SIGGRAPH 2010   Global Illumination Across Industries

Ray Tracing Solution for Film Production Rendering

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Distributed ray tracing, Cook et al.1984

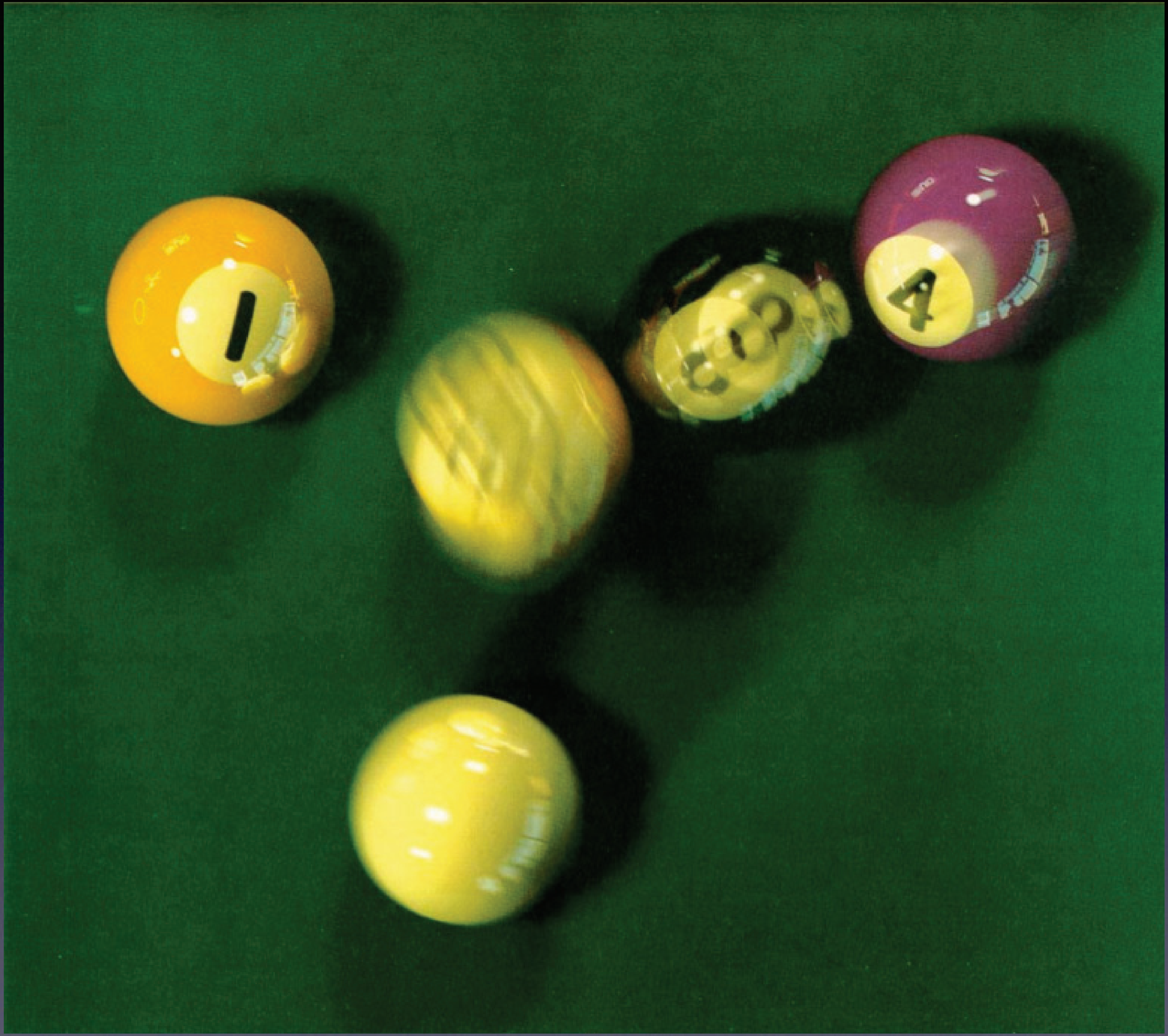


Image courtesy of Lucasfilm

Image courtesy of Lucasfilm

The Rendering Equation, Kajiya 1986

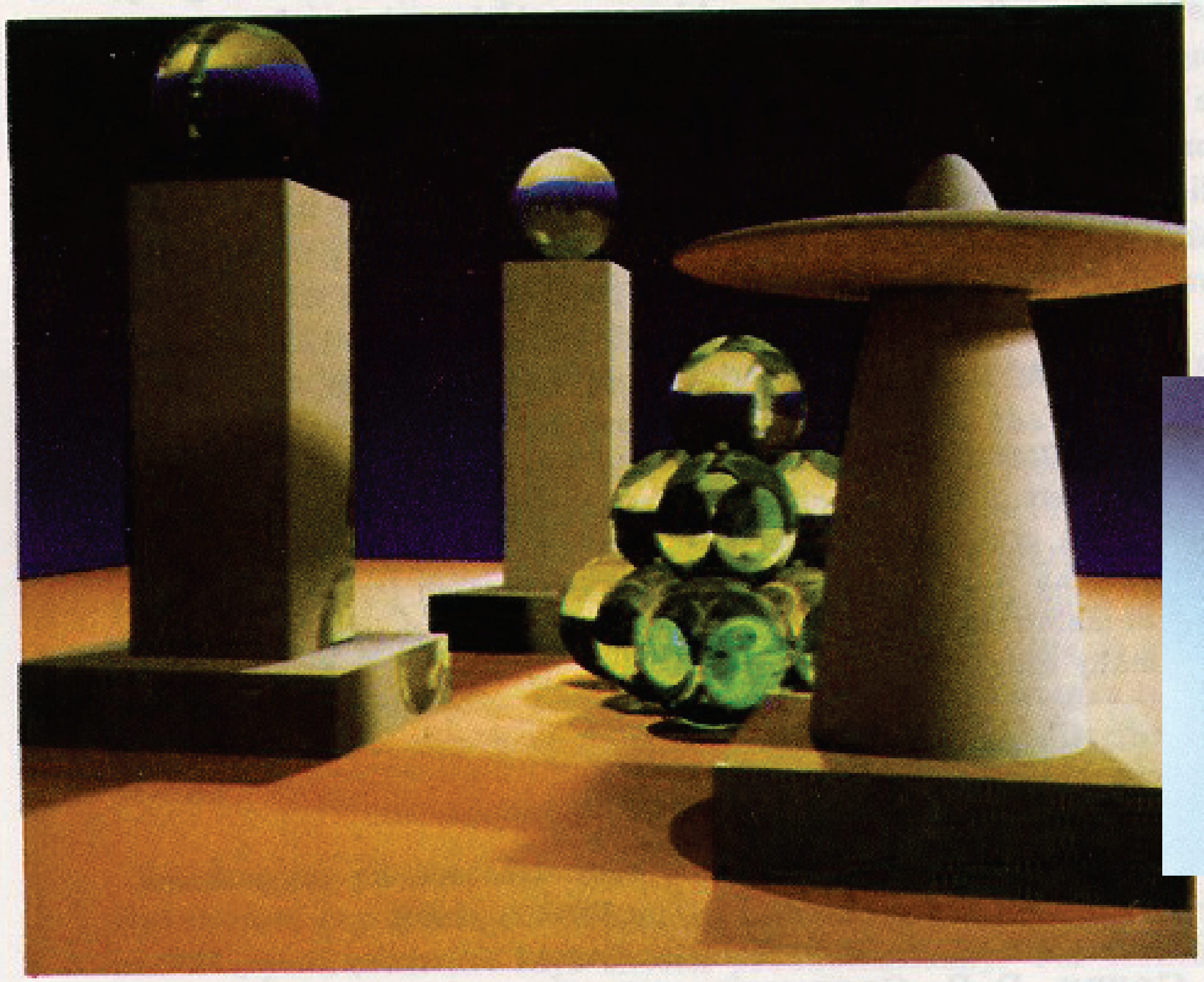
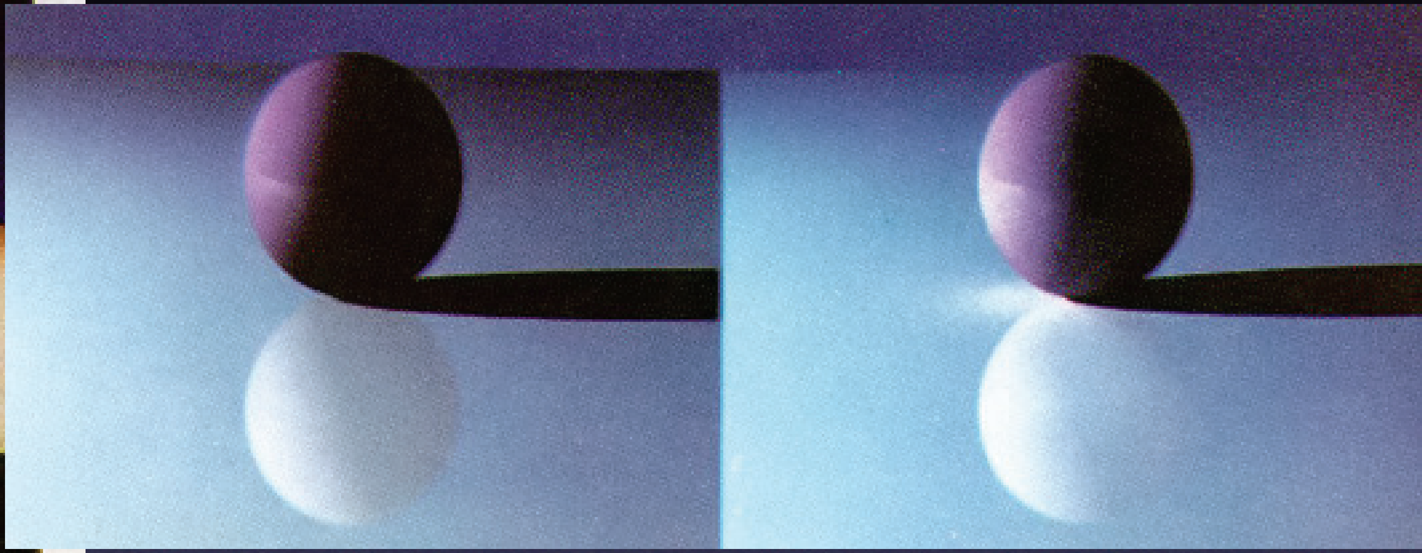


Figure 6. A sample image. All objects are neutral grey. Color on the objects is due to caustics from the green glass balls and color bleeding from the base polygon.



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 (!)

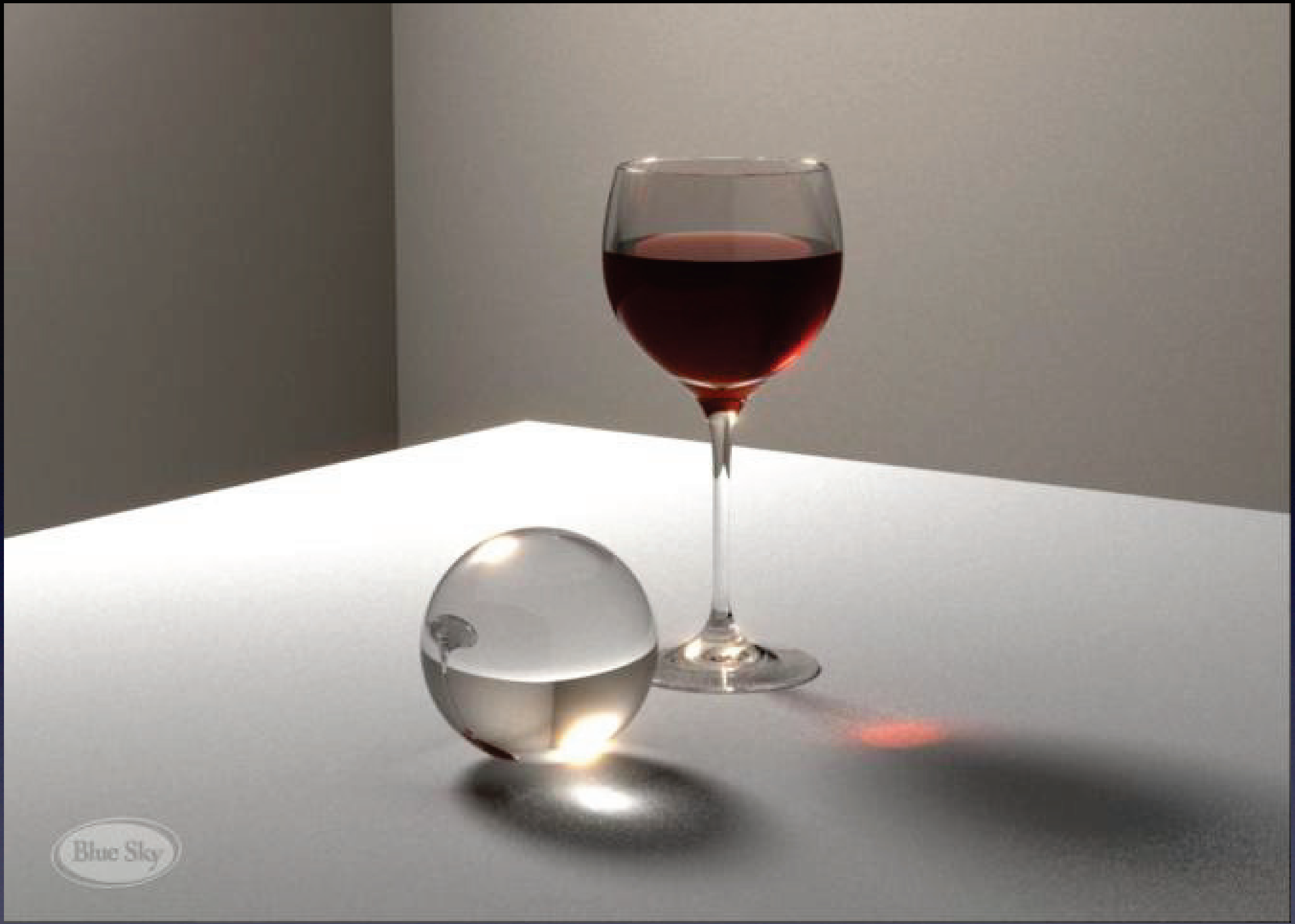


Image courtesy of Blue Sky Studios, Inc.

Image courtesy of Blue Sky Studios, Inc.

uncredited,1991

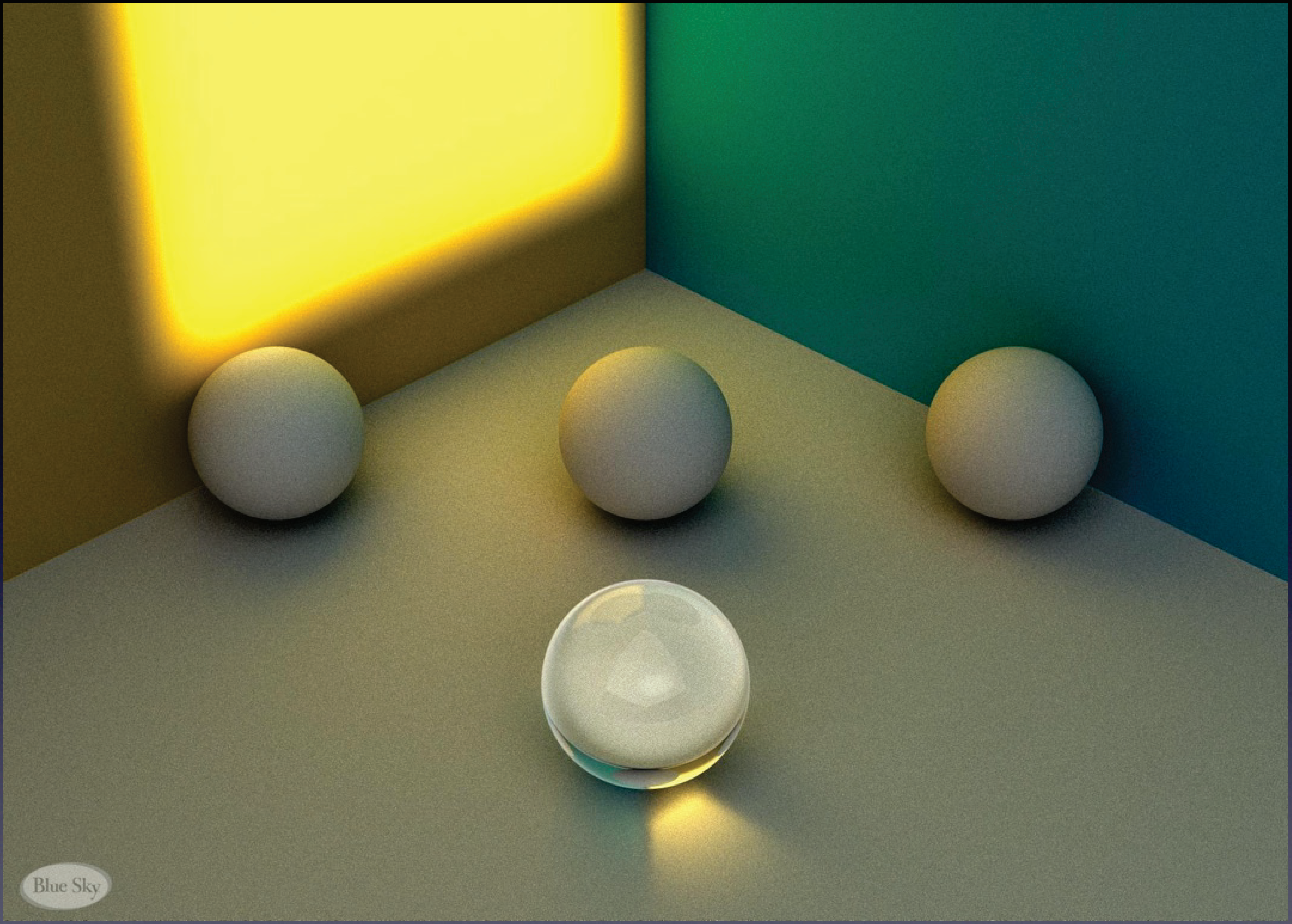


Image courtesy of Blue Sky Studios, Inc.

Image courtesy of Blue Sky Studios, Inc.

John Kars 1992

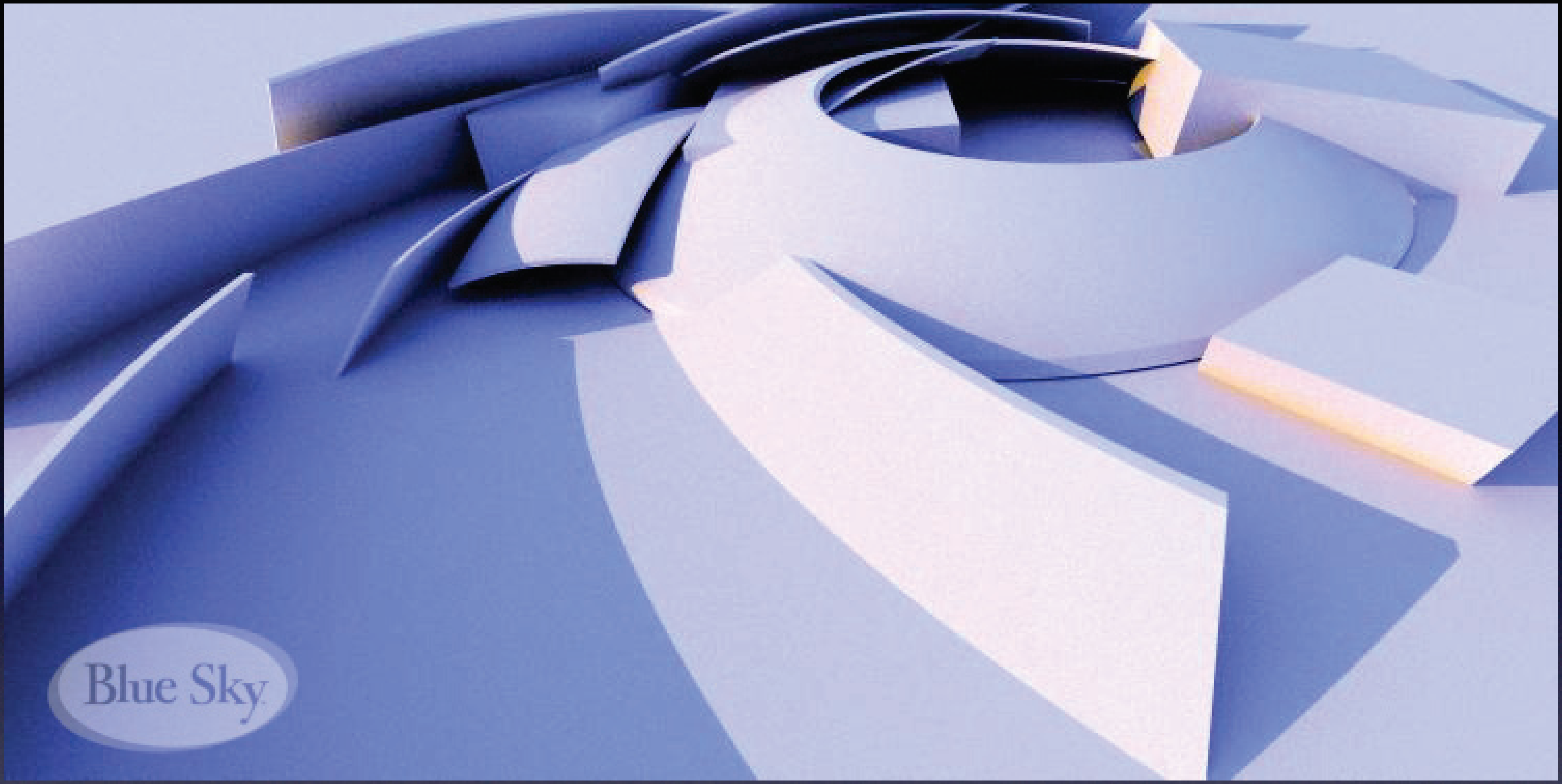


Image courtesy of Blue Sky Studios, Inc.

“Bunny”, Best Animated Short 1998

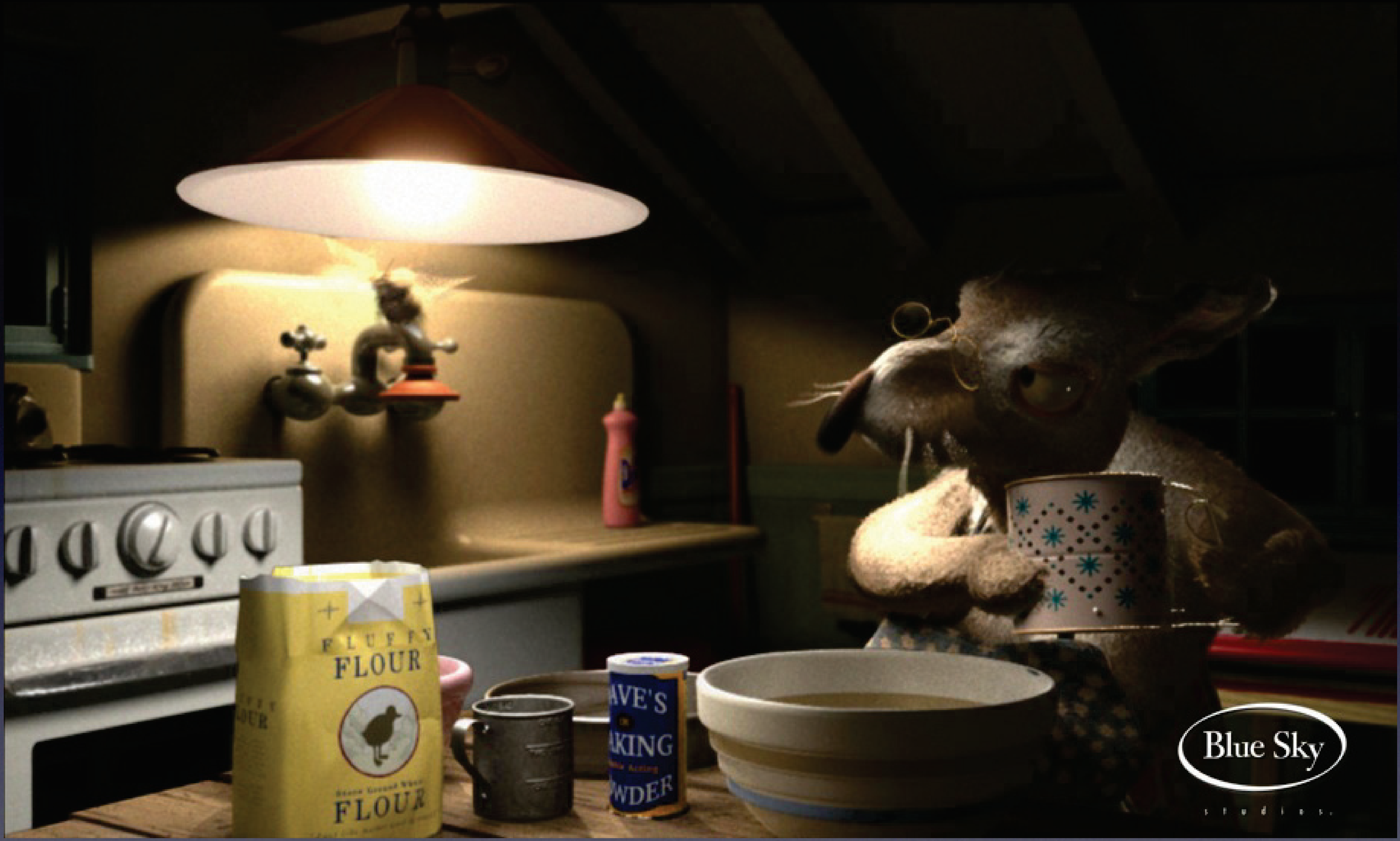
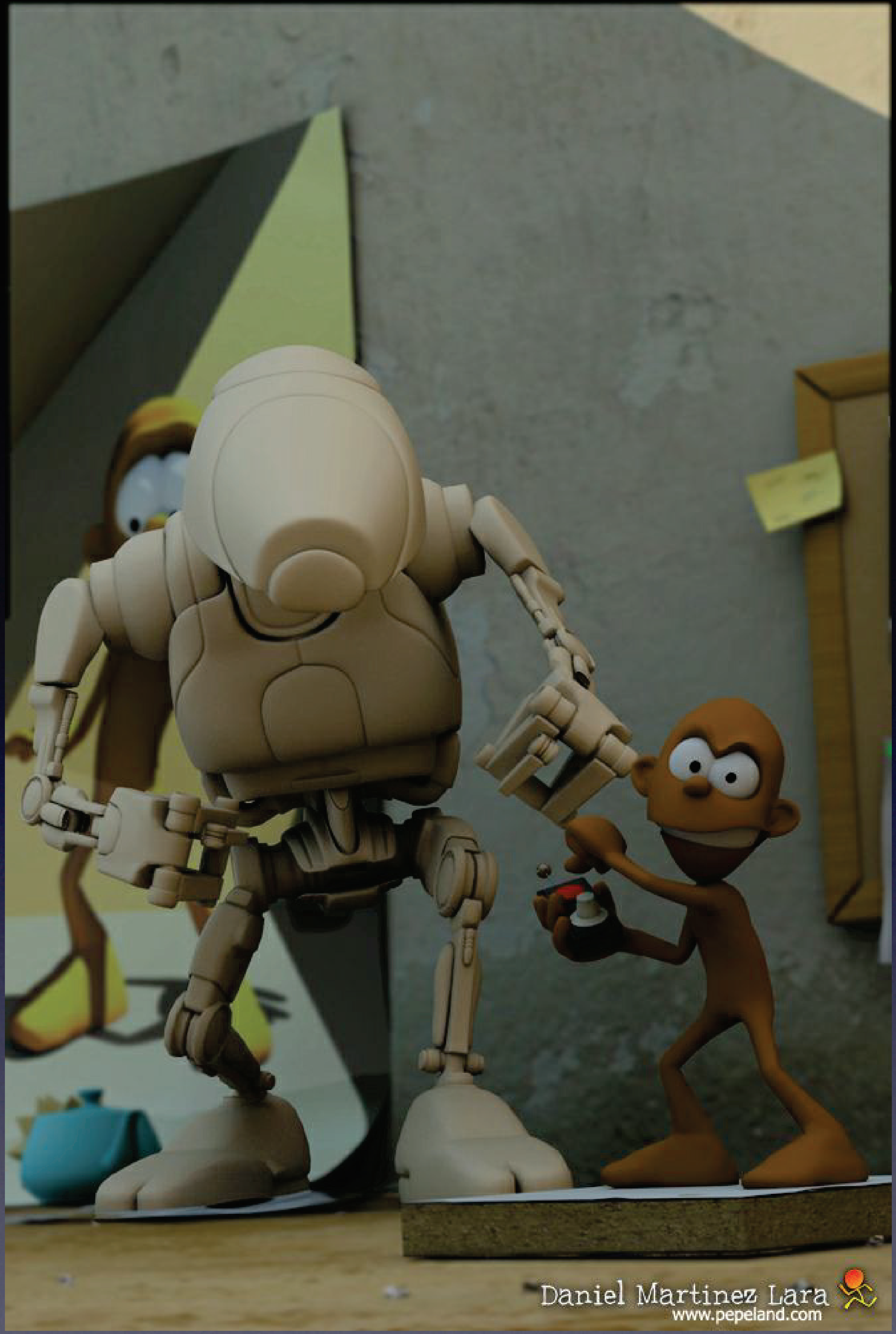


Image courtesy of Blue Sky Studios, Inc.

Image courtesy of Blue Sky Studios, Inc.

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

“Cloudy with a Chance of Meatballs” 2009

Image courtesy of Sony Pictures Animation. © 2009 Sony Pictures Animation, Inc. All rights reserved.

“2012” 2009

Image courtesy of Columbia Pictures. © 2009 Columbia Pictures Industries, Inc. All rights reserved.

“Alice in Wonderland” 2010

Lots of furry characters ...

Images courtesy of Walt Disney Pictures

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

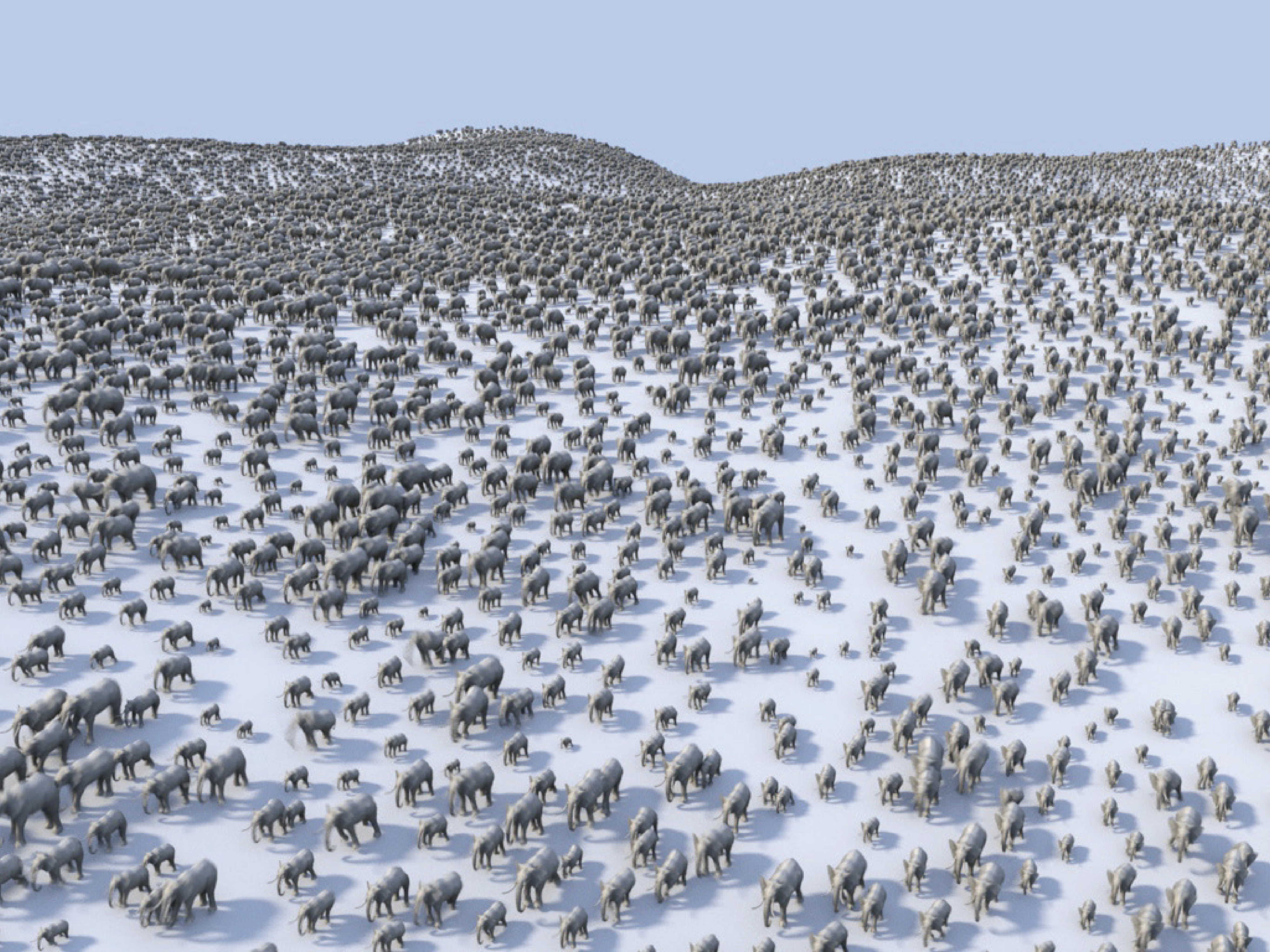
Variance reduction

- 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

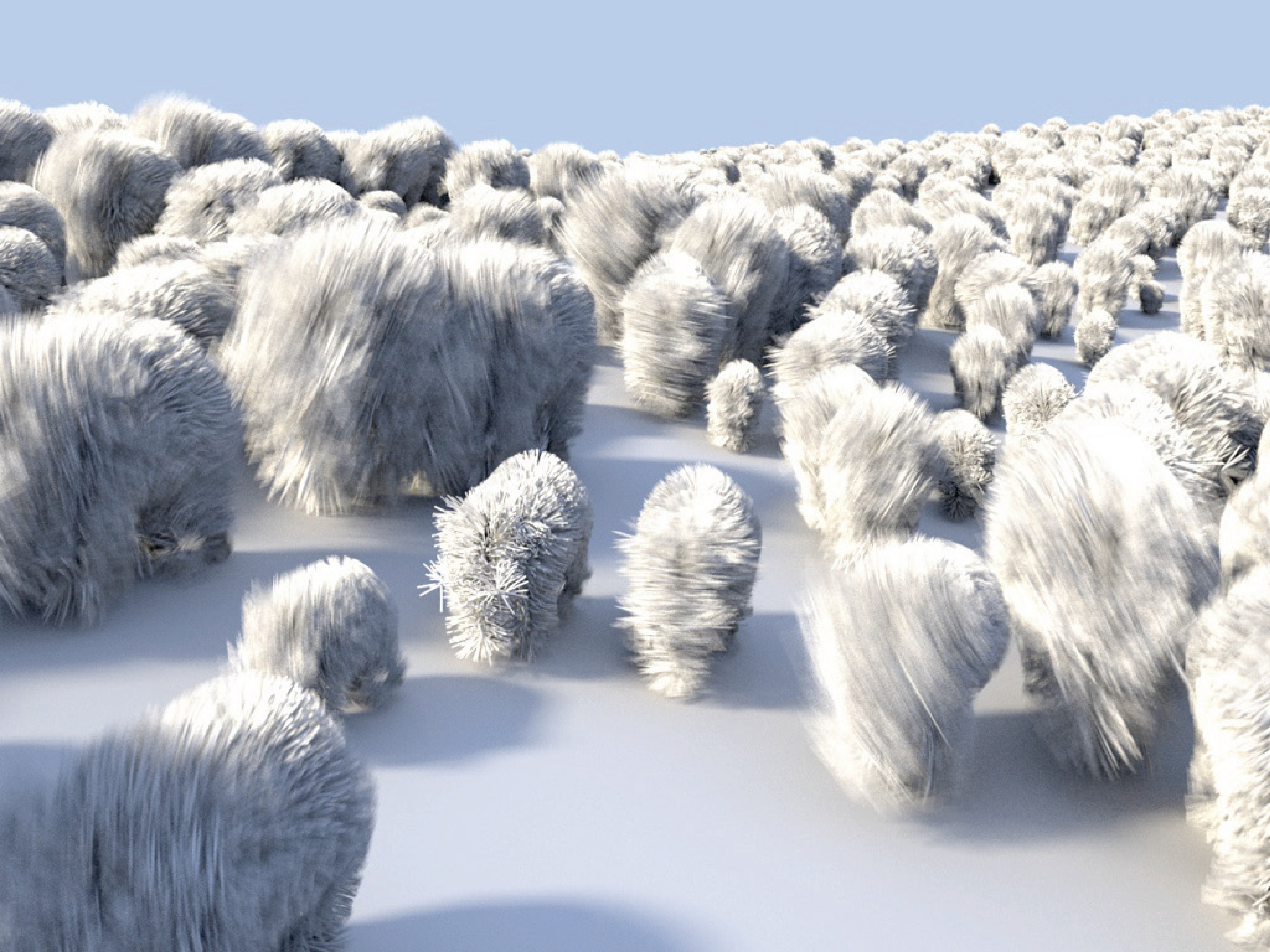
Geometry instancing

- 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



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 everytime they need to move a light
- Scene updates are interactive: lights, shaders, camera, moving geometry
- Inmediate 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

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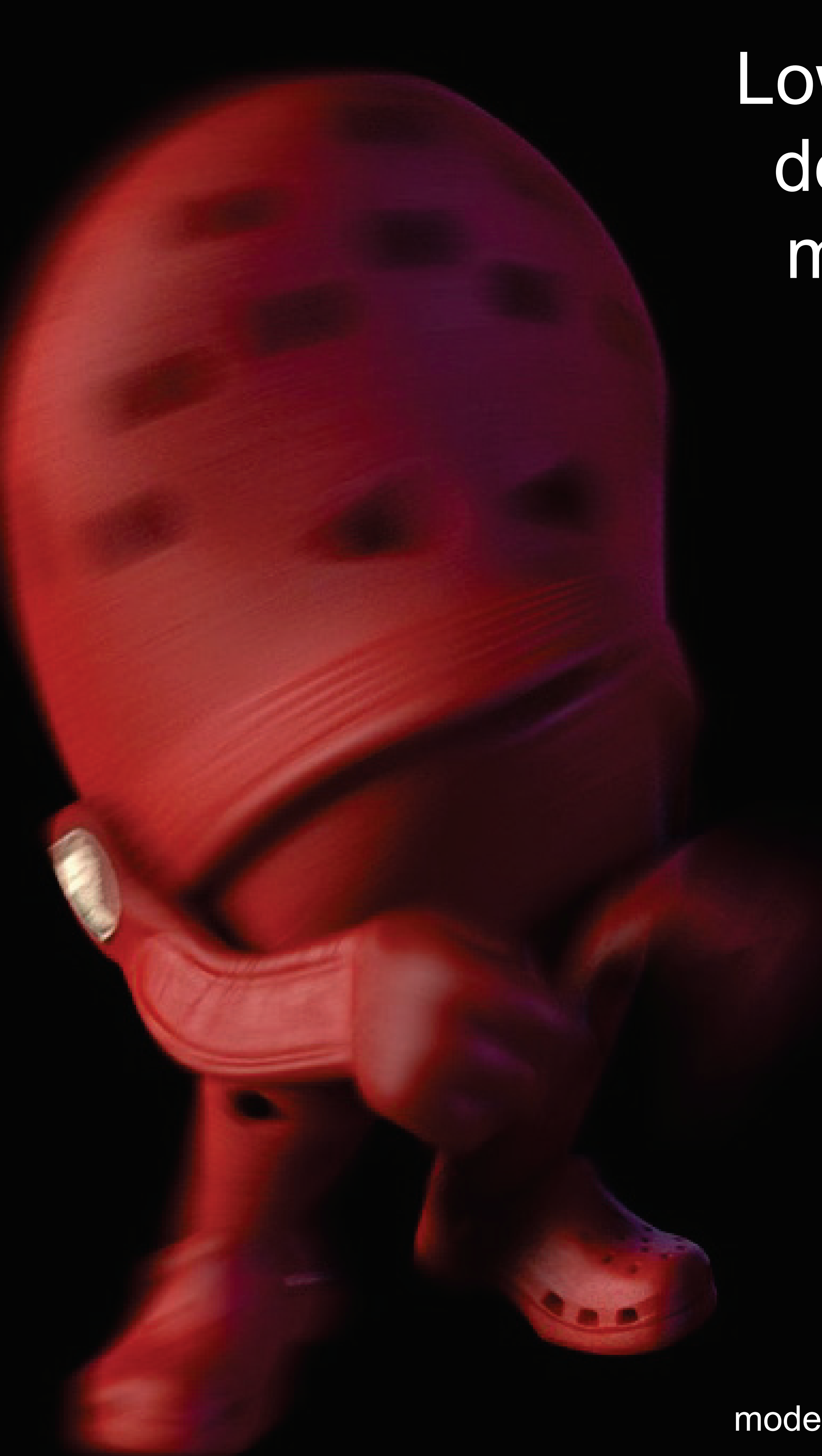
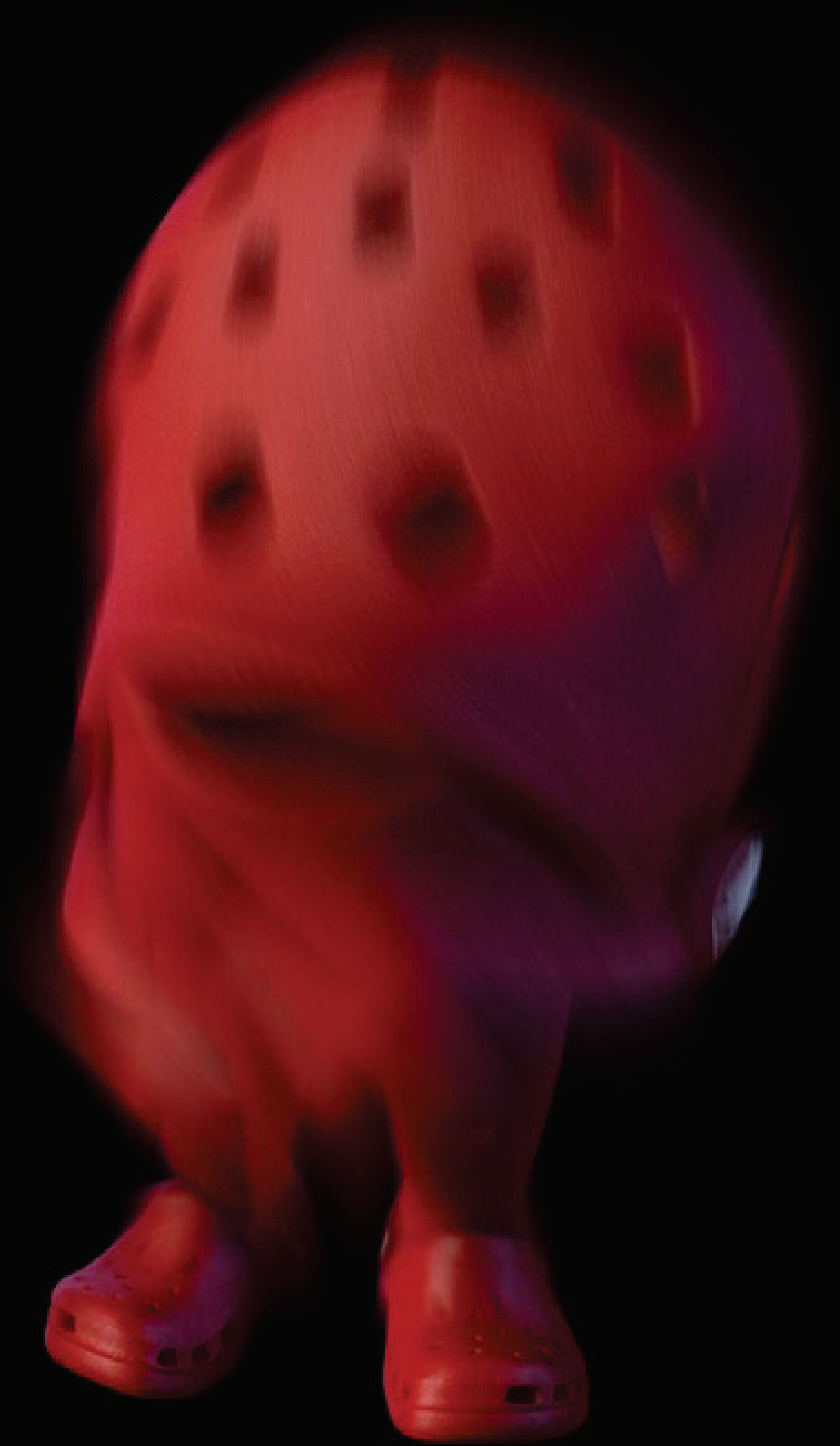
model by Glassworks London

Low-overhead deformation motion blur





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

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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

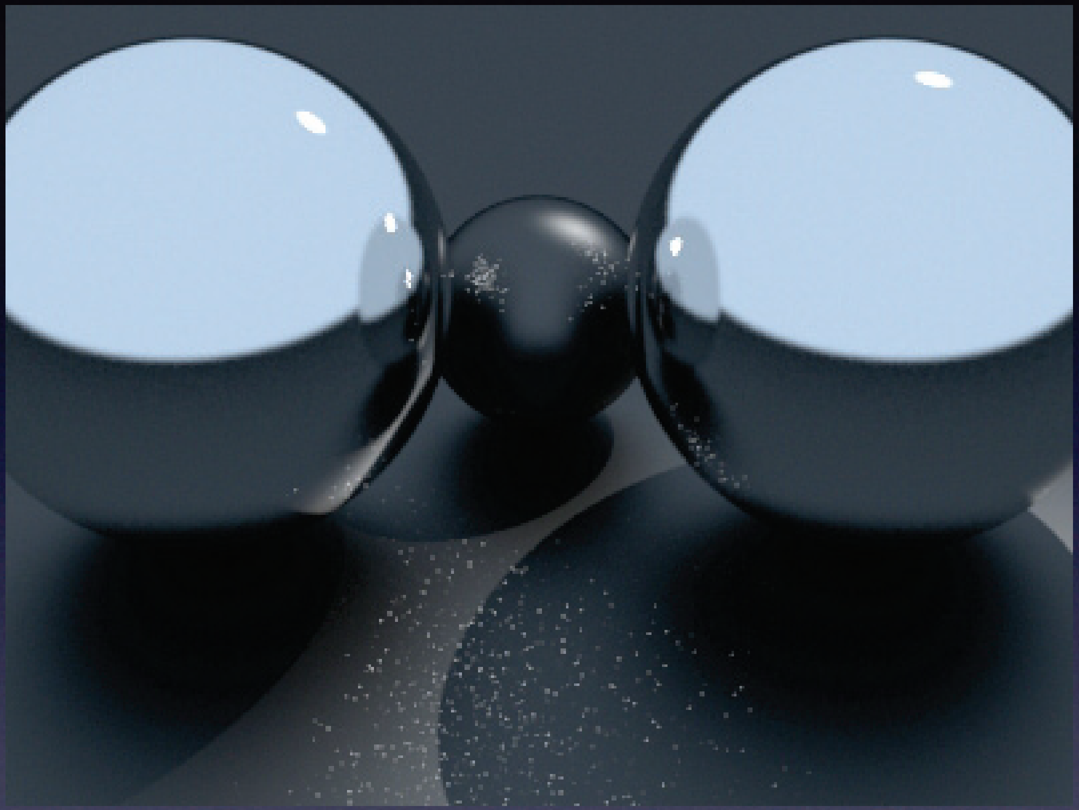
Initial reluctance

- 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

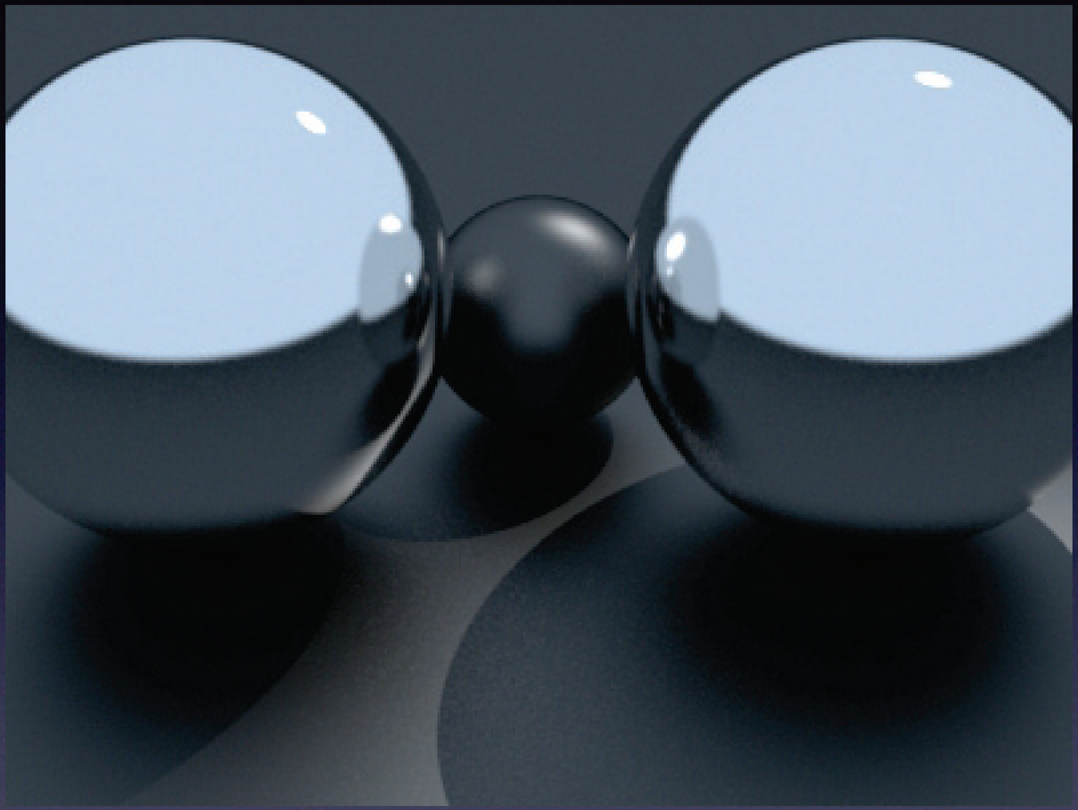
Some tricks

- 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



phong_exponent = 2000



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