Computer Graphics II: Rendering

CSE 168[Spr 25],Lecture 14: Environment, Texture Maps
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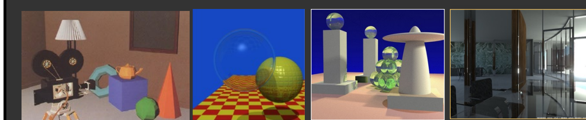
http://viscomp.ucsd.edu/classes/cse168/sp25



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To Do

- Start working on final projects (initial results and proposal due in < 2 weeks). Ask me if problems
- Adding HDR/Envmaps (this lecture) may be one component of the final project
- Will briefly also talk about texture mapping

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Reflection Maps

Blinn and Newell, 1976

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Environment Maps

Miller and Hoffman, 1984

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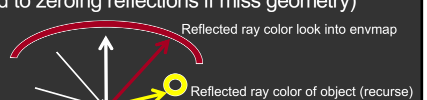
Using Environment for Reflection Map

- Simplest: Mirror reflections (refraction)
  - Start with a simple ray tracer
  - Reflected ray traced to environment (is emission/color)
  - Color += reflectivity * Color of reflected ray
  - Directly use envmap if miss geometry, otherwise recurse
  - (As opposed to zeroing reflections if miss geometry)



  - Easy to do in ray tracer. For path tracer, if reflected ray is sampled (BRDF has mirror component)

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Environment Maps

***Interface*, Chou and Williams (ca. 1985)**

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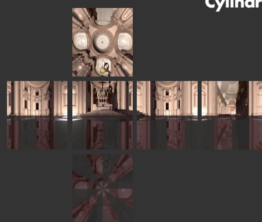
Environment Maps

Cylindrical Panoramas



Cubical Environment Map

180 degree fisheye
Photo by R. Packo

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Reflection Maps in the Movies

- From history, pauldebevec.com/ReflectionMapping
- First movie, Flight of the Navigator 1986

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Environment Map Representations

- Simplest lat-long spherical coords (θ,φ)
  - Convert direction to spherical coords, direct lookup

- Cubemaps popular (6 faces of cube)
  - Take biggest (abs) of (x,y,z)
  - Divide/renorm by it to get coords
  - E.g. if +z, use x/z, y/z, z=+1
  - Cubemap coord to vec: normalize
  - Easy convert bet cube, latlong

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High Dynamic Range

- Ratio of brightest to darkest environment regions can be a million to 1. High Dynamic Range HDR
- Acquiring (floating point) HDR envmaps is good
- Tonemap as needed for display (large topic)
- Accurate HDR values needed for accuracy
  - When considering diffuse/specular BRDFs
  - Tonemap mirror reflections, viewing environment
  - Photograph a mirror ball with HDR or use many HDR envmaps found online
  - See Debevec 97, 98 for discussion of HDR
  - (HDR Imaging images from Wikipedia)

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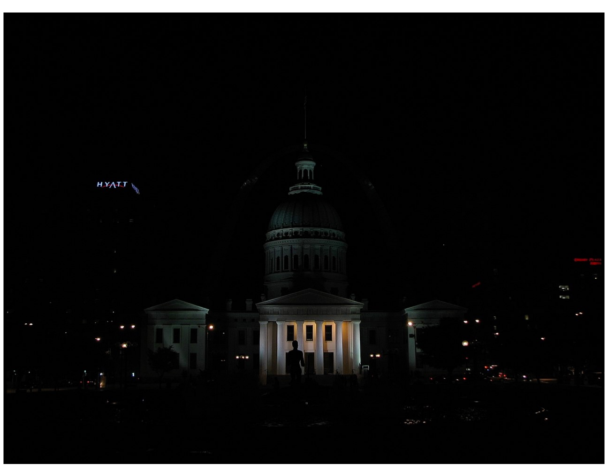

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Environment Maps Generally

- Mirror reflections good but not general
- Can we render all effects with envmap?
- Simple idea, envmap on large sphere around scene
  - When path leaves scene, it hits envmap
  - Consider emission (radiance) from given envmap pixel
  - Significant noise/aliasing for high-frequency HDR envmaps (e.g. you may almost always miss the sun)
- Challenge is we effectively have millions of lights
  - Need to importance sample the environment map
  - Effectively extend next-event estimation to envmaps
  - Or identify bright lights (Debevec 98,99 asked undergraduates to trace this out manually!)

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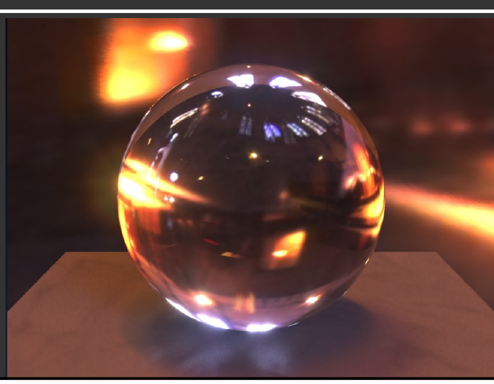
HDR Environment Illumination



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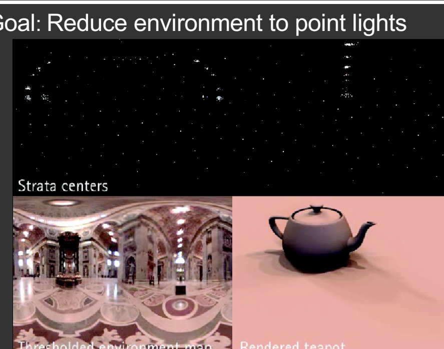
Structured Importance Sampling

- Goal: Reduce environment to point lights



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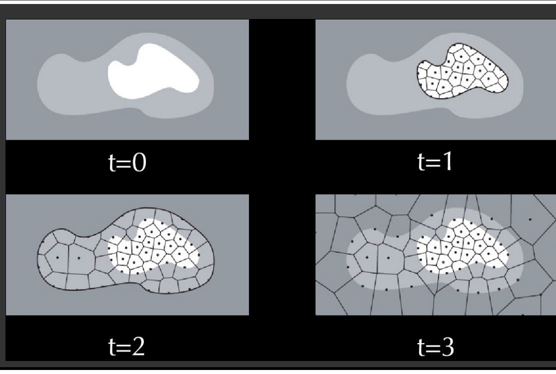
Hierarchical Stratification



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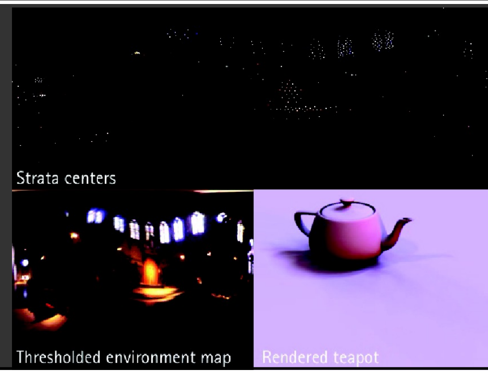
Structured Importance Sampling



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Lat-Long Importance Sampling

- Simple alternative (PBRT book)
- Multidimensional importance sampling θ,φ
  - Generate a numerical 1D CDF along φ integrating over all θ
  - For each φ generate a numerical CDF over θ
  - Essentially creates axis-aligned (lat-long) cells
  - Compatible with any sampling scheme (stratified)
  - I implemented this at Pixar (circa 2011)
  - Done properly, PDF (almost) cancels lighting (can work out on board). Many subtleties involved, MIS
- Other Simplifications
  - Integrate lighting in strata to create point lights
  - Jitter only for visibility (if at all)

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Sampling General 2D Distributions

- Treat Lighting as general 2D distribution
  - Doing this for 1 color channel, take avg for probs

$$\iint L(\theta,\varphi)\sin\theta\, d\theta\, d\varphi = \iint L(u,v)\,du\,dv \quad u=\cos\theta=z, v=\varphi$$

- Normalize to convert to probability to sample from
  - Note that probability distribution also enables MIS

$$p(u,v)=\frac{L(u,v)}{|L|} \quad |L|=\iint L(u,v)\,du\,dv$$

  - For direct lighting, illumination cancels out (careful re color)
    - Will bring down a term of L_c / L_{avg}

$$L_d(\omega_o)=\left\langle \frac{L(u,v)V(u,v)f(u,v;\omega_o)\max(0,n\bullet\omega_i(u,v))}{p(u,v)} \right\rangle = |L|\langle V(u,v)f(u,v;\omega_o)\max(0,n\bullet\omega_i(u,v))\rangle$$

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How to Sample 2D Distribution

- Form (numerical) 1D CDFs $p(v)=\int p(u,v)\,du \quad p(u\,|\,v)=\frac{p(u,v)}{p(v)}$
- Generate 2 random numbers in standard way
  - Use numerical 1D CDF inversion to find v, then u
  - Works with any sampling scheme (stratified etc.)
- Note that I've done everything in integrals, but you will need to discretely sum, dividing by resolution (and consider factors of Pi for environment maps)

$$|L|=\frac{4\pi}{n_u n_v}\sum_u\sum_v L(u,v) \qquad p(v)=\frac{2}{n_u}\sum_u p(u,v)$$

- Or look up SIS paper, code (Agarwal et al. 03)

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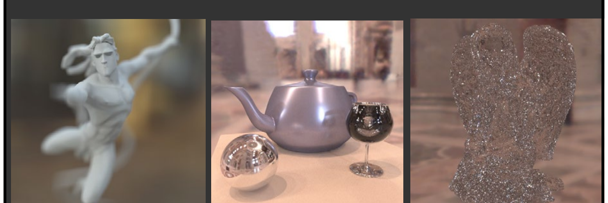
From UCB class many years ago



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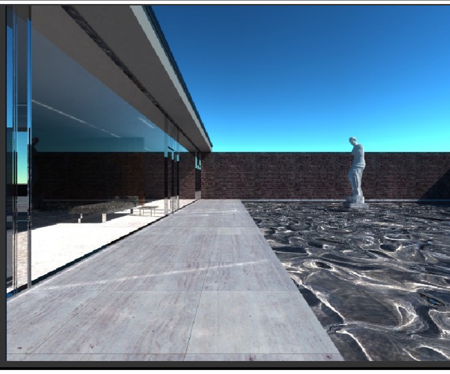
Mies House: Swimming Pool



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Texture Mapping

- Important topic: nearly all objects textured
  - Wood grain, faces, bricks and so on
  - Adds visual detail to scenes
- Meant as a fun and practically useful lecture

Polygonal model

With surface texture

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Adding Visual Detail

- Basic idea: use images instead of more polygons to represent fine scale color variation

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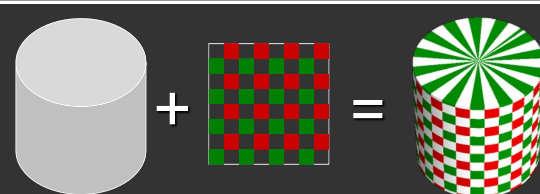
Parameterization



geometry image texture map

- Q: How do we decide *where* on the geometry each color from the image should go?

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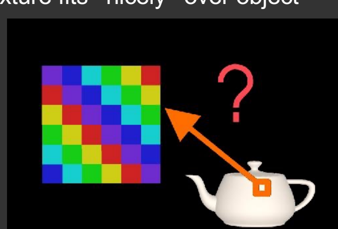
How to map object to texture?

- To each vertex (x,y,z in object coordinates), must associate 2D texture coordinates (s,t)
- So texture fits “nicely” over object



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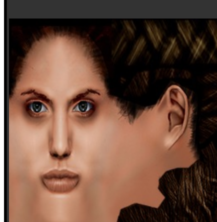
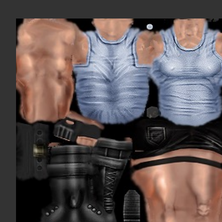
Option: it’s the artist’s problem





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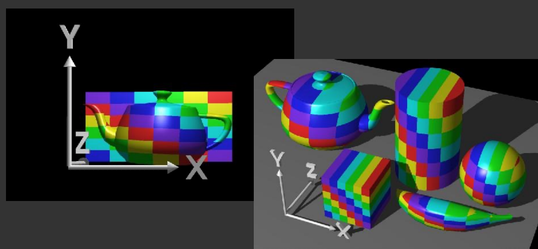
Planar mapping

- Like projections, drop z coord (s,t) = (x,y)
- Problems: what happens near z = 0?



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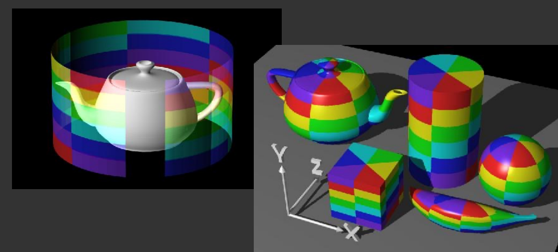
Cylindrical Mapping

- Cylinder: r, θ, z with (s,t) = (θ/(2π),z)
  - Note seams when wrapping around (θ = 0 or 2π)



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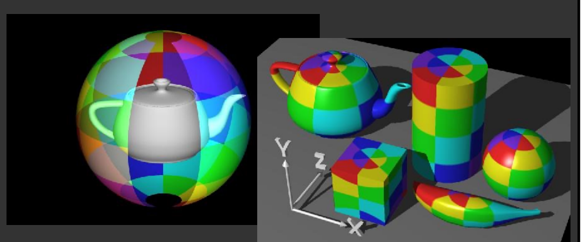
Spherical Mapping

- Convert to spherical coordinates: use latitude/long.
  - Singularities at north and south poles



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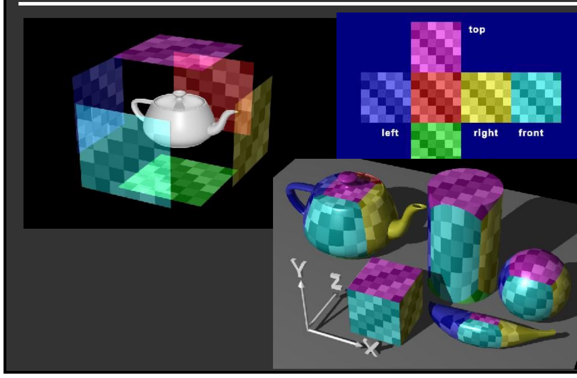
Cube Mapping



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Cube Mapping

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Interpolating Texture Coordinates

- Texture Coordinates at Vertices of Triangle
- How to compute coordinate at intersection?
- Use barycentric coordinates from in triangle test
- Same weights to combine texture coordinates
- Then use texture coordinates to look up texture

- Textures can also be procedural (use a formula)

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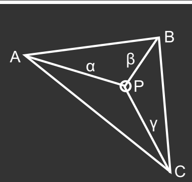
Ray inside Triangle



$$P = \alpha A + \beta B + \gamma C$$
$$\alpha \geq 0, \beta \geq 0, \gamma \geq 0$$
$$\alpha + \beta + \gamma = 1$$

$$P - A = \beta(B - A) + \gamma(C - A)$$
$$0 \leq \beta \leq 1 \;,\; 0 \leq \gamma \leq 1$$
$$\beta + \gamma \leq 1$$

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Texture Map Filtering

- Naive texture mapping aliases badly
- Look familiar?

```
int uval = (int) (u * denom + 0.5f);
int vval = (int) (v * denom + 0.5f);
int pix = texture.getPixel(uval, vval);
```

- Actually, each pixel maps to a region in texture
  - |PIX| < |TEX|
    - Easy: interpolate (bilinear) between texel values
  - |PIX| > |TEX|
    - Hard: average the contribution from multiple texels
  - |PIX| ~ |TEX|
    - Still need interpolation!

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Mip Maps

- Keep textures prefiltered at multiple resolutions
  - For each pixel, linearly interpolate between two closest levels (e.g., trilinear filtering)
  - Fast, easy for hardware

- Why “Mip” maps?

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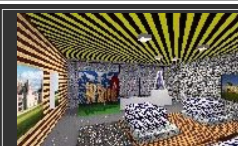
MIP-map Example

- No filtering:



AAAAAAAGH
MY EYES ARE BURNING

- MIP-map texturing:

Where are my glasses?

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Texture Mapping Applications

- Modulation, light maps
- Bump mapping
- Displacement mapping
- Illumination or Environment Mapping
- Procedural texturing
- And many more

In physically-based rendering, texture doesn’t give color directly, rather controls some attribute (like diffuse/specular BRDF coefficient, roughness etc.)

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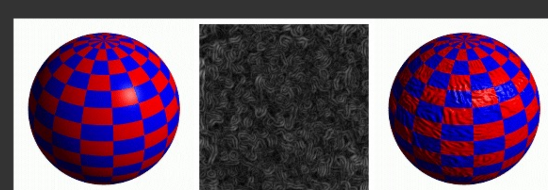
Bump Mapping

- Texture = change in surface normal!



Sphere w/ diffuse texture *Swirly bump map* *Sphere w/ diffuse texture and swirly bump map*

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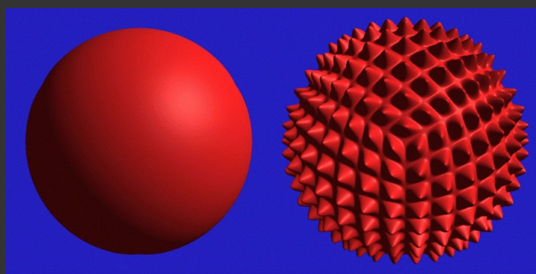
Displacement Mapping



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Environment Maps

Images from *Illumination and Reflection Maps: Simulated Objects in Simulated and Real Environments*
Gene Miller and C. Robert Hoffman
SIGGRAPH 1984 "Advanced Computer Graphics Animation" Course Notes

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Solid textures

Texture values indexed by 3D location (x,y,z)

- Expensive storage, or
- Compute on the fly, e.g. Perlin noise →

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