CS 563 Advanced Topics in Computer Graphics
Texture Mapping

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Texture

- A texture is "a color that varies with location."
- Textures modify the way a material responds to light.
  - Materials – reflection, scattering, transmission, emission, absorption
  - Bump Map, Displacement Map, Clip Map
- Declaration:

```
class Texture {
   public:
     // constructors, etc.

     virtual RGBColor get_color(const ShadeRec& sr) const = 0;
};
```

Example Textures – Constant Color

- The **constant color texture** returns a specified color, regardless of location.
- Useful for specular highlights, reflection coefficients, etc.

```
class ConstantColor : public Texture {
   public:
     // constructors, etc.

     void set_color(const RGBColor& c);
     virtual RGBColor& get_color(const ShadeRec& sr) const;
   private:
     RGBColor color;
};

RGBColor ConstantColor::get_color(const ShadeRec& sr) const {
   return color;
}
```

Example Textures – Image

- The **image texture** returns colors based on an image (e.g. JPEG, TIFF, PPM).
- Image textures are a cheap, efficient way to add detail to a surface.

```
class ImageTexture : public Texture {
   public:
     // constructors, etc.
     virtual RGBColor& get_color(const ShadeRec& sr) const;
   private:
     int hres, vres;
     Image* image_ptr;
     Mapping* mapping_ptr;
};
```

Example Textures – Image

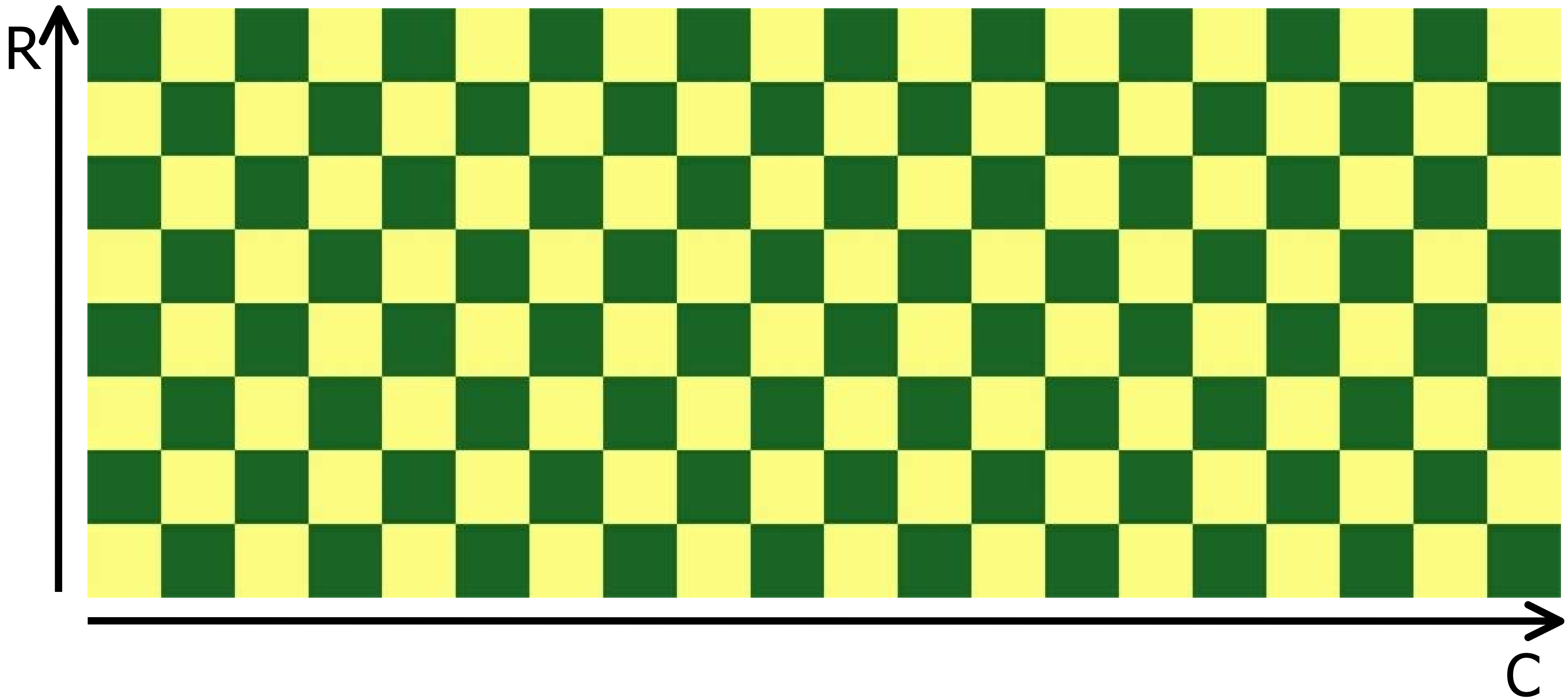
- The color returned from get_color() is determined by the local hit point (u, v).
  - Calculated at ray intersection.
  - Stored in ShadeRec.
- These coordinates might be displaced by a mapping.

```
RGBColor ImageTexture::get_color(const ShadeRec& sr) const {
   int row, column;

   if(mapping_ptr)
     mapping_ptr->get_texel_coordinates(sr.local_hit_point, hres,
                                         vres, row, column);
   else {
     row = (int)(sr.v * (vres – 1));
     column = (int)(sr.u * (hres – 1));
   }

   return (image_ptr->get_color(row, column));
```

A Texture



Spatially Varying Materials

- The properties of spatially varying materials (and the spatially varying BRDFs that define them) change with location.
- RGBColor values are replaced with Texture pointers.
- Any c* or k* value can be a texture!

SV_Lambertian BRDF

```
class SV_Lambertian : public BRDF {
   public:
        // constructors, etc.
        virtual RGBColor rho(const ShadeRec& sr, …);
        virtual RGBColor f(const ShadeRec& sr, …);
        virtual RGBColor sample_f(const ShadeRec& sr, …);
   private:
        float kd;
        Texture* cd;
};

RGBColor SV_Lambertian::rho(const ShadeRec& sr, …) {
   return (kd * cd->get_color(sr));

RGBColor SV_Lambertian::f(const ShadeRec& sr, …) {
   return (kd * cd->get_color(sr) * invPI);
}
```

SV_Matte Material

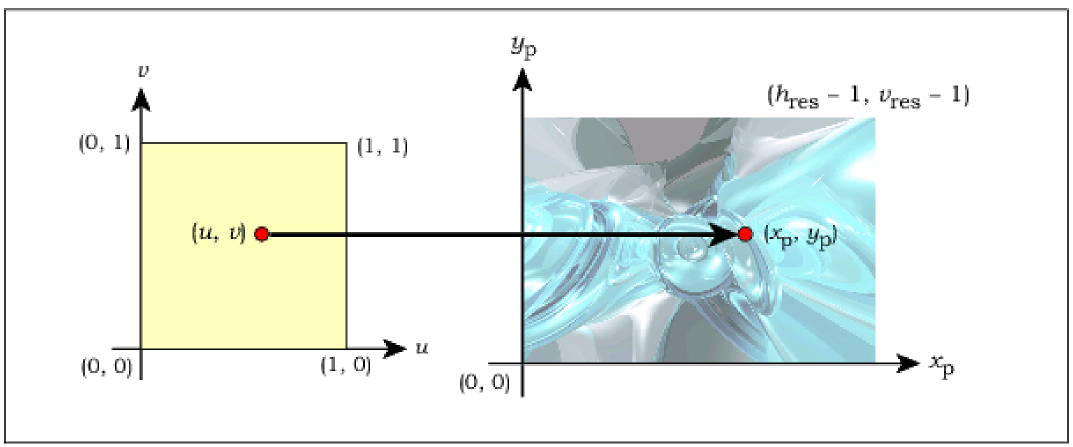
```
class SV_Matte : public BRDF {
   public:
        // constructors, etc.
        void set_cd(const Texture* t_ptr);
        virtual RGBColor shade(ShadeRec& sr);
   private:
        SV_Lambertian* ambient_brdf;
        SV_Lambertian* diffuse_brdf;
};

inline void SV_Matte::set_cd(const Texture* t_ptr) {
   ambient_brdf->set_cd(t_ptr);
   diffuse_brdf->set_cd(t_ptr);
}
```

The shade function does not change!

Mappings

- Each type of surface requires a different map to translate the 3D hit point into the correct pixel in a 2D texture.
- The 2D texture coordinates are *normalized*, so $\boldsymbol{(u,v) \in [0,1] \times [0,1]}$.
- Converting from (u,v) to texel coordinates (x_p, y_p):
  - $x_p = (h_{res} - 1)u$
  - $y_p = (v_{res} - 1)v$

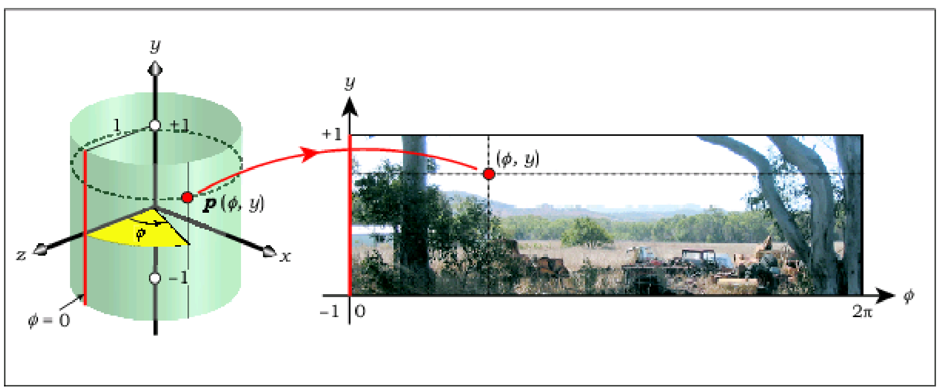


Rectangular Mapping

- Map to a generic rectangle $(x,z) \in [-1,+1] \times [-1,+1]$.
  - $u = (z + 1) / 2$
  - $v = (x + 1) / 2$
- This maps the entire texture, regardless of size or aspect ratio.
- Use transformations to adjust the rectangle.

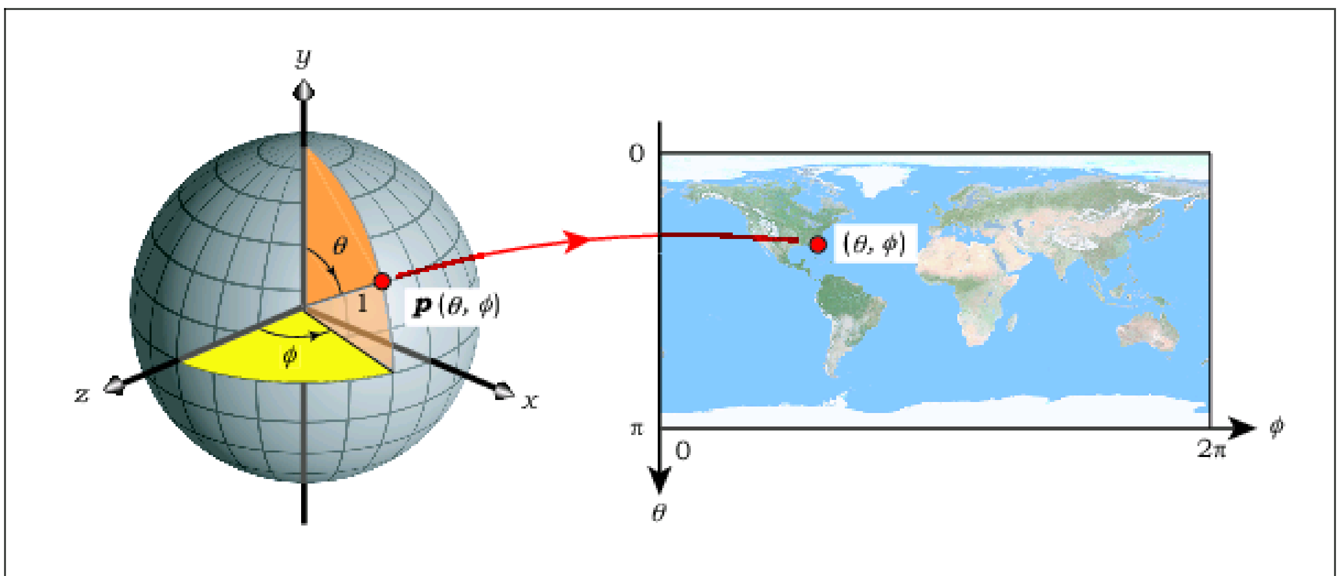
Cylindrical Mapping

- Using cylindrical coordinates, hit point ***p*** is defined by $\Phi \in [0,2\pi)$ and $y \in [-1,+1]$.
  - $\Phi = \tan^{-1}(x/z)$
  - $u = \Phi/2\pi$
  - $v = (y + 1)/2$
- Maps the left side of the image onto the line where the generic cylinder intersects the (y,z) plane with $x = 0$ and $z = 1$.
- Image must tile horizontally to avoid discontinuity.



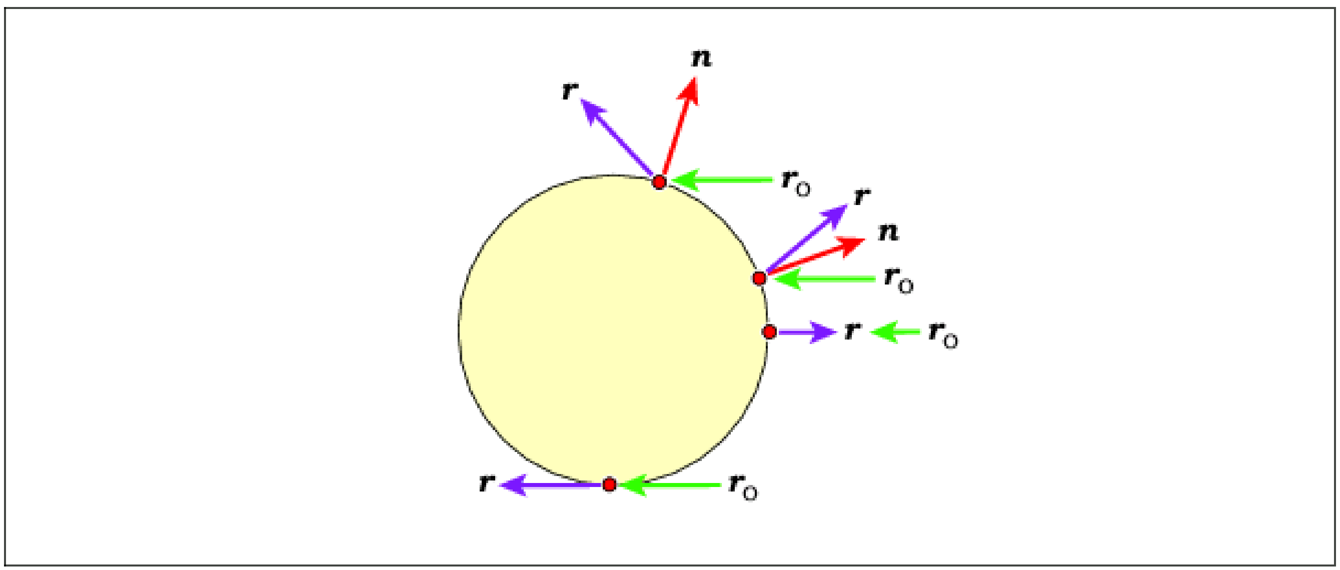
Spherical Mapping

- Spheres are not mathematically flat! Use Mercator.
- Φ is the same as the cylindrical map.
  - $\theta = \cos^{-1}(y)$
  - $u = \Phi/2\pi$
  - $v = 1 - \theta/\pi$
- Because $\Phi \in [0,2\pi]$ and $\theta \in [0,\pi]$, textures must have a 2:1 aspect ratio to cover the sphere.



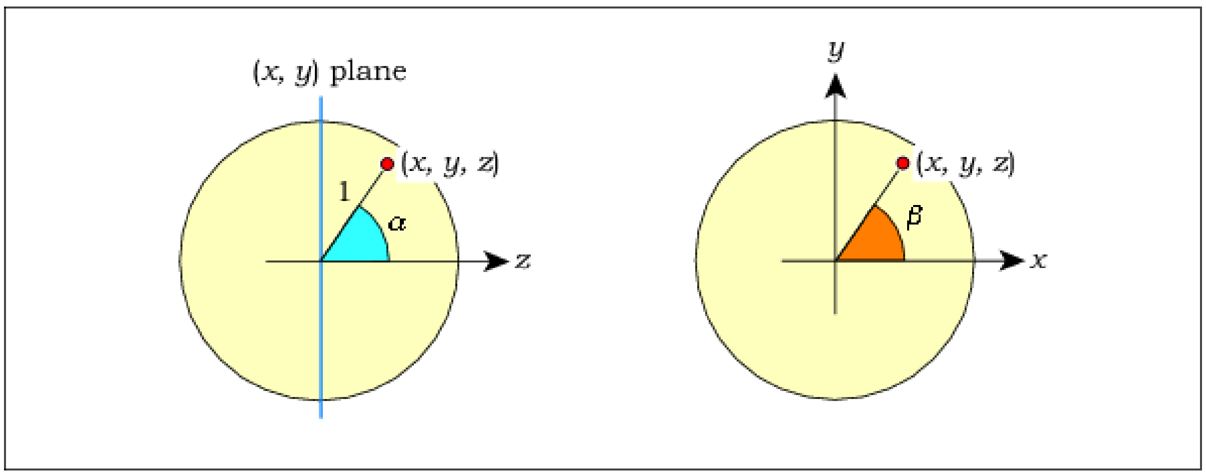
Light-Probe Mapping

- Place a reflective sphere in the middle of a scene and photograph it multiple times to sample the whole environment.
- The area directly behind the sphere is not reflected without multiple photographs.



Light-Probe Mapping

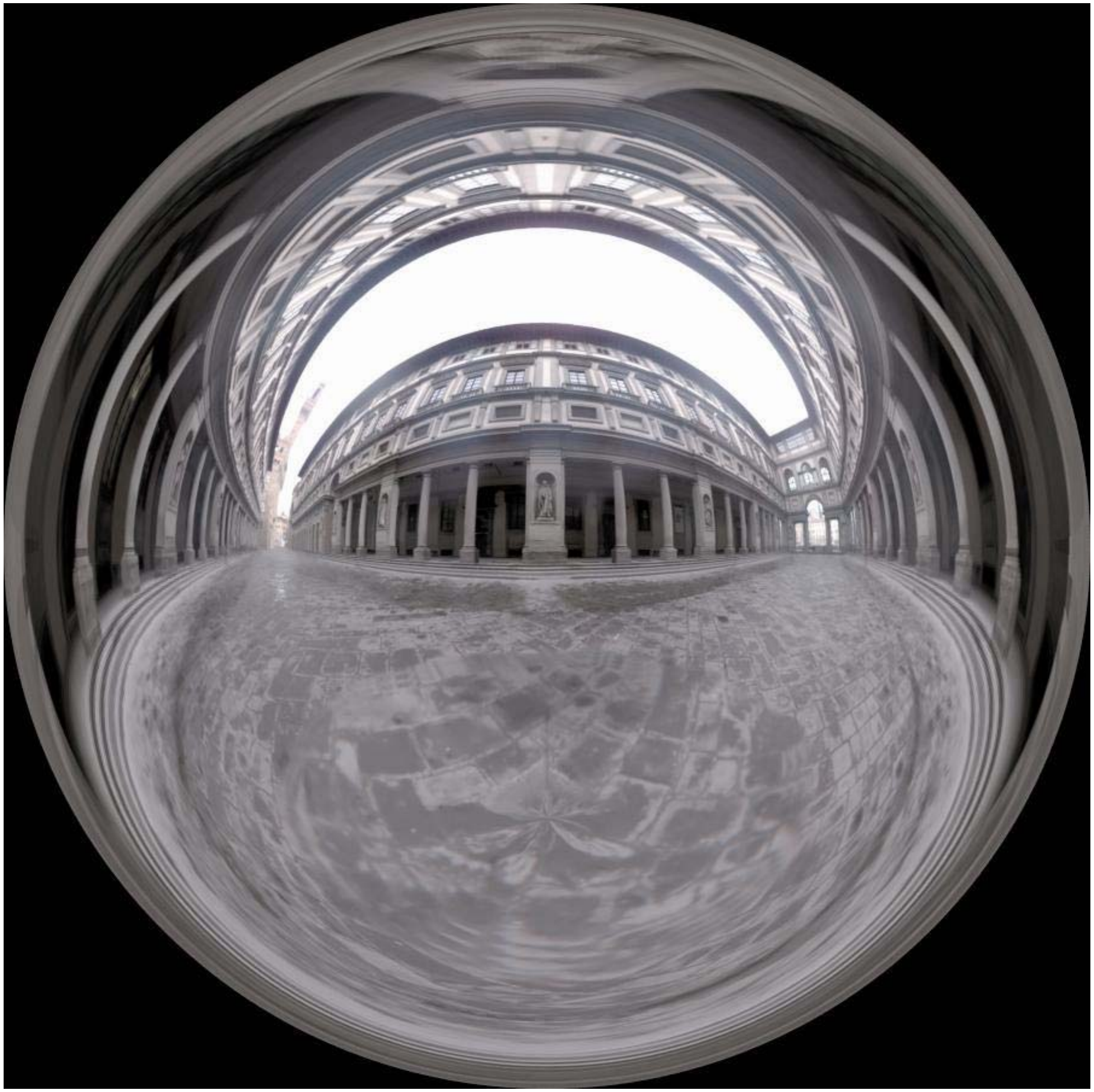
- Hit point has coordinates $(x,y,z) \in [-1,+1]^3$ on a unit sphere at the origin. Then,
  - $\alpha = \cos^{-1}(z)$
  - $\sin \beta = y/(x^2 + y^2)^{1/2}$
  - $\cos \beta = x/(x^2 + y^2)^{1/2}$
- So, the (u,v) coordinates are:
  - $u = [1.0 + (\alpha/\pi) \cos \beta]/2.0$
  - $v = [1.0 + (\alpha/\pi) \sin \beta]/2.0$



Light-Probe Mapping

- Create a texture from the photographs and apply it to a large sphere surrounding the scene.
- Gives the illusion of being inside the photographed environment.
- Light-Probed images are mirror reversals of reality, so flip z for actual panorama photographs.

Light-Probe Mapping



Antialiasing

- If pixels and texels do not match exactly, image textures will suffer from aliasing.
  - A given pixel covers many texels. The resulting texture generally looks good.
  - A given pixel covers only a fraction of a texel. The resulting texture looks pixelated.
- To prevent aliasing,
  - Use textures with high resolutions
  - Do not zoom in close on objects with image-based textures
  - Use intrinsic antialiasing, where the texture antialiases itself by averaging neighboring pixels for the returned color.

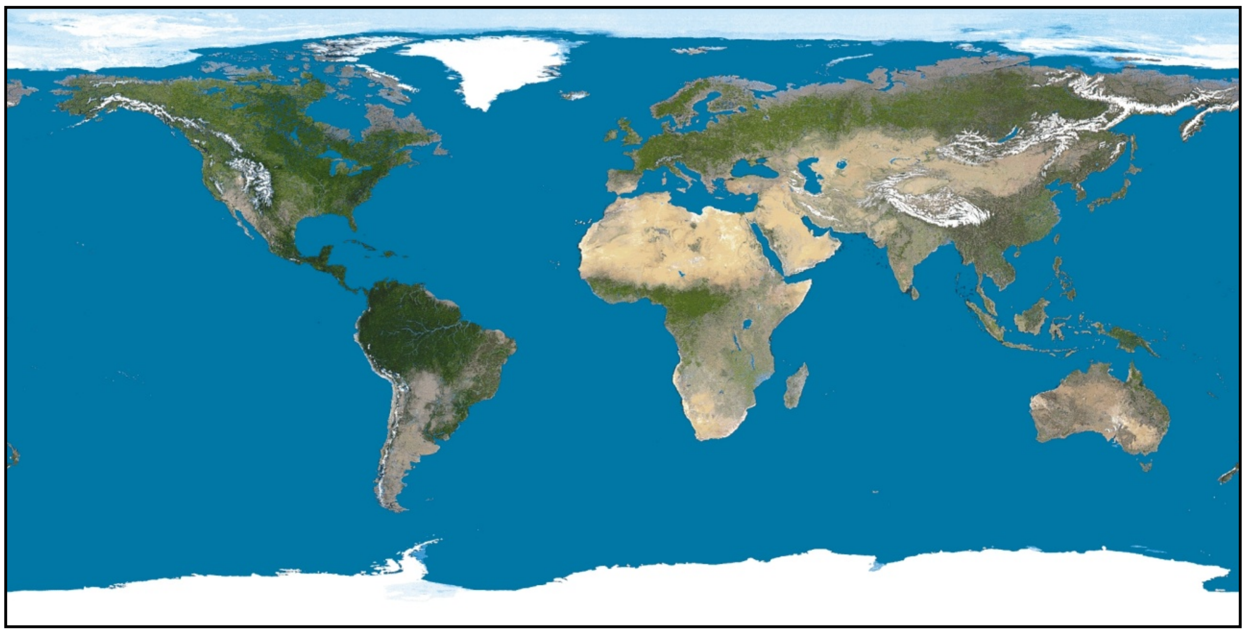
Triangle Meshes

- Triangles meshes are the most commonly textured objects in commercial ray tracers.
- To add support for textures triangle meshes, add two new parameters to the PLY file for u and v.
- Two new triangle types:
  - FlatUVMeshTriangle
  - SmoothUVMeshTriangle
- The u and v values are interpolated in the base MeshTriangle class since the process is the same for both flat- and smooth-shaded triangles.

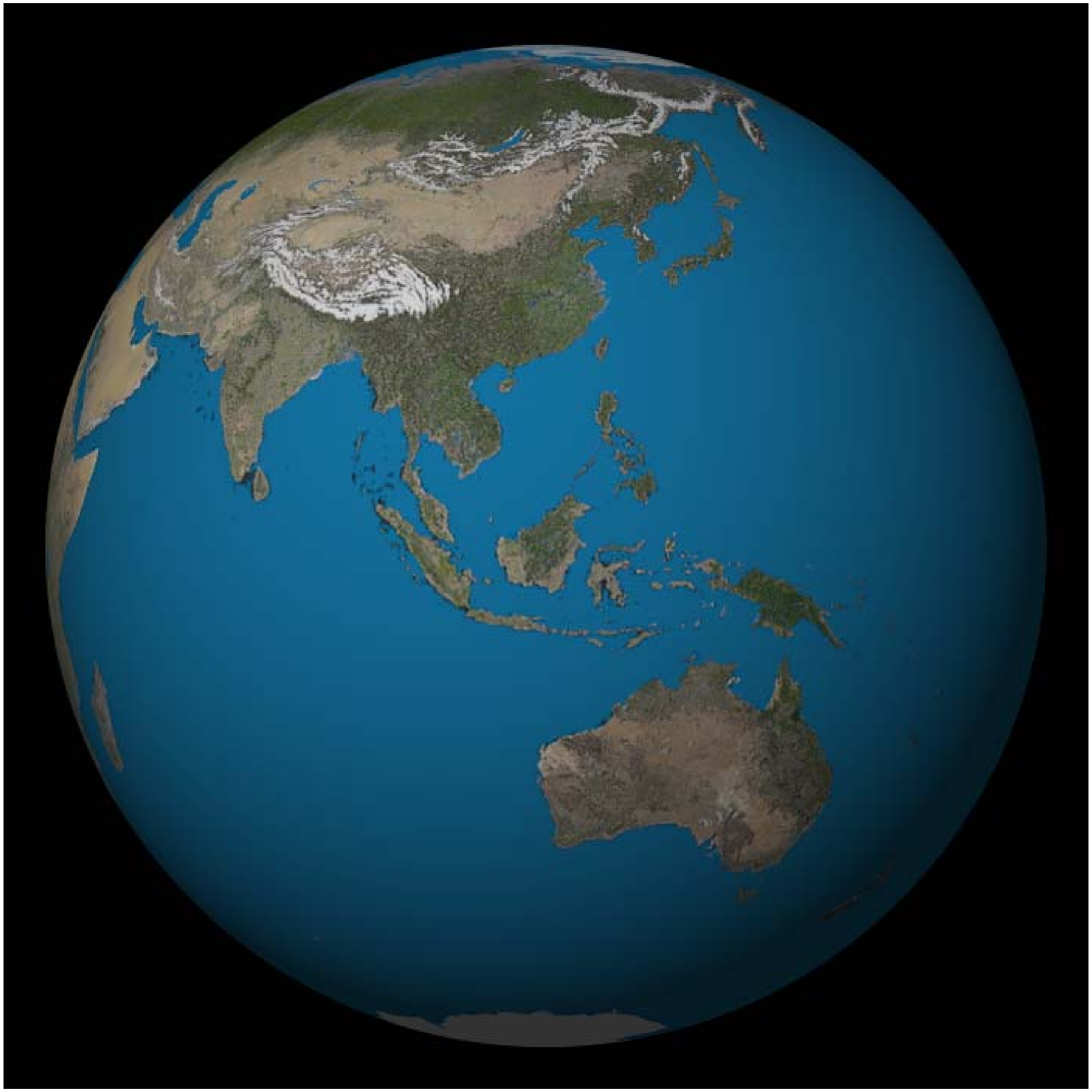
PLY File with UV Data

```
ply
format ascii 1.0
element vertex 4
property float x
property float y
property float z
property float u
property float v
element face 2
property list int int vertex_indices
end_header
-1.0 0.0 -1.0 0.0 0.0
-1.0 -1.0 1.0 1.0 0.0
1.0 0.0 1.0 1.0 1.0
1.0 -1.0 -1.0 0.0 1.0
3 0 1 2
3 0 2 3
```

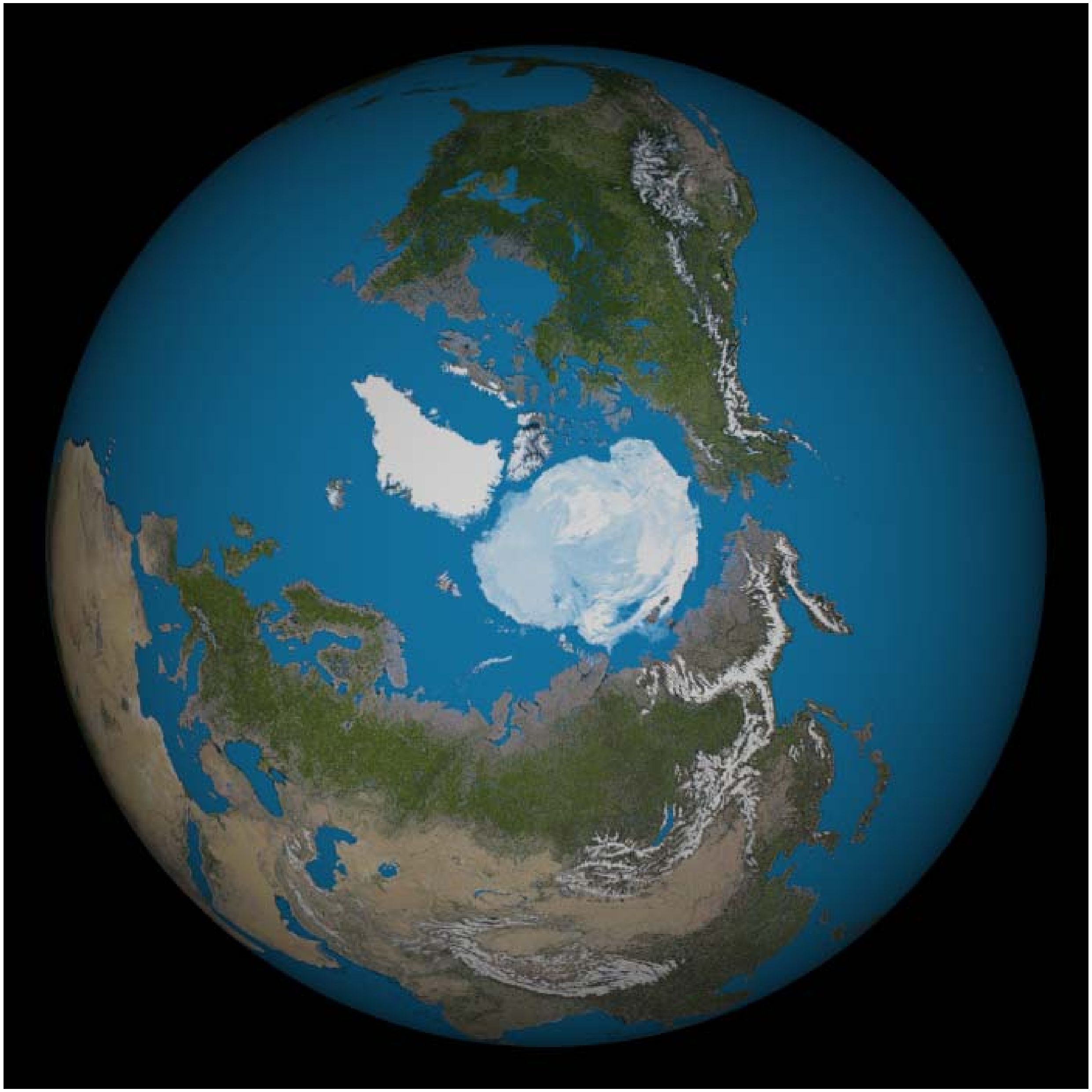
Example: Earth



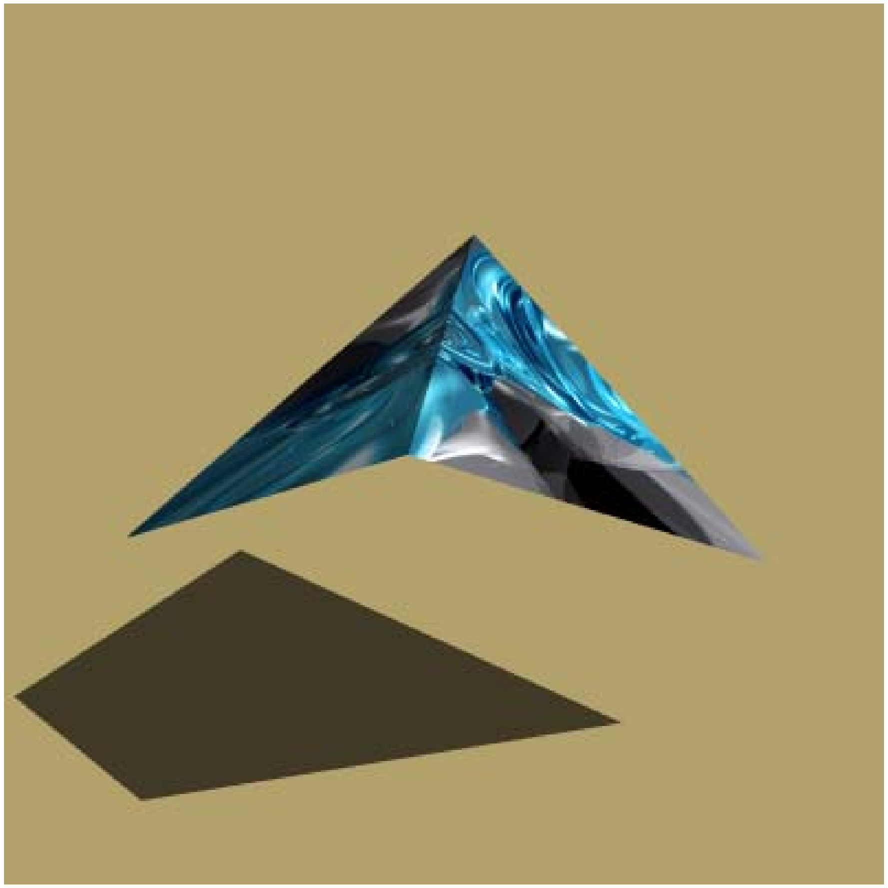
Example: Earth



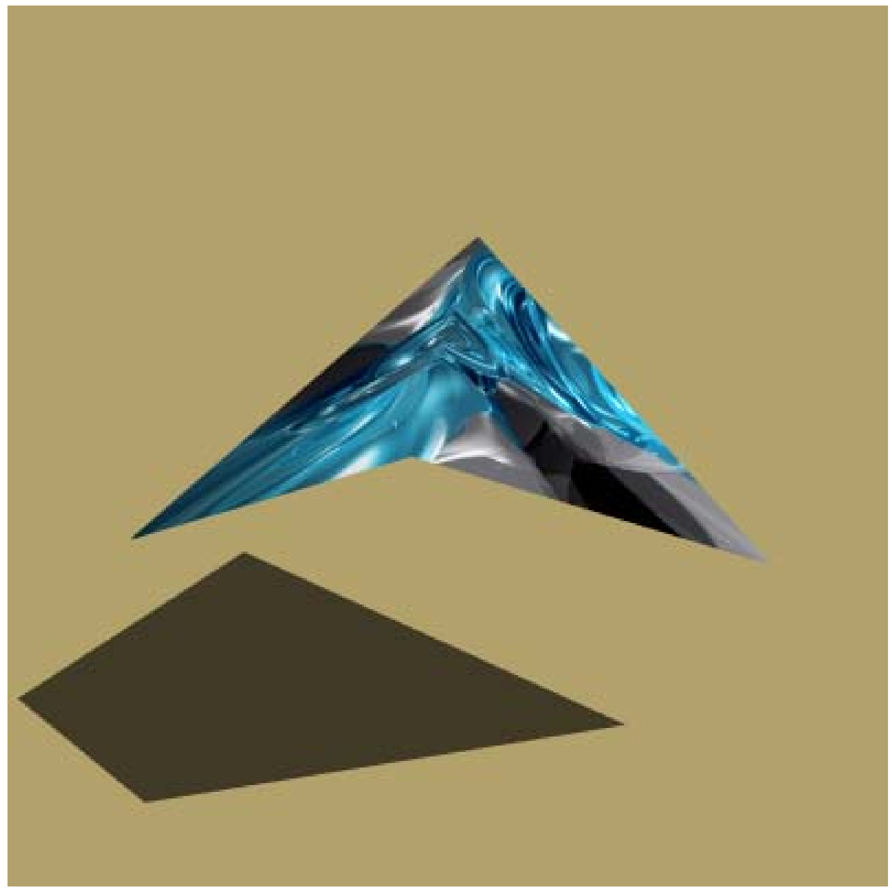
Example: Earth



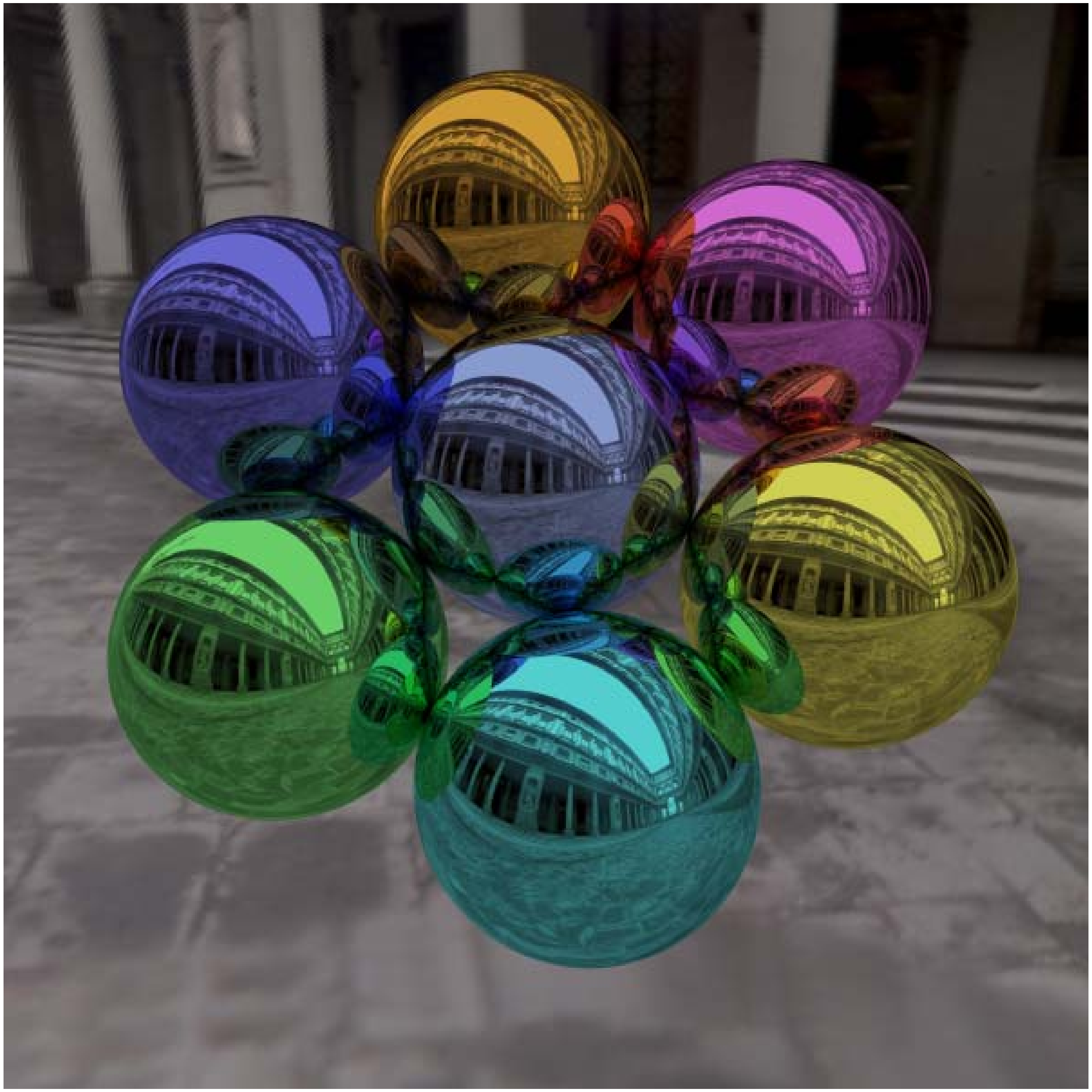
Example: Two Triangles



Example: Two Triangles



Example: Light Probe



QUESTIONS?