# PHYSICALLY BASED RENDERING

CIS 565 Fall 2014

University of Pennsylvania
by Harmony M Li

# Announcements

- Project 3 RELEASED
  - Due Wed, 10/8
- Office Hours on 10/5, 10/8 and 10/12
  - Out of town, will be looking on Google forums
  - Be specific about your questions!

# Outline

- Motivation
- Review and basics
- Rendering equation
- Naïve pathtracing
- Parallelization
- Optimization
- Base Code Tour

# Acknowledgements

- Karl Yining Li
- Liam Boone

# MOTIVATION

# Motivation

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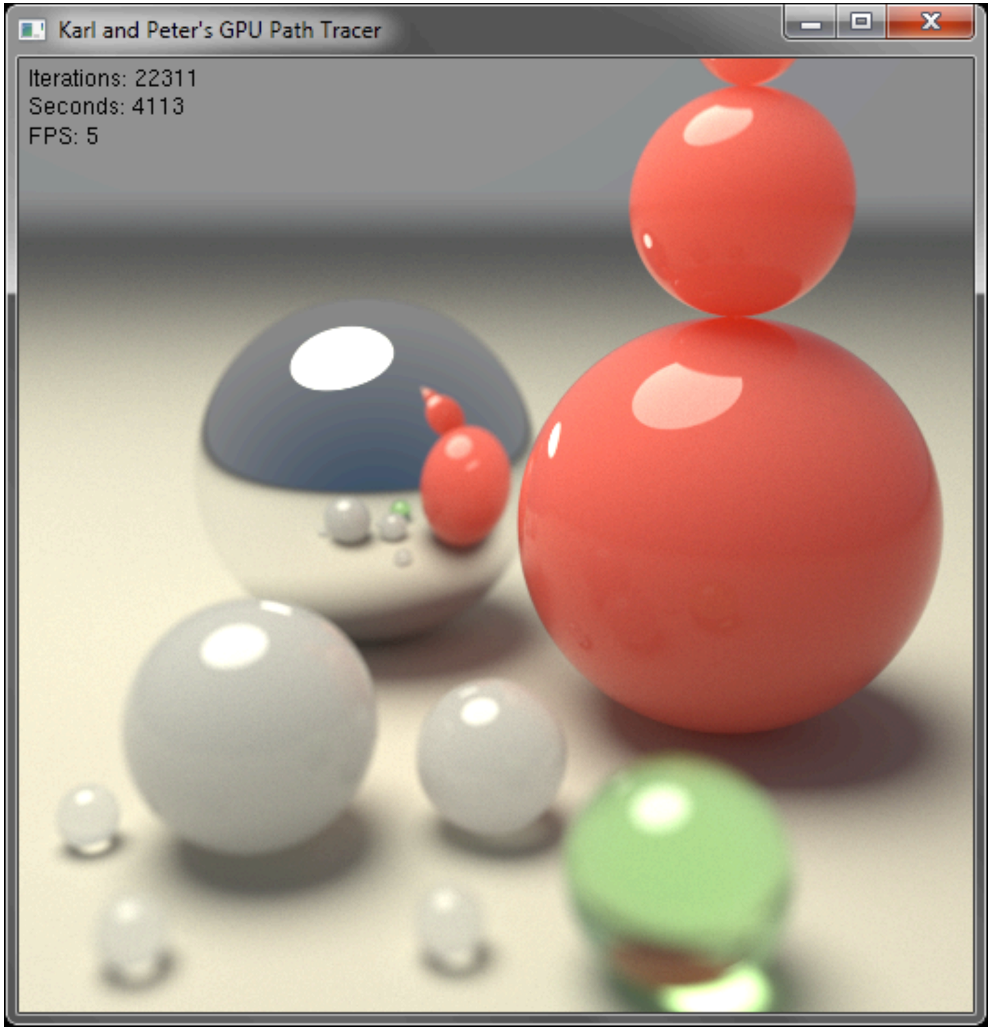
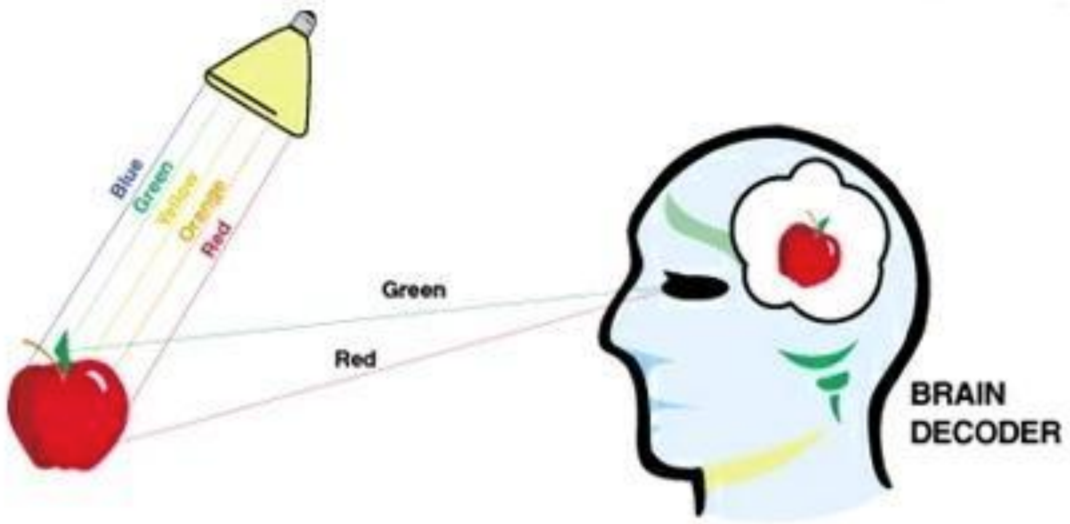


Karl and Peter's GPU Path Tracer
Iterations: 22311
Seconds: 4113
FPS: 5

# RENDERING 101

# Rendering 101 : Human Perception

- Human vision : what we “see” is reflected light
- Light scattered from objects



# Rendering 101 : Human Perception

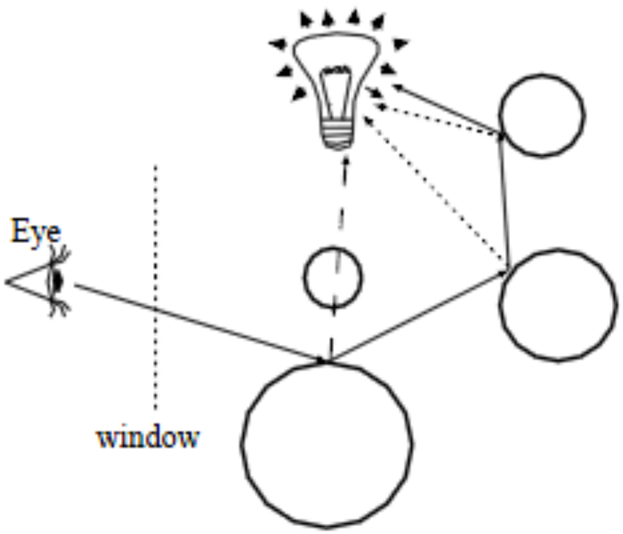
- Different materials have different scattering properties

# Rendering 101 : Physics

- Light : wave-particle duality
  - Photons
  - Waves
- Energy

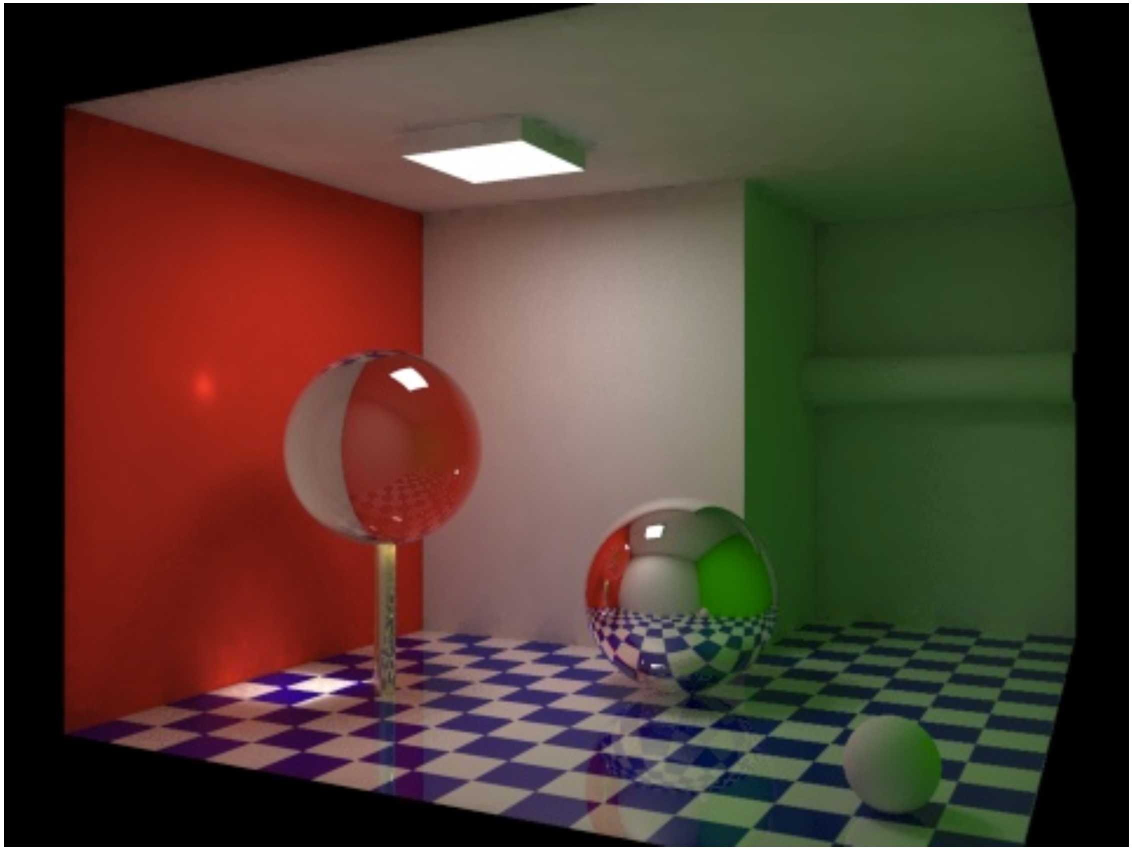
# Rendering 101 : Rays

- Model light as rays
  - Assume light moves relatively straight
  - When hitting an object, the direction of the ray is modified



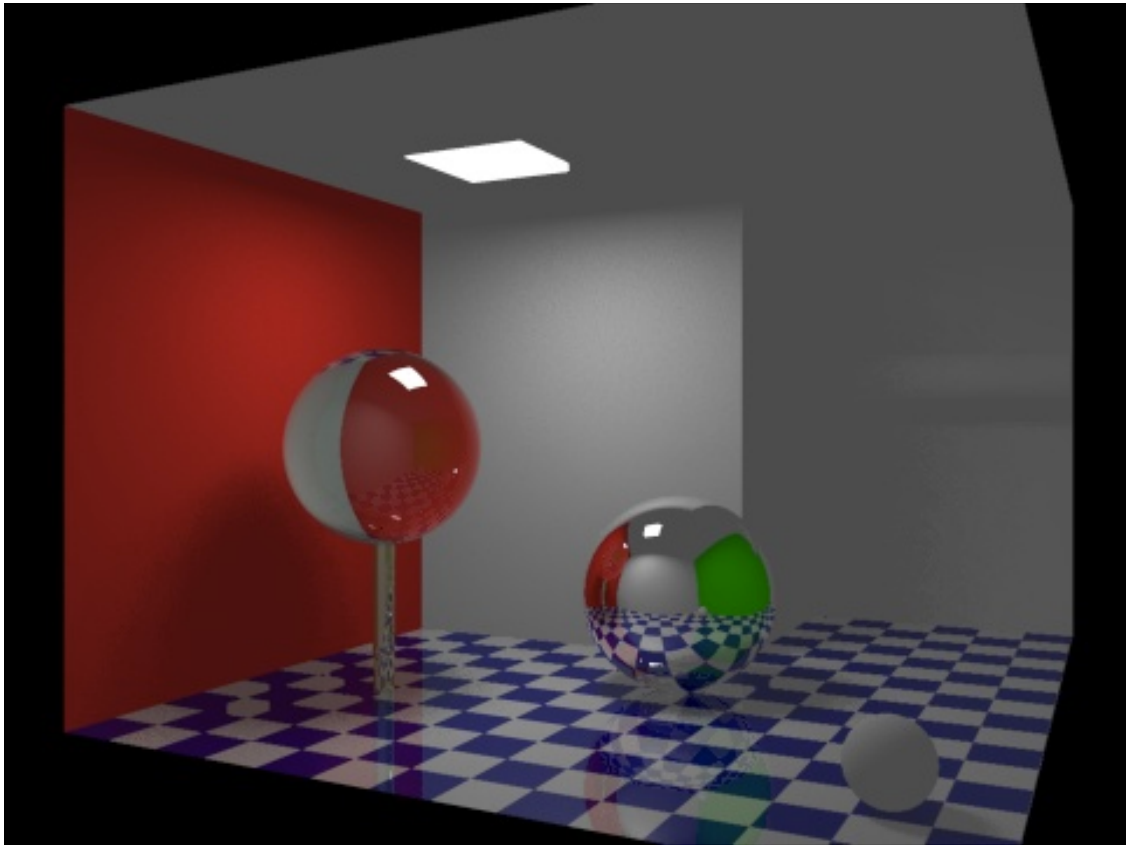
# Rendering 101 : Global Illumination

- Illumination not only from direct sources

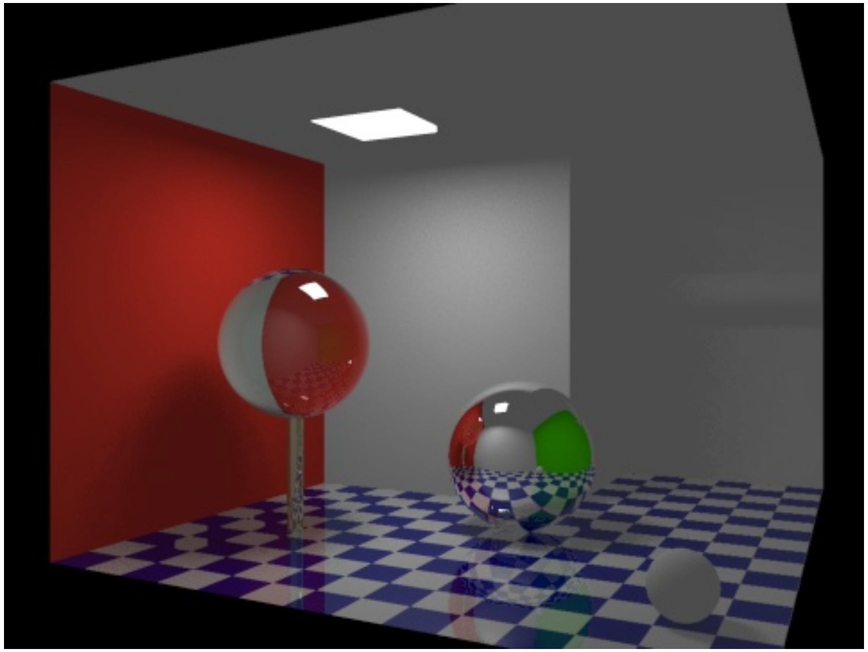


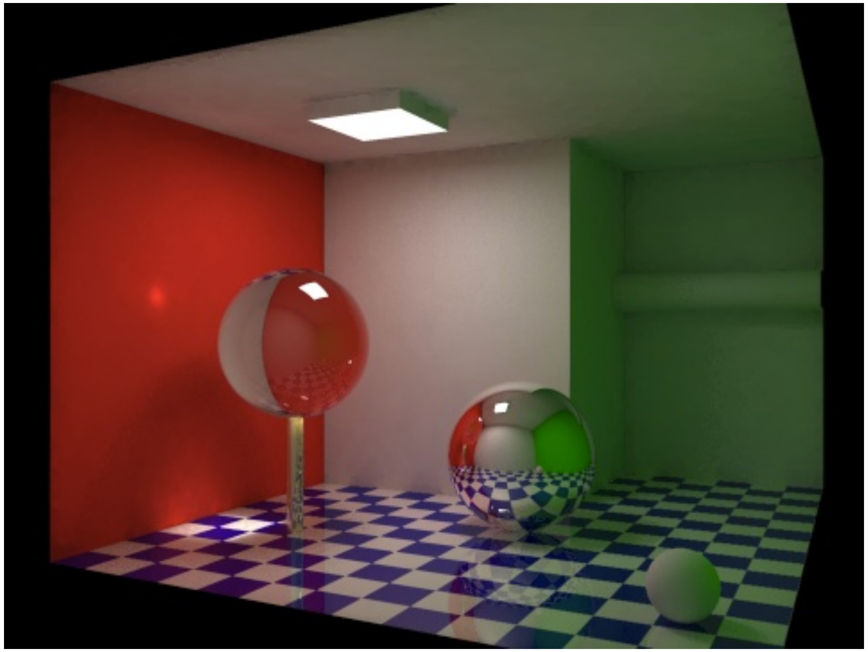
# Rendering 101 : Global Illumination

- Direct Illumination ONLY

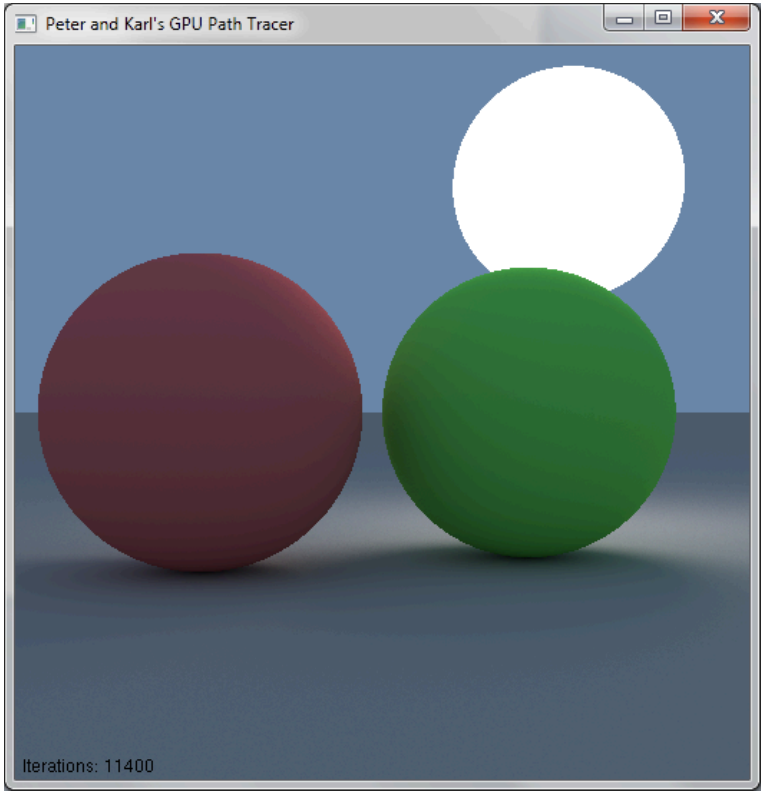


# Rendering 101 : Global Illumination

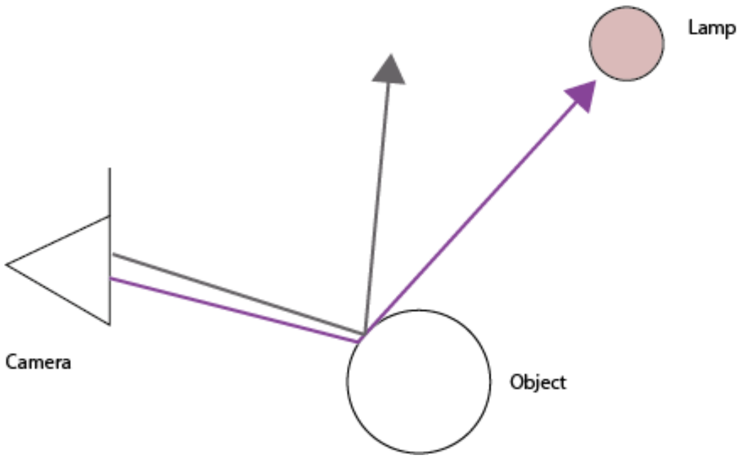




# Rendering 101




- "Light simulation"
- Costly to simulate from light's perspective
  - Therefore, rays shot from camera

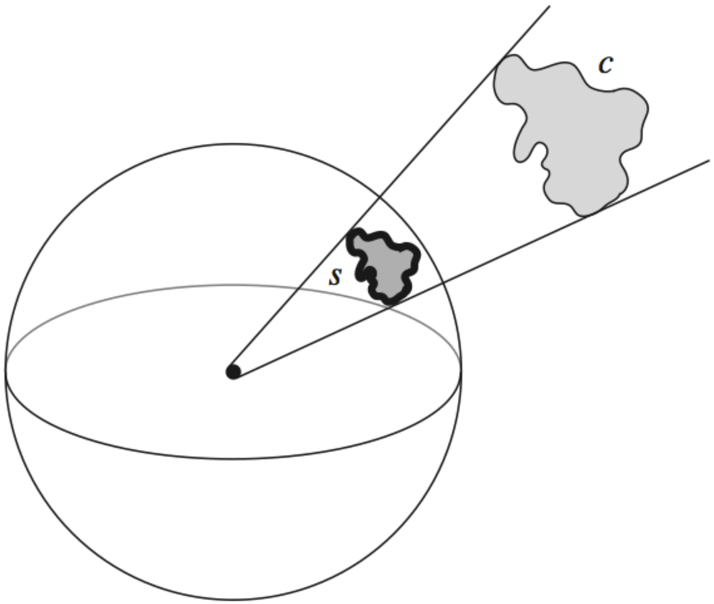


# RENDERING EQUATION

# Rendering Equation

- Kajiya,1986 : “The Rendering Equation”

$$L_o(\mathrm{p}, \omega_o) = L_e(\mathrm{p}, \omega_o) + \int_{S^2} f(\mathrm{p}, \omega_o, \omega_i)\, L_d(\mathrm{p}, \omega_i)\, |\cos\theta_i|\, d\omega_i$$



# Rendering Equation : Diffuse

- Equal probability of scattering in all directions

# Rendering Equation : Specular

- Perfect :
  - Ray reflected about the normal

# Rendering Equation : Dielectrics

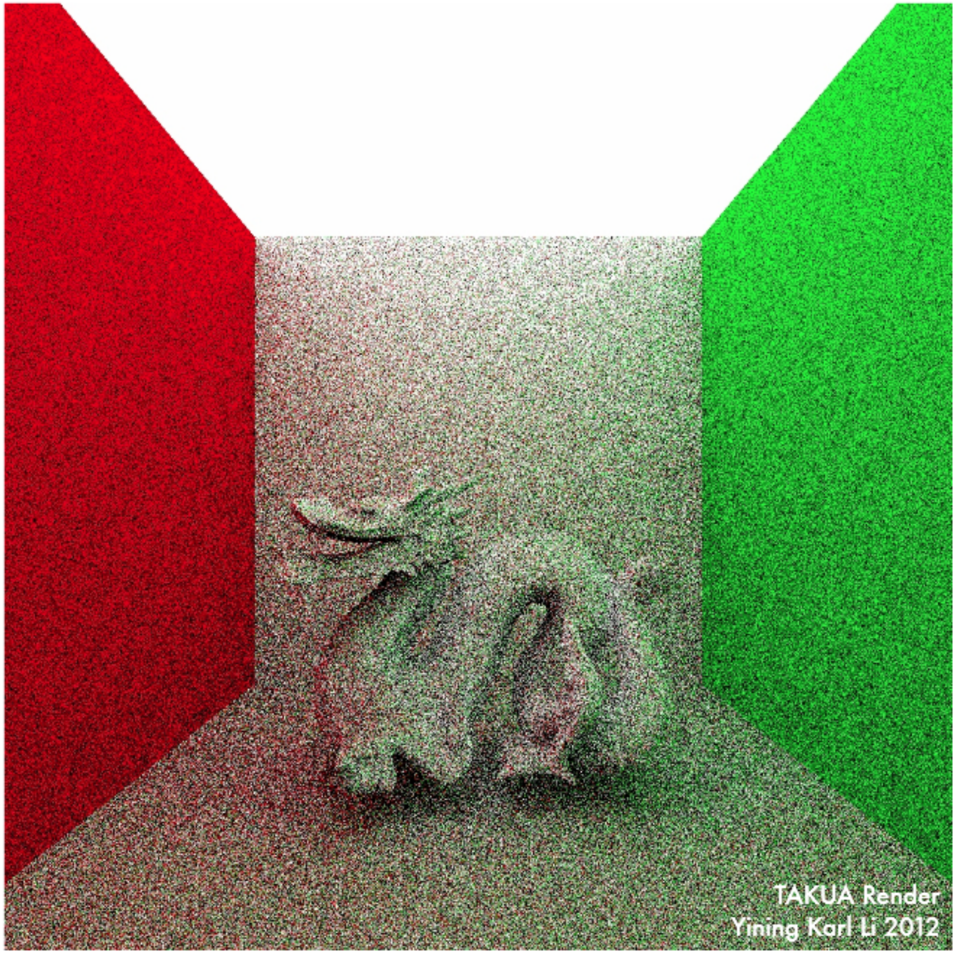
- Fresnel reflection / refraction
  - Shlick’s approximation

# PATHTRACING

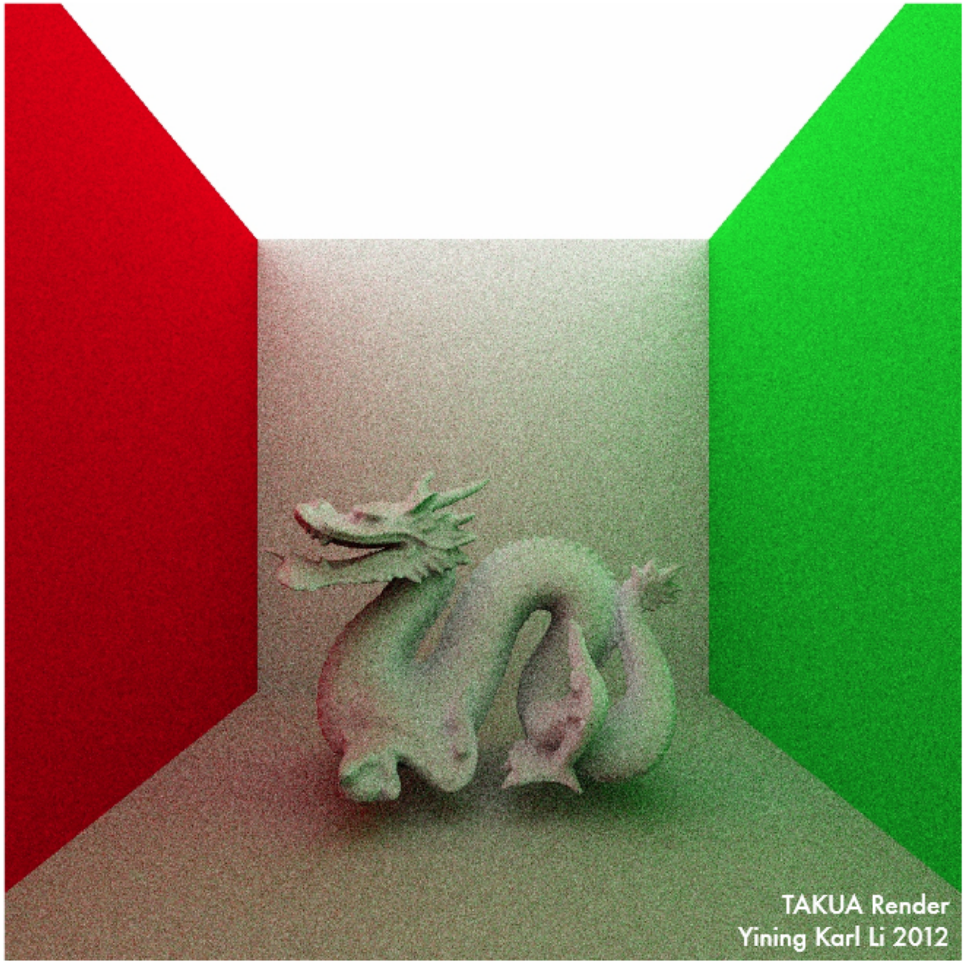
# Pathtracing

**Algorithm 3** Path Tracing Main Loop

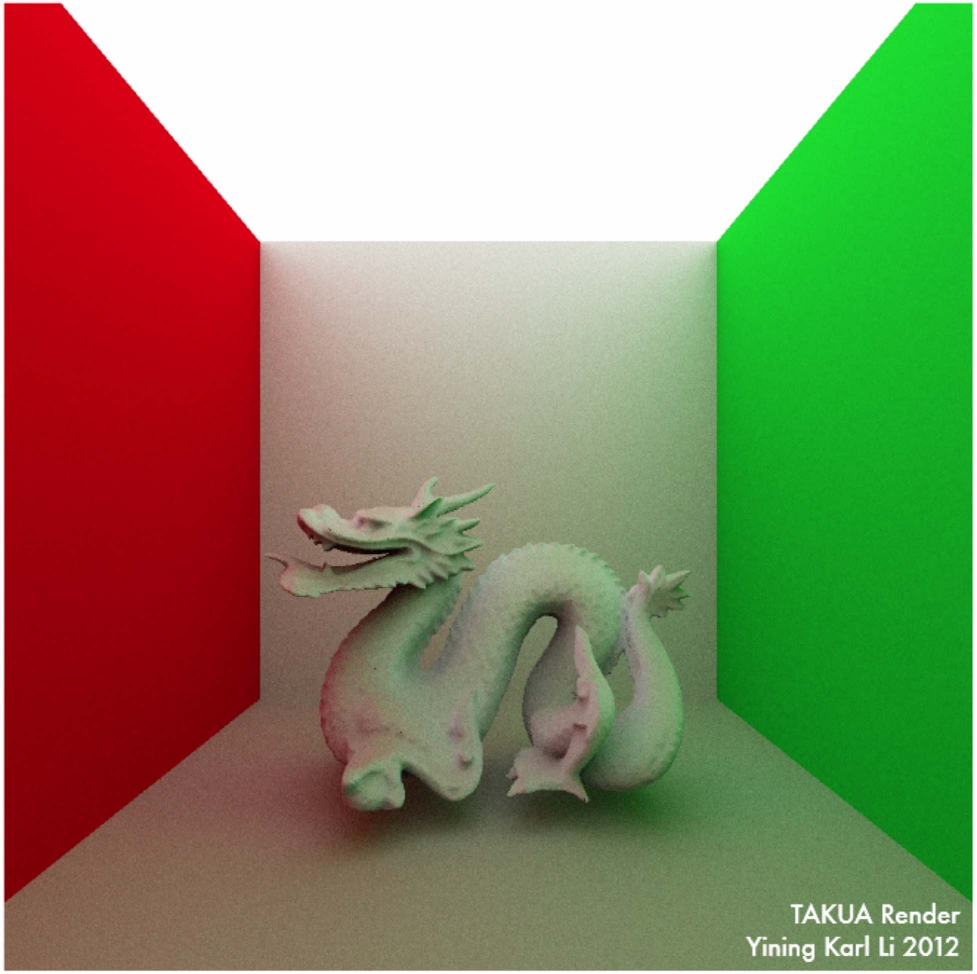
```
for each pixel (i,j) do
    Vec3 $C$ = 0
    for (k=0; k $<$ samplesPerPixel; k++) do
        Create random ray in pixel:
            Choose random point on lens $P_{lens}$
            Choose random point on image plane $P_{image}$
            $D$ = normalize($P_{image} - P_{lens}$)
            Ray ray = Ray($P_{lens}$, $D$)
        castRay(ray, isect)
        if the ray hits something then
            $C$ += radiance(ray, isect, 0)
        else
            $C$ += backgroundColor($D$)
        end if
    end for
    image(i,j) = $C$ / samplesPerPixel
end for
```




1 Iteration




20 Iterations




250 Iterations

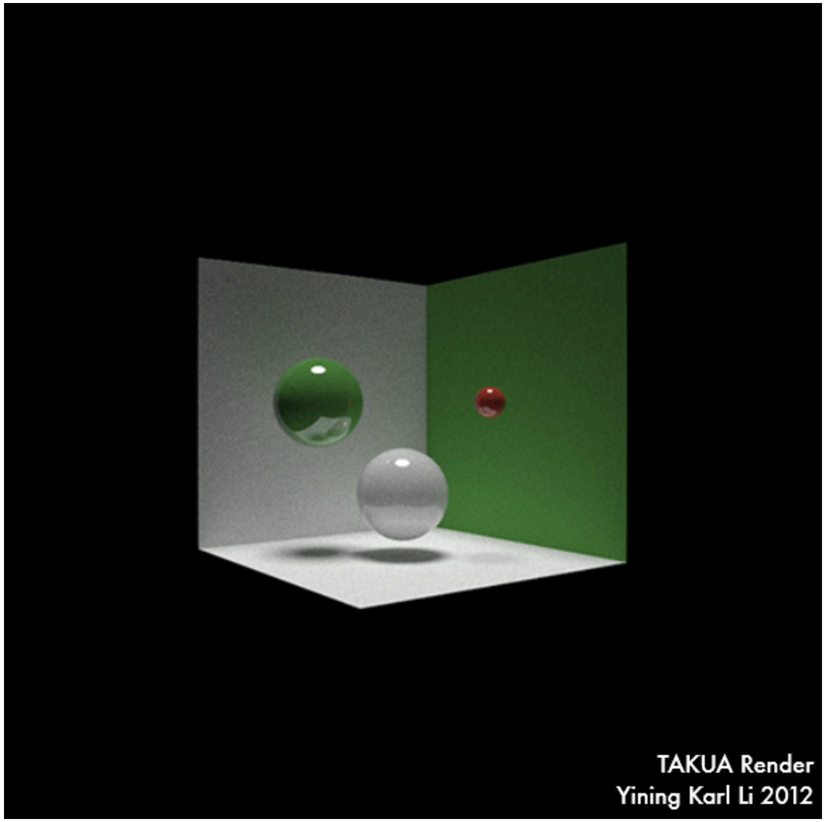
# PARALLELIZATION

# GPU Pathtracers

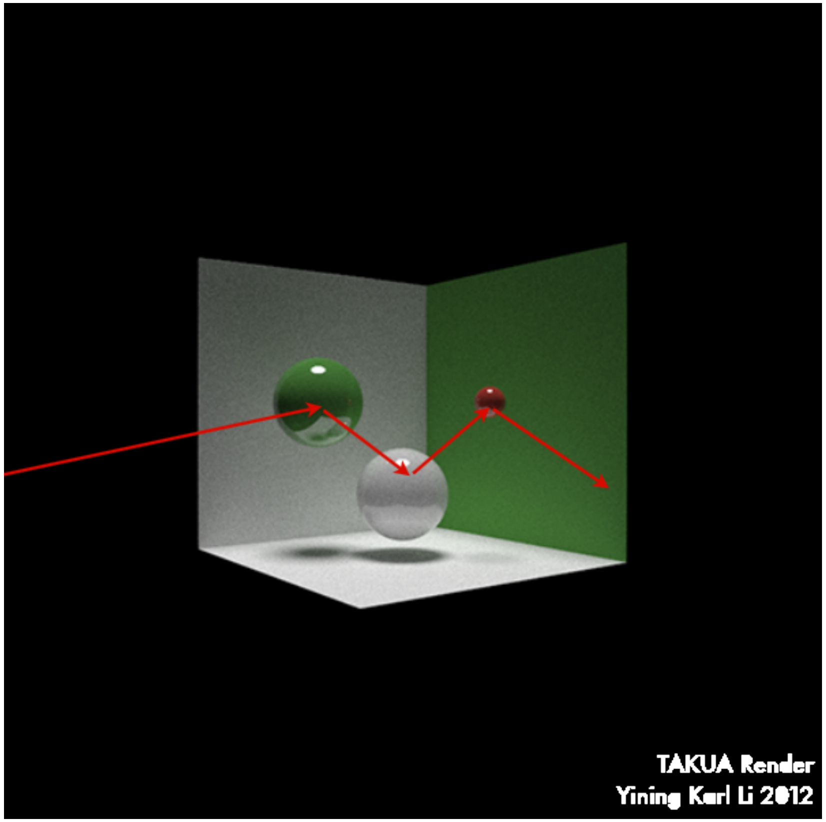
- Peter and Karl's GPU Path Tracer:
  - https://vimeo.com/41109177
- BRIGADE Renderer:
  - http://www.youtube.com/watch?v=FJLy-ci-RyY
- Octane otoy:
  - http://render.otoy.com/gallery.php

# OPTIMIZATION

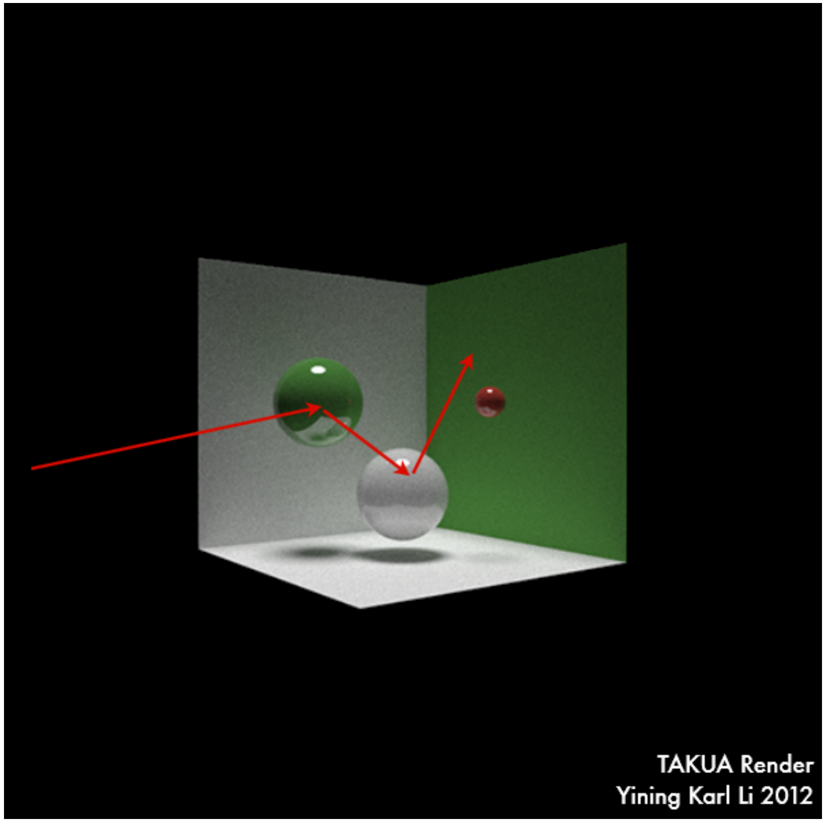
# How many bounces per path?



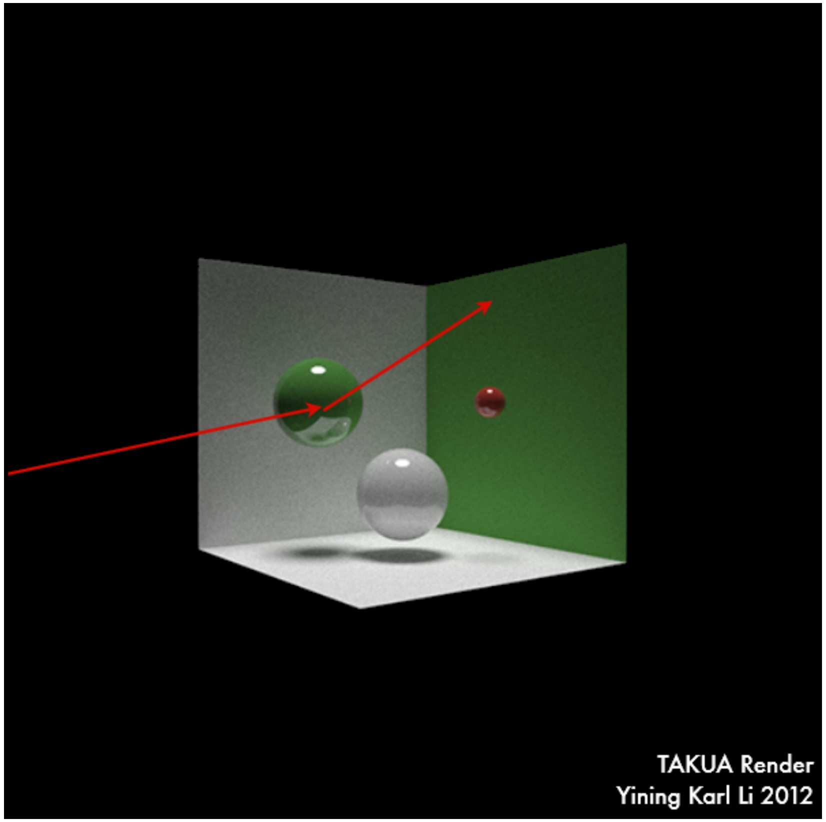
# How many bounces per path?
# 4?



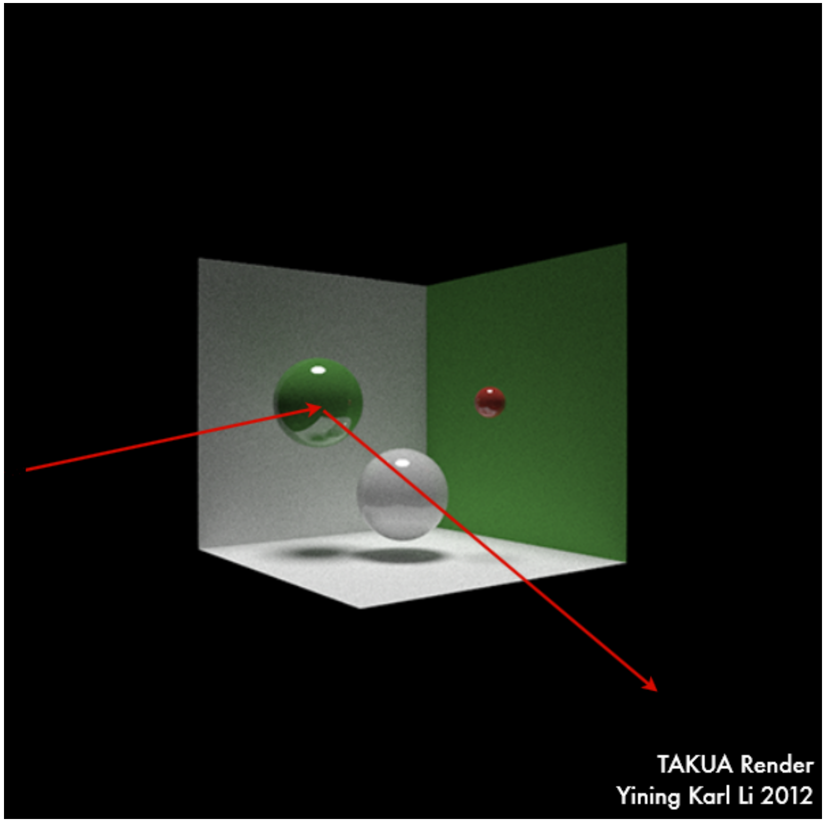
# How many bounces per path?
# 4? 3?



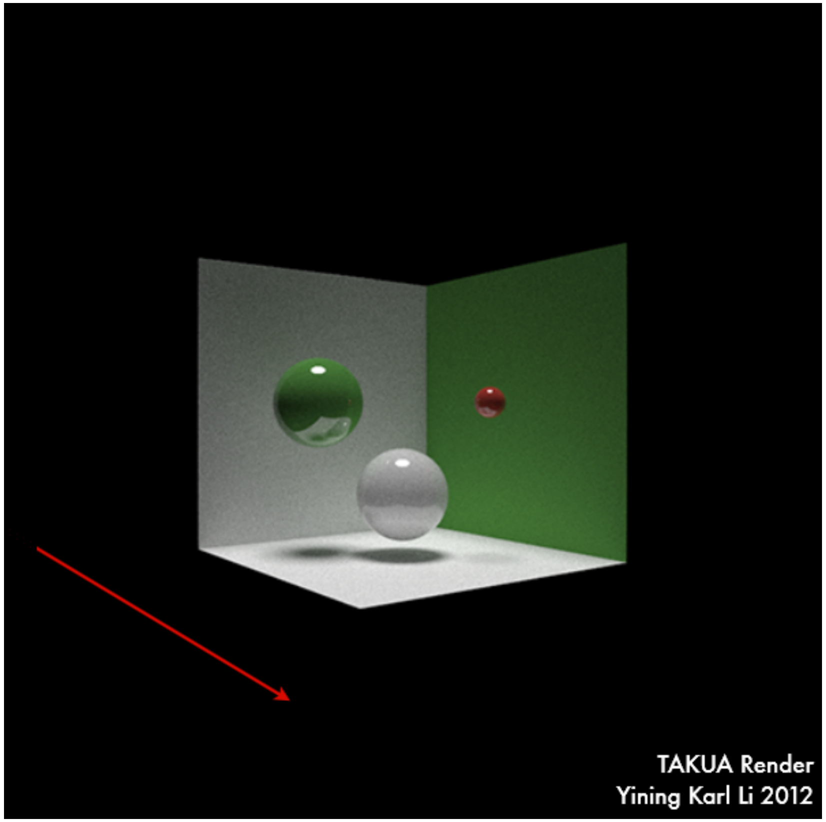
# How many bounces per path?
# 4? 3? 2?



# How many bounces per path?
# 4? 3? 2? 1?



# How many bounces per path?
# 4? 3? 2? 1? 0?



# How many bounces per ray?

- We have no idea!
- What does this imply about parallelizing by pixel?

# Wasted Cycles

- GPU can only handle finite number of blocks at a time
- If some threads need to trace more bounces, then others might spend too much time idling

| Thread 1 | Thread 2 | Thread 3 | Thread 4 | Thread 5 | Thread 6 |
|---|---|---|---|---|---|
| Bounce 1 | Bounce 1 | DONE | Bounce 1 | Bounce 1 | Bounce 1 |
| Bounce 2 | DONE | | Bounce 2 | DONE | DONE |
| Bounce 3 | | | DONE | | |
| Bounce 4 | | | | | |
| DONE | | | | | |

WASTED CYCLES

# Ray Parallelization

- Parallelize by ray, not pixel
- Multiple kernel launches that trace individual bounces

1. Construct pool of rays that need to be tested
2. Construct accumulator image, initialize black
3. Launch a kernel to trace ONE bounce
4. Add any new rays to the pool
5. Remove terminated rays from the pool
6. Repeat from 3 until pool is dry

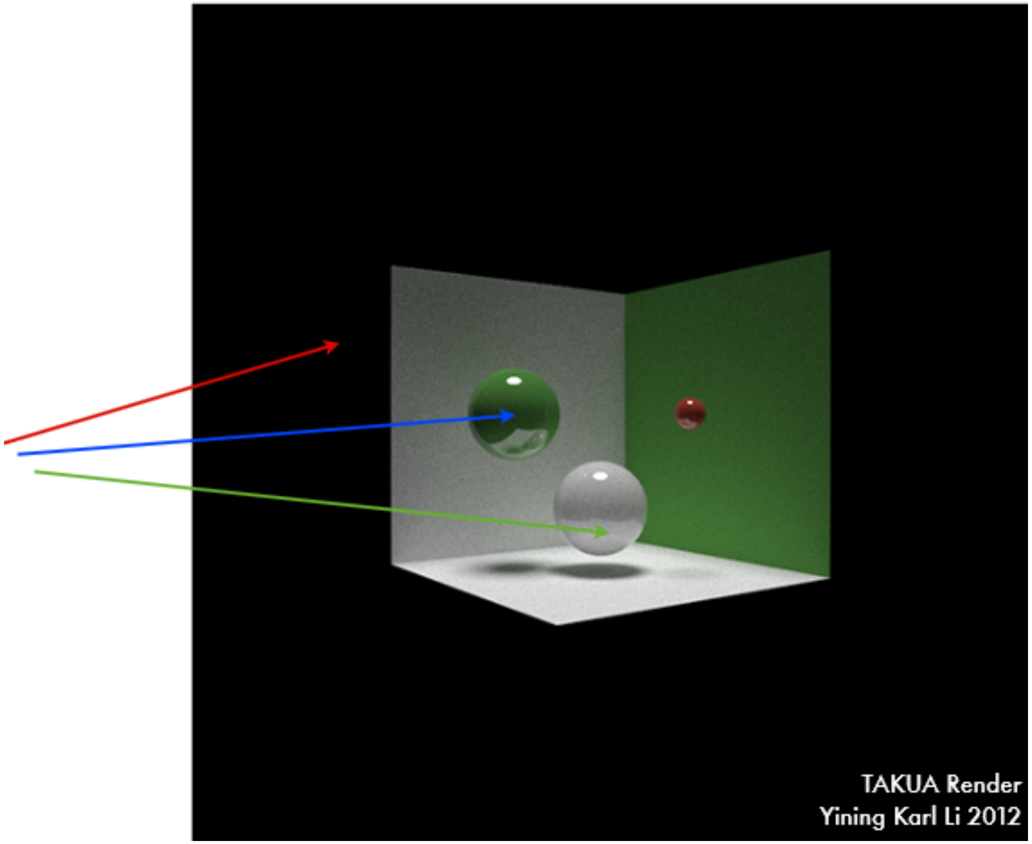
# Ray Parallelization

- Each iteration will have fewer rays, requiring fewer blocks, and giving faster execution.
- Works very well (even in practice)
- Be careful of edge cases!

# Example

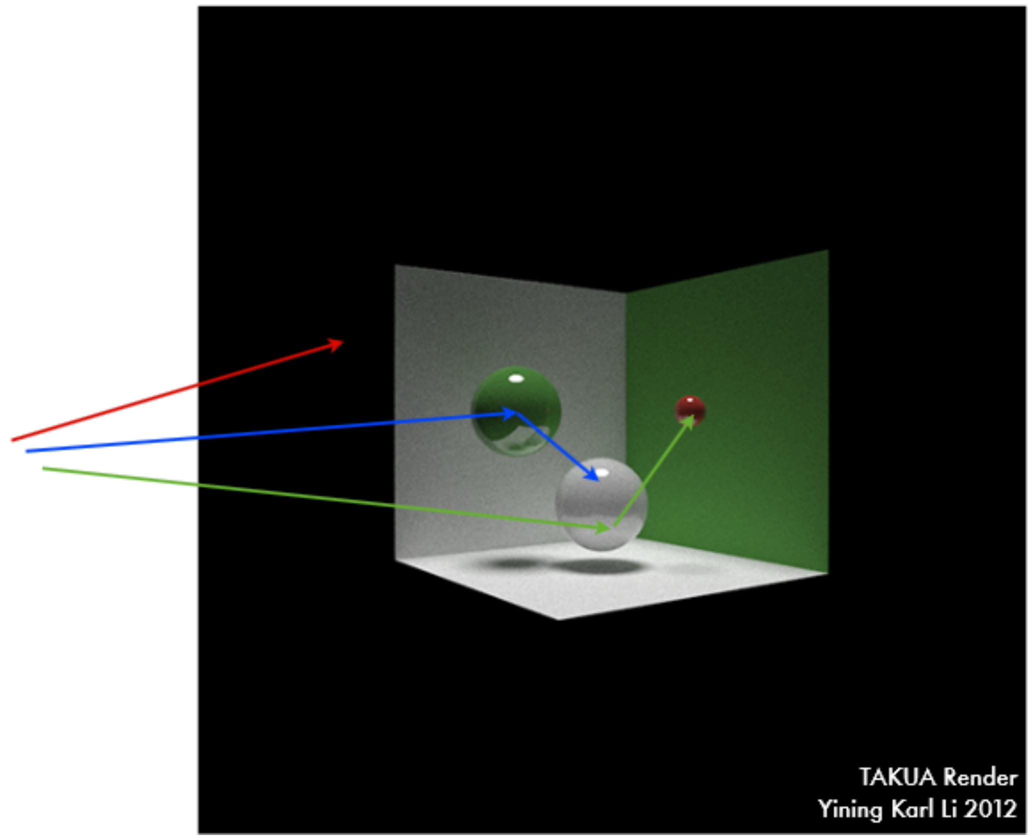
- Ray pool:
  - 1, 2, 3
- Threads needed:
  - 3

- Ray 1 terminates



# Example

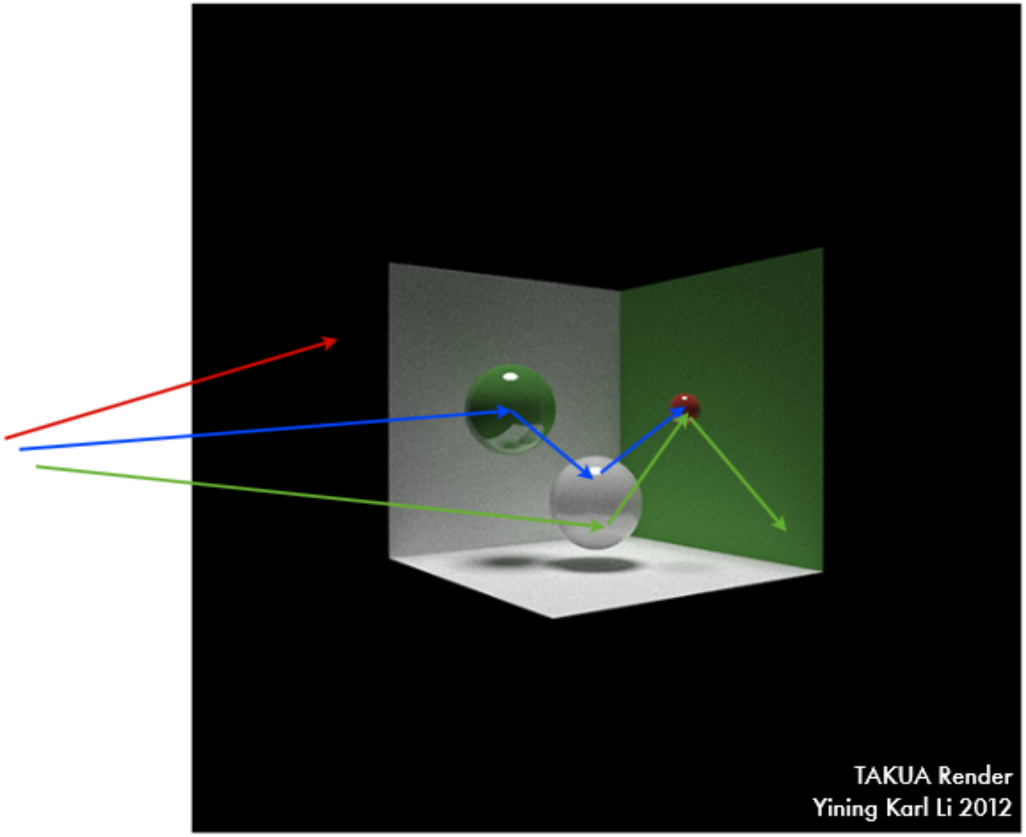
- Ray pool:
  - 2, 3
- Threads needed:
  - 2



# Example

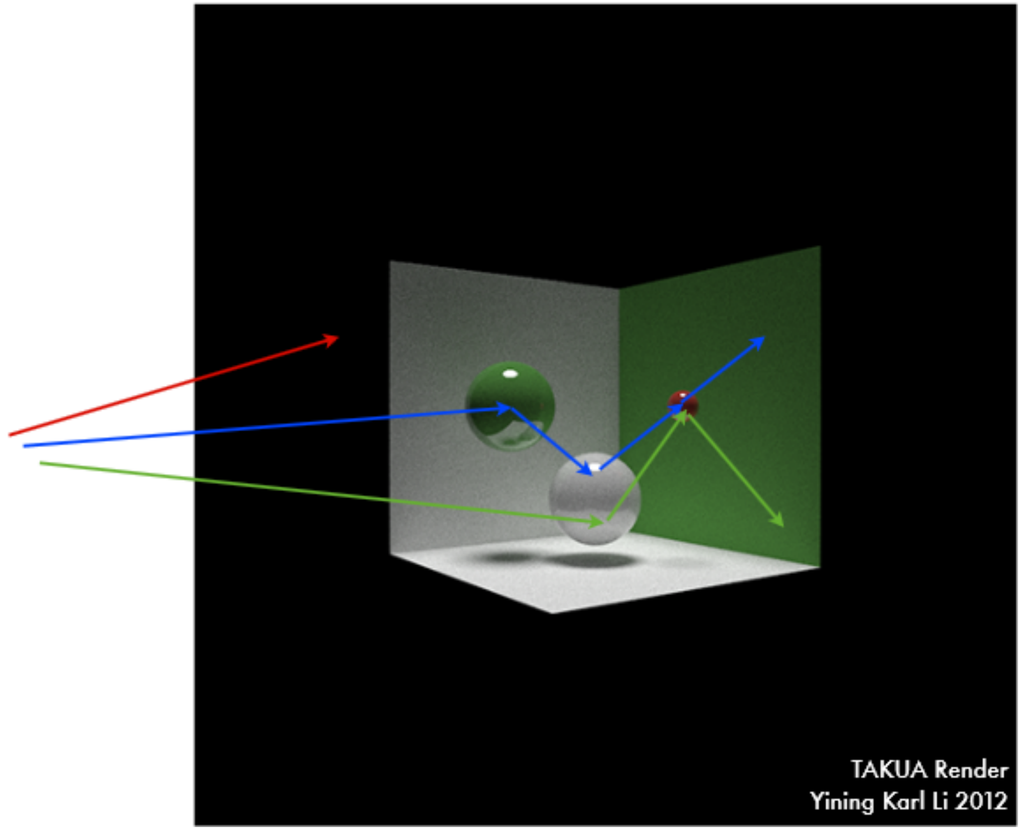
- Ray pool:
  - 2, 3
- Threads needed:
  - 2

- Ray 3 terminates



# Example

- Ray pool:
  - 2
- Threads needed:
  - 1
- Ray 2 terminates



# Optimization

- Wasted cycles / Zero contribution rays
  - Stream compaction!
- Acceleration structures

# BASE CODE TOUR

# Base Code

- Scene reader
- UI / Rendering visualization
  - PBO transfer
- Intersection code
- CPU image write

# Project Expectations

- GPU Path tracing
  - Intersections, accumulation, etc. on GPU
- Diffuse and specular materials
- 2 of the following features:
  - Fresnel reflection / refraction
  - OBJ loading
  - Acceleration structure (BVH, k-d tree, etc.)
  - Depth of field
  - Subsurface scattering
  - Etc. (If you have other ideas, be sure to contact us)

# Project Expectations

- Analysis for every extra feature:
  - Overview write up
  - When adding this feature, what is the performance impact? Why?
  - If there are special cases, why you implemented it the way you did.
  - How can this be optimized any further?
  - Pros / cons of GPU vs. CPU implementation

# Tips for README

- Sell your project
- Assume reader has base knowledge of path tracing
- View this as a wiki to document your code
- Do NOT leave this for the last minute

# Further Reading

- Physically Based Rendering, 2e. (Pharr, Humphreys)
- Realistic Image Synthesis Using Photon Mapping (Jensen)
- smallPT