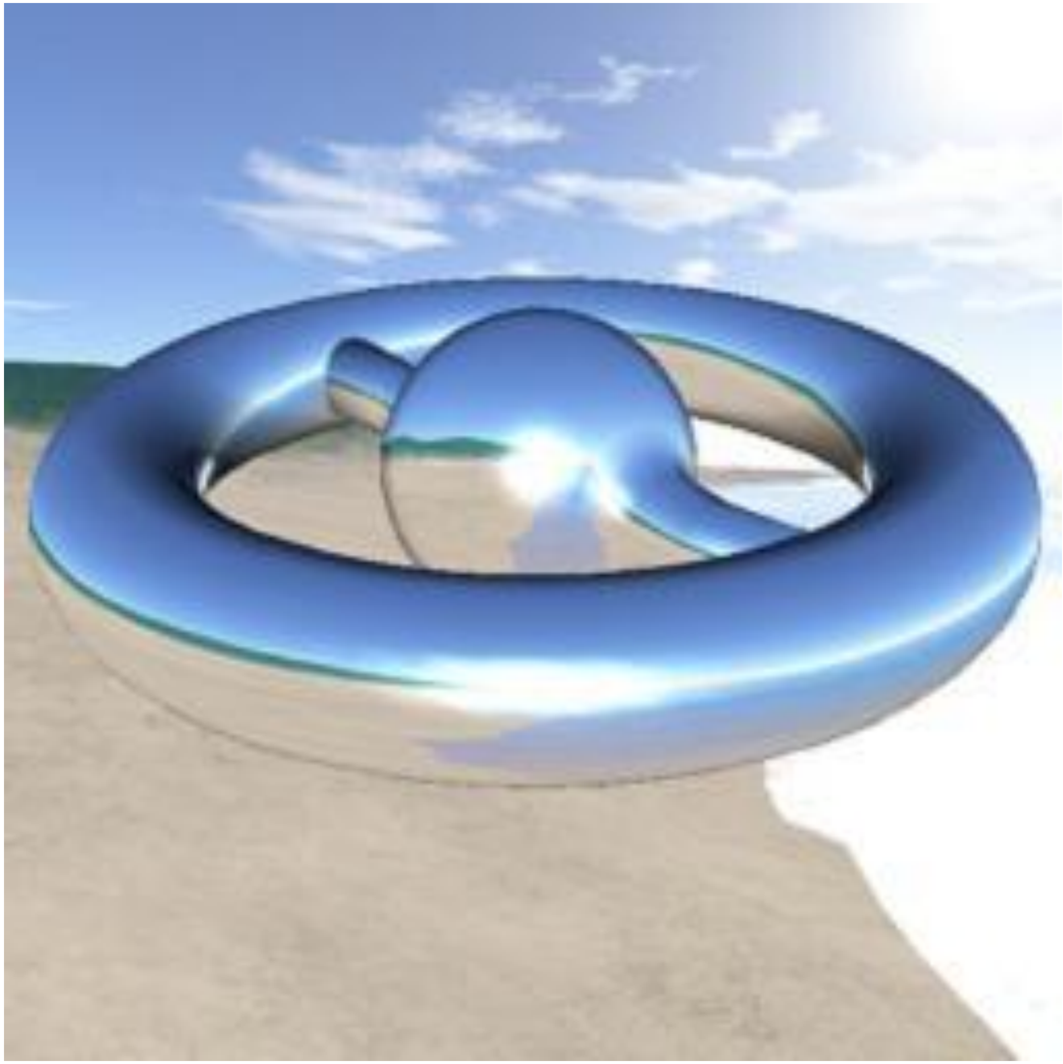


Environment Mapping





Environment Mapping

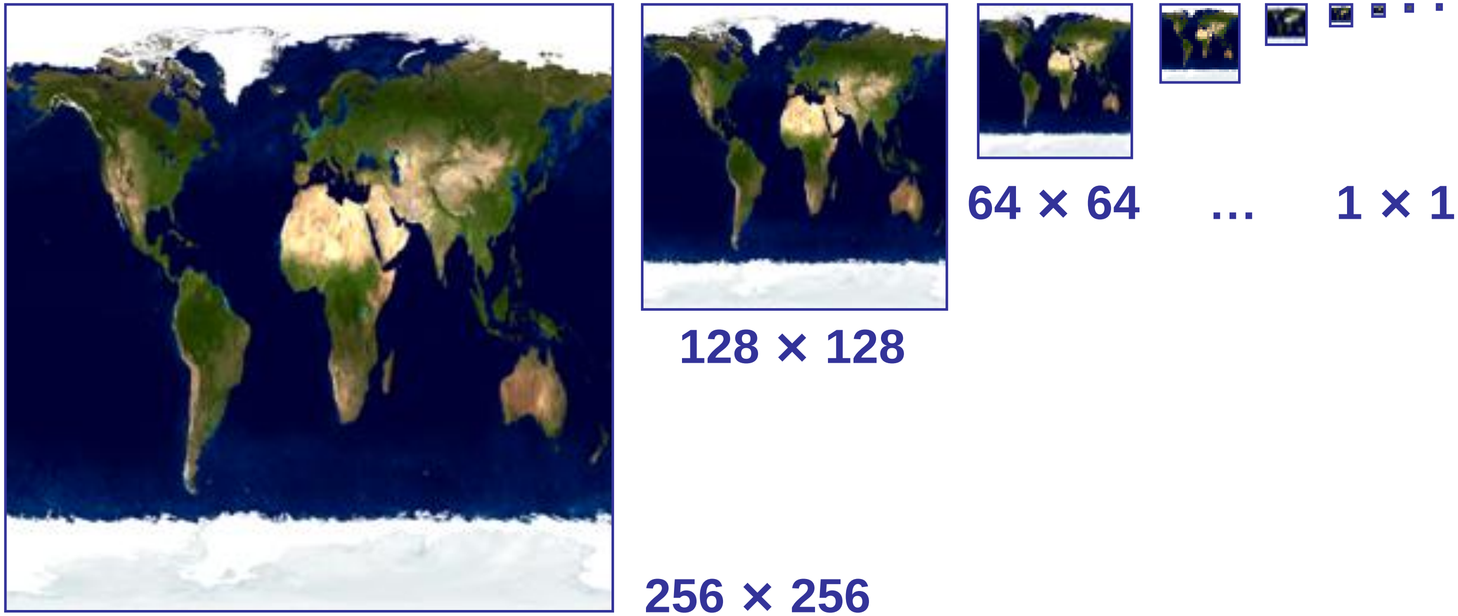


Texture Mapping

Quality Considerations

Texture Mapping: Mip Mapping

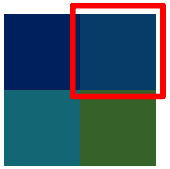
- optimal texture mapping (speed & quality): texel size ≈ pixel size
- idea: use stack of textures and select the most appropriate one w.r.t. situation



Texture Mapping: Mip Mapping

- optimal texture mapping (speed & quality): texel size ≈ pixel size
- interpolation: **GL_NEAREST_MIPMAP_NEAREST**

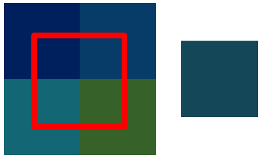
  select nearest mipmap level, select nearest pixel of 2×2 neighbourhood



Texture Mapping: Mip Mapping

- optimal texture mapping (speed & quality): texel size ≈ pixel size
- interpolation: **GL_LINEAR_MIPMAP_NEAREST**

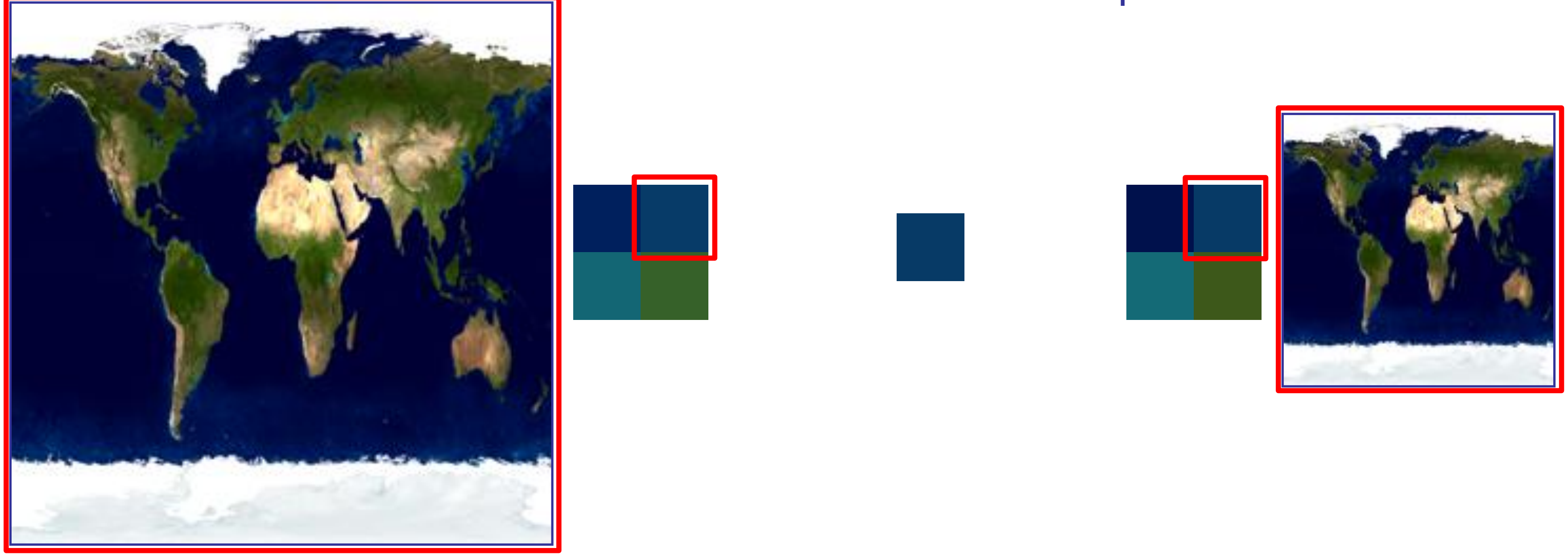
  select nearest mipmap level, linearly interpolate pixel in 2×2 neighbourhood



Texture Mapping: Mip Mapping

- optimal texture mapping (speed & quality): texel size ≈ pixel size
- interpolation: **GL_NEAREST_MIPMAP_LINEAR**

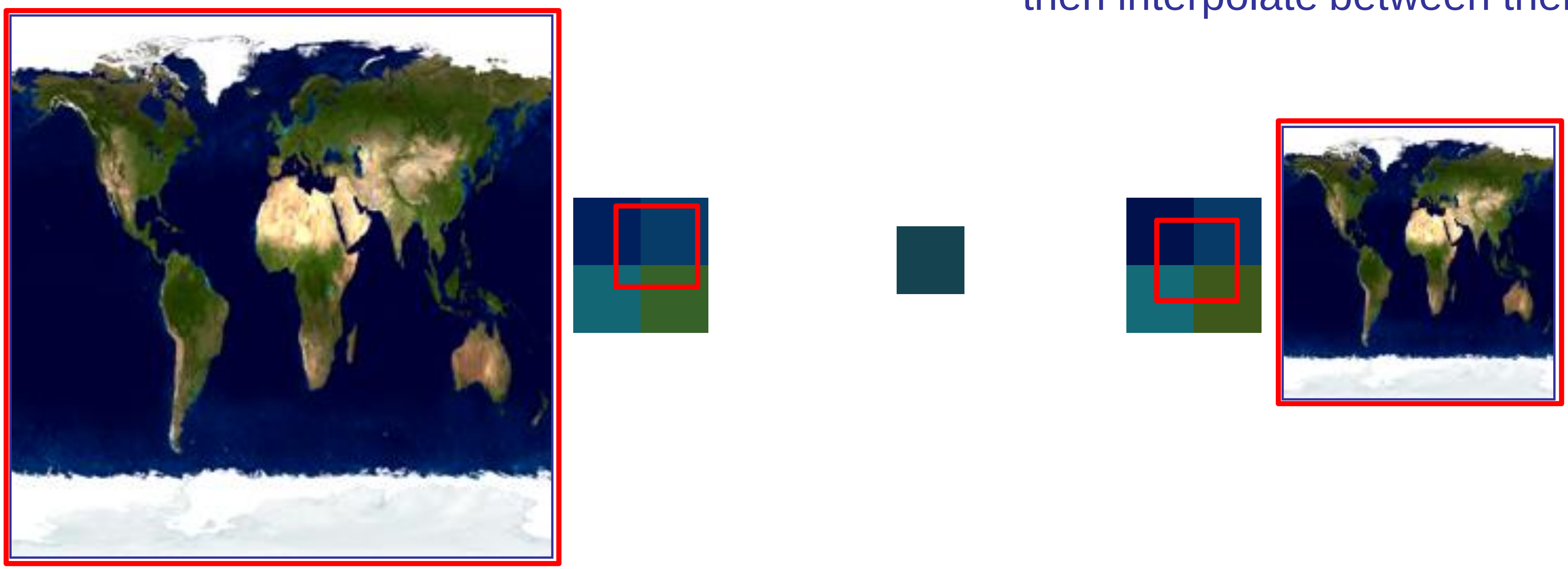
  select 2 adjacent mipmap levels, select nearest pixel in 2×2 neighbourhoods, then interpolate between them



Texture Mapping: Mip Mapping

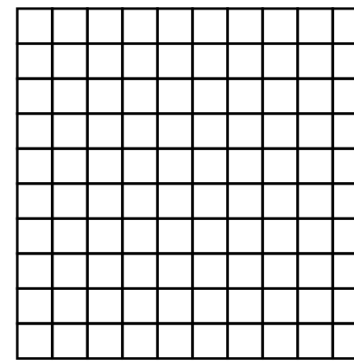
- optimal texture mapping (speed & quality): texel size ≈ pixel size
- interpolation: **GL_LINEAR_MIPMAP_LINEAR**

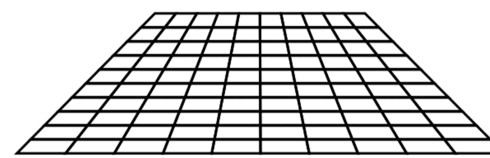
  select 2 adjacent mipmap levels, linearly interpolate pixel in 2×2 neighbourhoods, then interpolate between them



Texture Mapping: Anisotropic Filtering

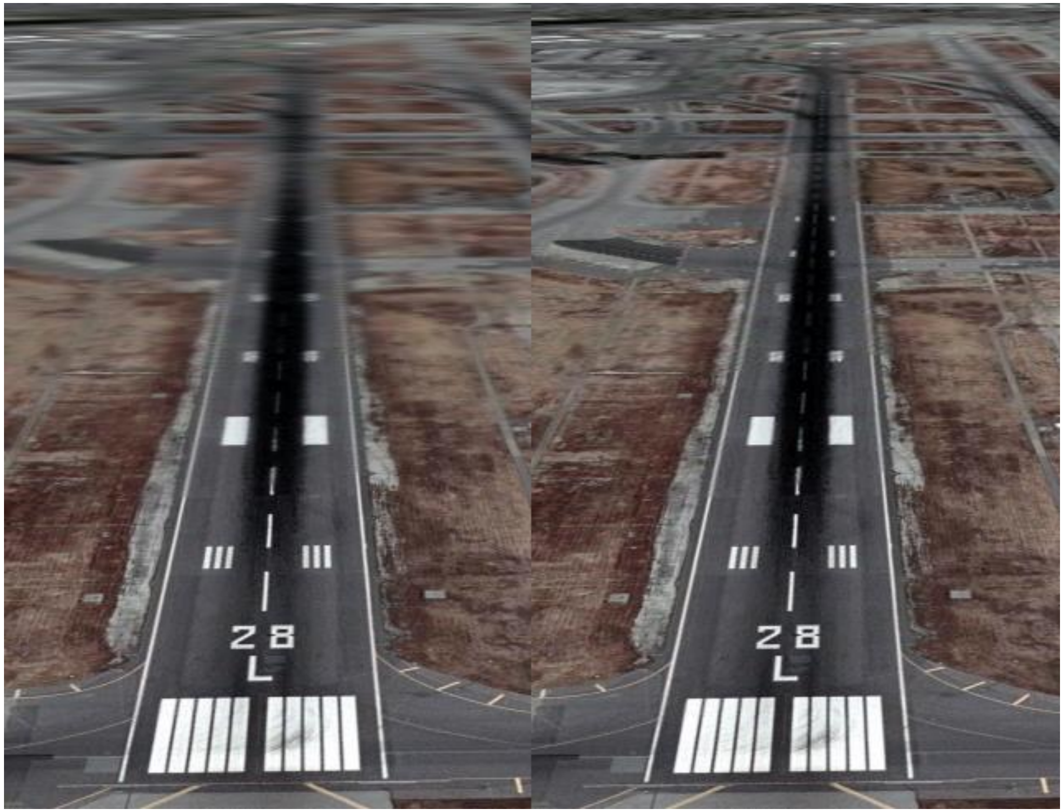
- large textures not perpendicular to viewing direction: blurring problems w.r.t. angle
- appropriate mip map selection not possible





Texture Mapping: Anisotropic Filtering

- large textures not perpendicular to viewing direction: blurring problems w.r.t. angle
- appropriate mip map selection not possible
- generate mip maps favoring one direction: 256×128, 256×64, 128×64, 128×32, ...



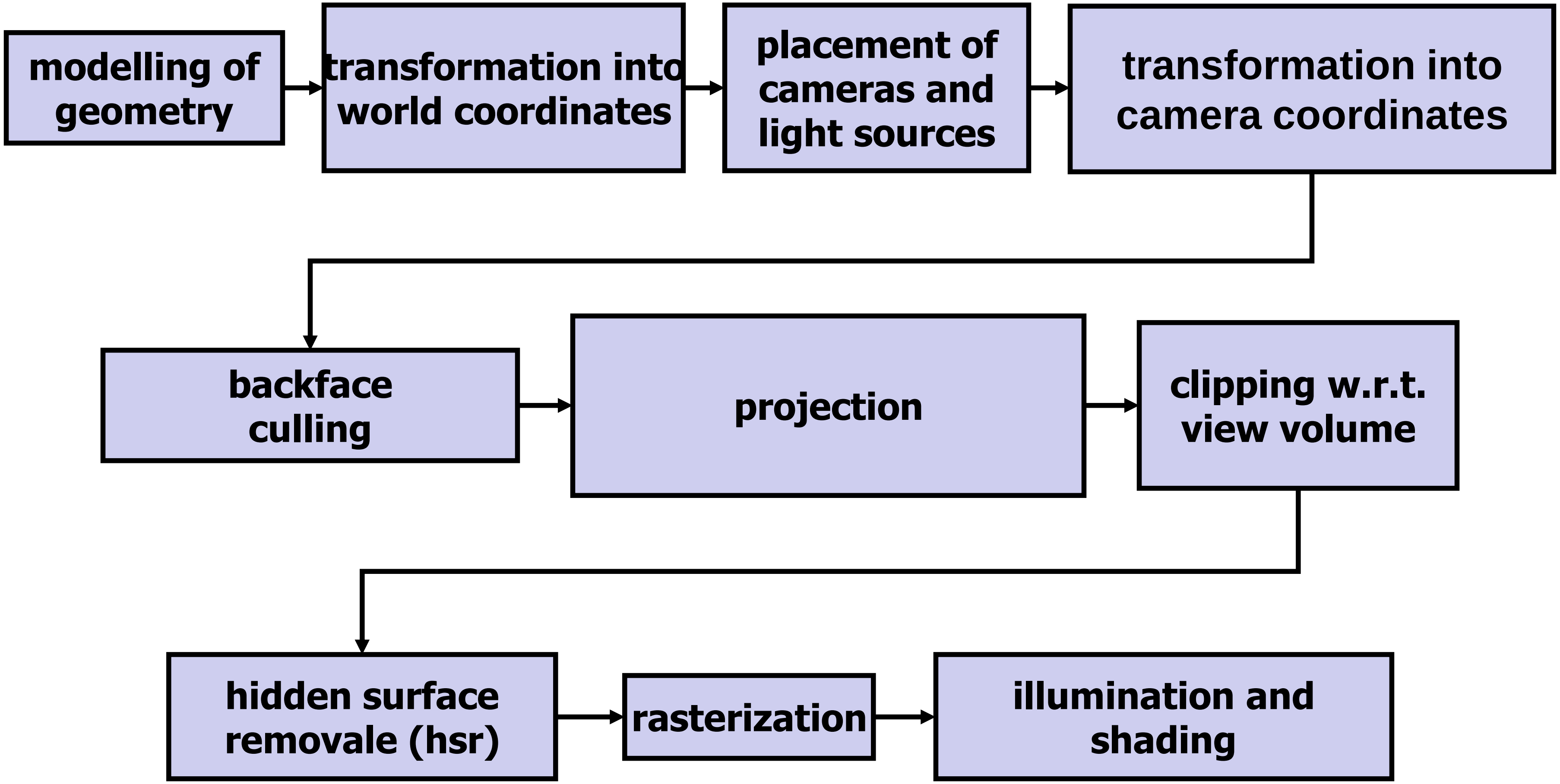
Texture Mapping: Summary

- a way to avoid having to model each detail using geometry and materials (modeling & rendering effort!)
- need textures and texture coordinates
- texture coordinates usually using 2 steps
- texture values typically affect diffuse/ ambient material color, but can change virtually anything in the rendering process

Pipeline-based Rendering

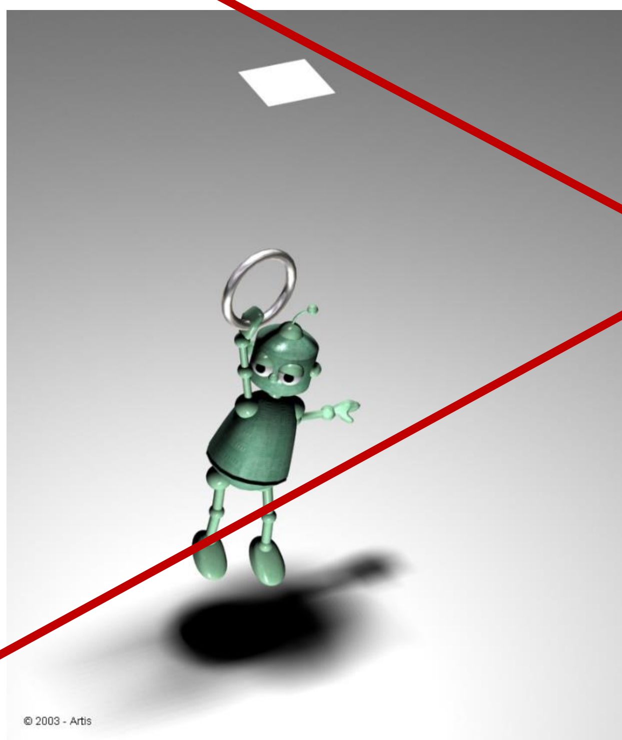
General Recaps

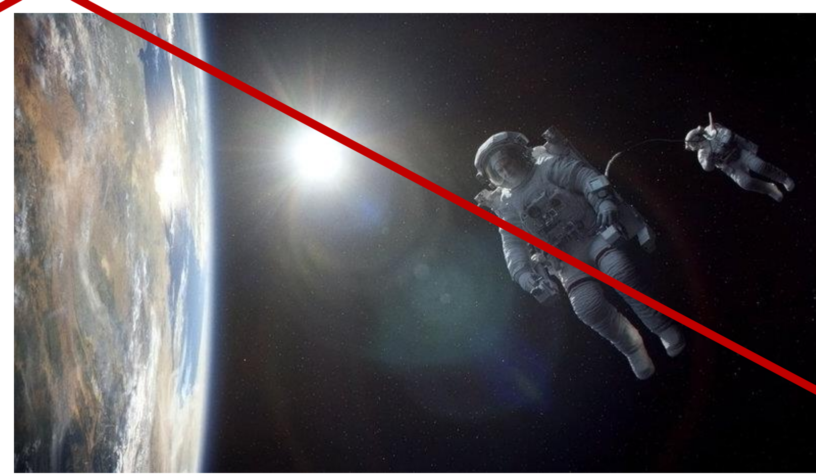
Recap: Rendering Pipeline



Recap: Differences from Cameras

- no shadows, no field of view, no lens flare, no motion blur

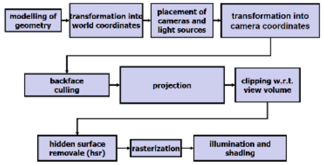


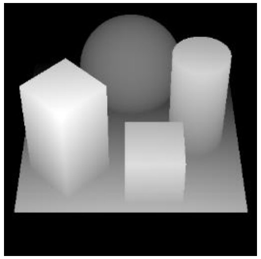


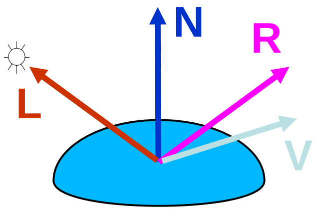
Recap: Efficiency & Effectiveness

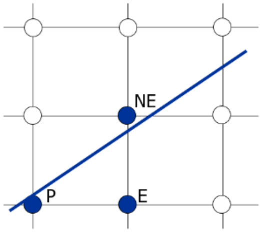
CG uses several “tricks”/strategies:

- only compute what is absolutely needed
- trade memory for speed
- trade precision for speed
- pre-“capture” data
- simplify, use heuristics
- reflect about the under-lying math & computation









Quality vs. Cost (GPU or Memory)

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Quality settings in games

Quality settings in games