Ray Tracing Solution for Film Production Rendering

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Distributed ray tracing, Cook et al. 1984

Image courtesy of Lucasfilm
Figure 6. A sample image. All objects are neutral grey. Color on the objects is due to caustics from the green glass balls and color bleeding from the base polygon.
CGI Studio

- Blue Sky Studio’s proprietary renderer
- Physically-based Monte Carlo ray tracer
- Created by Carl Ludwig, Eugene Troubetzkoy, Michael Ferraro et al.
- ex-MAGI/SynthaVision team (TRON etc)
Carl Ludwig 1990 (!)
John Kars 1992

Image courtesy of Blue Sky Studios, Inc.
“Bunny”, Best Animated Short 1998
Arnold

- Physically-based Monte Carlo ray tracer
- Unbiased, uni-directional path tracing
- Co-developed by Solid Angle SL and Sony Pictures Imageworks, Inc.
“Pepe” 1999

Image courtesy of Daniel Martinez Lara. © 1999 Daniel Martinez Lara. All rights reserved.
“Fifty Percent Grey” 2001

Image courtesy of Ruairi Robinson. © 2001 Zanita Films. All rights reserved.
“Monster House” 2006

Image courtesy of Columbia Pictures. © 2006 Columbia Pictures Industries, Inc. All rights reserved.

SIGGRAPH 2010
“Cloudy with a Chance of Meatballs”
2009
“2012” 2009
“Alice in Wonderland” 2010

Lots of furry characters ...
What is Arnold?

- Unbiased Monte Carlo ray tracer
- Uni-directional path tracer
- 200k lines of highly optimized C/C++ code
- Fully multi-threaded + SIMD architecture
Production features

- Motion blur (xform and deformation)
- Networked, programmable shaders
- Hundreds of millions of triangles and hair splines
- Deferred/procedural loading of geometry
- Texture caching
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all at the same time!
Pros

• Single-pass: dramatically simpler pipeline (no extra files or caches)
• Only one quality knob (number of samples)
• Shadows are always perfect (no shadowmaps etc)
• Interactive (via progressive refinement)
• No memory used to store lighting/GI
Cons

• Slow?
• Noise
• Indoors are hard
• Geometry must reside in memory at all times
Address the cons!

- Three orthogonal axes:
  - make rays faster
  - reduce memory use (cost per polygon)
  - variance reduction
Address the cons!

• Aim for optimal multi-threading performance (linear scalability)
• 8-core machines are the norm at the workstation
• 32- and 64-core machines are in the horizon
Address the cons!

• Explore new ray acceleration structures
• BVH, kd-tree etc
• Build time is less important than traversal
• Geometry quantization
Variance reduction

- Good 2D (pixel, lens, light, BRDF) and 1D (motion blur, volume) sample sets
- BRDF importance sampling
- Solid angle-based light source importance sampling
- Multiple importance sampling
- Volume importance sampling
- Careful with correlation between dimensions
Geometry instancing

• Easy to generate billions of visible polygons

• Greatly helps in many common scenarios:
  • cities
  • crowds
  • debris
Chew and Swallow city from Cloudy with a Chance of Meatballs
1 million separate instanced objects, 2.5 GB
Geometry instancing

SIGGRAPH 2010
Geometry instancing
Interactivity

• Why is interactive feedback so important?

• CPU time: $0.1 / hour

• artist time: $40 / hour

• Final “beauty” render time is not as important as reducing lighting overhead
1 million polys, area light, sky, 2-bounce GI, reflections (rendered on a single quad-core CPU, 4 threads)
Interactivity

• Can’t afford to have lighters waiting for shadowmaps, pointclouds and caches every time they need to move a light

• Scene updates are interactive: lights, shaders, camera, moving geometry

• Immediate feedback via progressive refinement
Low-overhead deformation motion blur

1.5 M displaced tris
3 area lights + sky
diffuse + glossy + sss
10x10 pixel samples
1920x1080

00:14

model by Glassworks London
Low-overhead deformation motion blur

1.5 M displaced tris
3 area lights + sky
diffuse + glossy + sss
10x10 pixel samples
1920x1080

00:16

model by Glassworks London
Less artistic freedom?

- Often mentioned as a criticism for global illumination renderers
- ... but in practice we are not getting many complaints, specially in photoreal projects
- Many optional controls:
  - light groups (e.g. lights for eyes only)
  - per-light spec/diffuse switches
  - hide/substitute objects for certain ray types
Less artistic freedom?

"The initial expectation was that combined specular and reflection parameters would result in reduced ability to art-direct and dial the looks. In practice however, the imagery looked more correct out of the box, we almost never received direction to dial specular illumination and reflection independently."

Adam Martinez on Alice in Wonderland
Initial reluctance

- Traditionally too slow for production use...
- But both algorithms and hardware have improved dramatically in recent years
- GI is now “always on”, rarely turned off
- By having it on by default, first-time artists don’t have to press extra buttons and get up to speed more quickly
Some tricks

• Noisy caustics: turn off certain light paths

• Noisy caustics: broaden specular lobes for secondary bounces

• Clamp $1/d^2$ term near the lights
Broaden specular lobes for direct lighting in secondary bounces

\[ \text{phong\_exponent} = 2000 \quad \text{phong\_exponent} = 50 \]

same render time!
Conclusion

• Path tracing for film production is here to stay

• Radically changes the rendering pipeline at film studios (after an initial period of scepticism)

• Still lots of room for improvement (sampling, new accels etc)
Thanks!

- **Blue Sky**: Carl Ludwig
- **Imageworks**: Cliff Stein, Chris Kulla, Larry Gritz, Alex Conty, Rene Limberger, Rob Bredow
- **Solid Angle**: Angel Jimenez, Borja Morales, Luis Armengol
- **Glassworks**: Andreas Byström