GLOBAL ILLUMINATION

Mirror’s Edge (2008)
WHAT IS GLOBAL ILLUMINATION?

- Scene recreates feel of physically-based lighting models
- All objects affect rendering of individual objects
- Desirable effects include:
  - Shadows
  - Reflection
  - Refraction
  - Diffuse inter-reflection
  - Caustics
THE PHYSICS OF GI

- Must model photon interactions (i.e. light bounce) with world objects based on position and material
  - Light sources
  - Illuminated objects
  - Object materials
  - Viewing properties
DISCUSS

- What are some of the challenges of making a real-time lighting model?
- What parts of the system can be optimized and how?
PRE-BAKED LIGHTING

- Compute lighting offline
- Good-looking effects without limitations of real-time rendering
  - Diffuse inter-reflection (color bleed)
  - Ambient occlusion (indirect shadows)
  - Translucent shadows
- True dynamic lighting not possible
SCREEN SPACE TECHNIQUES

- Screen space techniques only use information within the rasterization pass (pixels)
  - Fragment depths
  - Positions
  - Normals
  - Tangent spaces
- Deferred shading technique breaks down rendering pass into multiple computations
  - Render lighting information into individual textures
  - Combine these textures into single screen texture
  - Compute lighting based on this texture
EXAMPLE: SCREEN SPACE AMBIENT OCCLUSION

- Ambient occlusion provides soft shadows as if seen with a highly diffuse light source (e.g. an overcast day)
CALCULATING AO IN REAL-TIME

- Calculate visibility function $V$ for integral over hemisphere
- Depth buffer is a discrete approximation of frontmost scene geometry
- Crytek method generates random points then approximates visibility and distance attenuation

$$AO(p, n) = \frac{1}{\pi} \int_{\Omega} V(p, \omega) n \cdot \omega d\omega,$$
SSAO ADVANTAGES AND DISADVANTAGES

- Advantages
  - Provides better self-shadowing on objects
  - Simple to implement
  - Not affected by scene complexity
  - Works on dynamic scenes

- Disadvantages
  - Coarse approximation
  - Halo artifacts can appear where depth buffer has sharp discontinuities
  - No directionality in lighting
  - Incorrect shadow color
SSAO’S WANING POPULARITY

- Many SSAO variants:
  - HBAO (Horizon-based Ambient Occlusion)
  - HDAO (High-definition Ambient Occlusion)
  - SSDO (Screen-space Directional Occlusion)
- All have same, fundamental visual artifacting issues
- Screen space techniques also becoming less performant as monitors/TVs become higher resolution
VXAO AND RTAO

- Voxel Ambient Occlusion (VXAO) introduced by NVidia within VXGI pipeline
  - Not a screens pace technique
  - Uses information from world space voxel information to calculate AO
- Ray-traced Ambient Occlusion (RTAO) introduced by NVidia with RTX hardware support
  - Not a screen space technique
  - Uses ray-traced information from world space to calculate AO
VXAO TO HBAO COMPARISON

Fig 1. HBAO+ channel

Fig 2. VXAO channel
SHADOW MAPS

- Pre-render scene from point of view of light to compute distance to scene objects in depth buffer
- During actual render, check if fragment is occluded by object in shadow map
  - Fragment is farther from light than the shadow map depth
- Soft shadows achieved by imitating shadow’s penumbra and blurring
SHADOW MAPS

Variance Shadow Maps (Donnelly & Lauritzen)
REFLECTIVE SHADOW MAPS

- Treat all fragments of shadow map as indirect light sources
- Use these light sources to approximate the indirect illumination on each pixel
  - Imitates an extra bounce of lighting
- Infeasible to consider all pixels, so pixels ranked by importance
- Results in indirect lighting on pixel that may come from occluded light
  - Not physically accurate but plausible
REFLECTIVE SHADOW MAPS
CALCULATING GI IN WORLDSpace

- To accurately depict global illumination, we need to simulate light bounce in the actual scene
  - Expensive and time-consuming
  - Not feasible in realtime
- Use precomputes, acceleration structures and simplifications to compensate
**Radiosity**

- Accounts for transfer of energy from both light sources and surfaces
- Models diffuse lighting with fewer calculations than ray-tracing based techniques
- View independent
- Color-bleed artifacts
- Distorts specular highlights
VIRTUAL POINT LIGHTS

- Used in radiosity-based renderers
- VPLs approximate direct and indirect lights in scene to reduce light bounce calculations

INSTANT RADIOSITY

- Add VPLs into scene by tracing photons shot out from the light source
- Treat VPLs as point lights
- Gather light from all VPLs in scene to compute indirect illumination
- Take dynamic visibility into account using shadow maps
- Use imperfect shadow maps for greater efficiency
CASCADING LIGHT PROPAGATION VOLUMES

- Used for low-frequency (indirect) lighting
- Built using 3-D nested lattices for efficient light transport
- Used in Cryengine in 2010 for both PC and console
SPARSE VOXEL CONE TRACING (SVOGI)

- Computes indirect illumination and ambient occlusion
- GPU-based
- Octree-based
- Stores voxels as 3D textures
- Rasterize primary rays
- Cone-trace secondary rays through octree
- Works for forward and deferred rendering
VXGI

- Built into UE4 (NVIDIA only)
- https://www.youtube.com/watch?v=O9y_AVYMEUs
BRIGADE PATH TRACER

- Optimized BHV, work queue, and convergence algorithm

- https://www.youtube.com/watch?v=FbGm66DCWok
Bi-directional path tracers populate the scene with photon information emitted from the source lights then bounce rays from the camera to calculate final light.

Uses Monte Carlo method to perform unbiased sampling to converge on lighting integration.

- Requires a large number of samples to reduce noise.

Denoising is process of reducing noise without a large number of samples.

- Historically done with image processing techniques but machine learning works extremely well.
RAYTRACING HARDWARE

- Hardware solutions can allow for faster calculations and interactions...doesn’t fundamentally solve the problem, though...

https://www.youtube.com/watch?v=7Yn09UHWYFY
FURTHER READING/VIEWING

- Real-Time Global Illumination Siggraph 2009 ([http://www0.cs.ucl.ac.uk/staff/J.Kautz/RTGiCourse/](http://www0.cs.ucl.ac.uk/staff/J.Kautz/RTGiCourse/))
- Brigade Article ([https://www.hindawi.com/journals/ijcgt/2013/578269/](https://www.hindawi.com/journals/ijcgt/2013/578269/))