

Feasibility Study of Real Time Path Tracing

Or: How Much Noise Is Too Much?

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Table of Contents

Introduction

- Topic

- Motivation

- Leading Question and Goals

Real Time Path Tracing Explained

- History of Path Tracing

- Physically Based Approach

- Theoretical Basis

- Algorithm

- Current State of Technology

Research

- Implementation Design Overview

- Results

- Evaluation

Conclusion and Outlook

- Conclusion

- Outlook

Topic

Main topic of the thesis

When will real time path tracing be viable on consumer grade hardware?

Motivation

- ▶ Current generation graphics made up of many complex tricks

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Motivation

- ▶ Current generation graphics made up of many complex tricks
- ▶ Path tracing is simple in comparison
- ▶ Superior graphics quality
- ▶ Allows for simulation of caustics, global illumination, light dispersion, etc.
- ▶ Real time path tracing appears to be in reach

Leading Question and Goals

- ▶ Find out when real time path tracing will be viable
- ▶ Theoretical indicators (GPU peak FLOPS)
- ▶ Practical indicators (benchmarks)
- ▶ Prefer performance to quality

History of Path Tracing

History of Path Tracing part 1

- ▶ 1968: Ray casting by Arthur Appel
- ▶ 1980: Ray tracing by Turner Whitted



Figure: Turner Whitted's original 1980 image

History of Path Tracing

History of Path Tracing part 2

- ▶ 1986: Monte Carlo ray tracing (path tracing) by James T. Kajiya
- ▶ 1996: Bidirectional path tracing by Eric Lafortune
- ▶ 1997: Metropolis Light Transport by Eric Veach and Leonidas J. Guibas

Physically Based Approach

Forward path tracing

Light source (\Rightarrow scene interactions) \Rightarrow observer

Backward path tracing

Observer (\Rightarrow scene interactions) \Rightarrow light source

Theoretical Basis

James Kajiya's rendering equation

$$L_o(\mathbf{x}, \omega_o, \lambda, t) = L_e(\mathbf{x}, \omega_o, \lambda, t) + \int_{\Omega} f_r(\mathbf{x}, \omega_i, \omega_o, \lambda, t) L_i(\mathbf{x}, \omega_i, \lambda, t) (\omega_i \cdot \mathbf{n}) d\omega_i$$

Simplified rendering equation

$$L_o(\mathbf{x}, \omega_o) = L_e(\mathbf{x}, \omega_o) + \int_{\Omega} f_r(\mathbf{x}, \omega_i, \omega_o) L_i(\mathbf{x}, \omega_i) (\omega_i \cdot \mathbf{n}) d\omega_i$$

- ▶ Path tracing is a numerical approximate solution to the rendering equation

Rendering equation breakdown

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$(\omega_i \cdot n)$ is the **normal attenuation** at x .

Algorithm

Algorithm part 1

```
1   max_depth = 5
2   scene = [triangle_1, ..., triangle_n]  # Many triangles defined here
3
4   def trace_ray(ray, depth):
5       if depth >= max_depth:
6           # Return black since we haven't hit anything but we're
7           # at our limit for bounces
8           return RGB(0, 0, 0)
9
10      intersection = None
11      for triangle in scene:
12          intersection = check_intersection(ray, triangle)
13          if intersection:  # Break at first intersection
14              break
15
16      if not intersection:
17          # If we haven't hit anything, we can't bounce again so
18          # we return black
19          return RGB(0, 0, 0)
```

Algorithm

Algorithm part 2

```
20     material = intersection.material;
21     emittance = material.emittance
22
23     # Shoot a ray into random direction and recurse
24     next_ray = Ray()
25     next_ray.origin = intersection.position
26     next_ray.direction = random_vector_on_hemisphere(intersection.normal)
27
28     # BRDF for diffuse materials
29     reflectance_theta = dot(next_ray.direction, intersection.normal)
30     brdf = 2 * material.reflectance * reflectance_theta
31     reflected = trace_ray(next_ray, depth + 1)
32
33     return emittance + (brdf * reflected)
34
35 for sample in range(samples):
36     for pixel in pixels:
37         trace_path(ray_from_pixel(pixel), 0)
```

Current State of Technology

Projects utilizing real time path tracing:

- ▶ Jacco Bikker's and Jeroen van Schijndel's *Brigade Renderer*
- ▶ David Bucciarelli's *sfera*
- ▶ Evan Wallace's *WebGL Path Tracer*

Current State of Technology

Current State of Technology

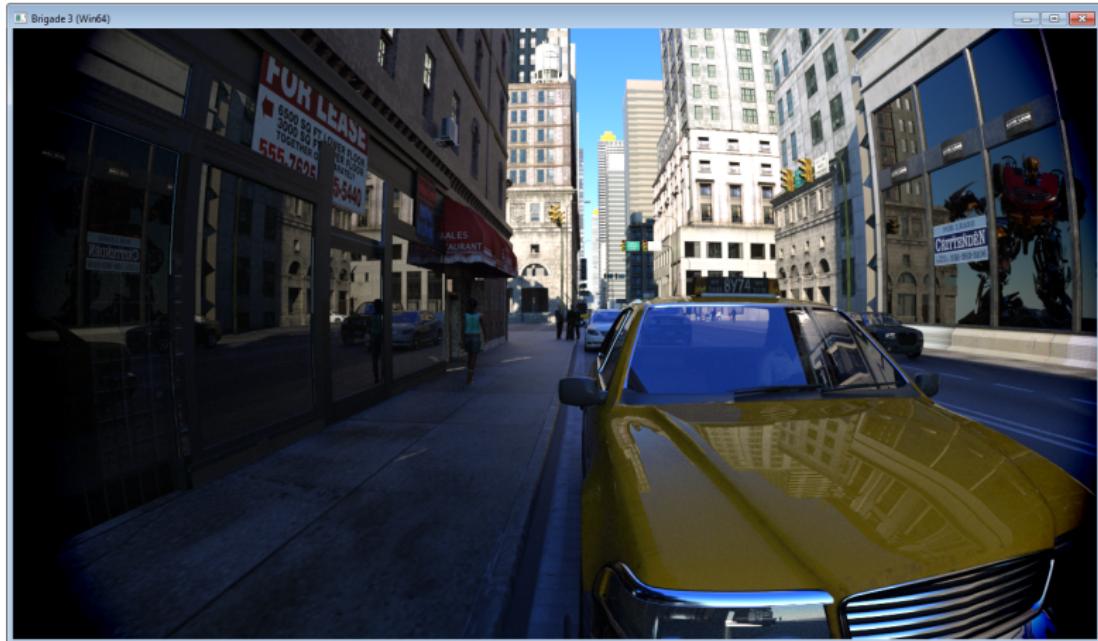


Figure: Brigade Renderer

Current State of Technology

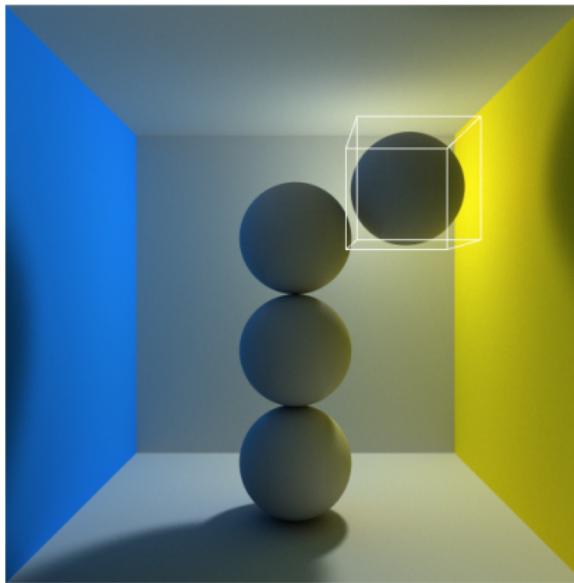
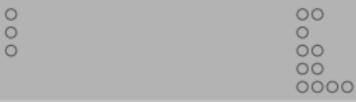


Figure: WebGL real time path tracer

Current State of Technology



Figure: Sfera real time path tracing video game.



Implementation Design Overview

Design Overview

Design Overview

Design goals:

1. **Speed**
2. **Ease of implementation**
3. **Interactivity**
4. **Portability**
5. **Maintainability**

Design Overview

Components:

- ▶ Random number generation
- ▶ Camera
- ▶ Material system
- ▶ AABBs
- ▶ Triangles
- ▶ Shapes and geometry
- ▶ Scene
- ▶ Intersection/Scene lookup
- ▶ Viewer

Design Overview

Materials:

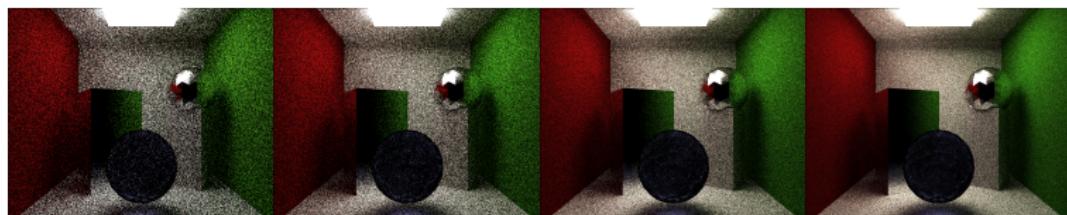
- ▶ Emissive
- ▶ Diffuse
- ▶ Glass
- ▶ Glossy

Visual Results

Visual Results



(i) $n = 1$ (j) $n = 2$ (k) $n = 3$ (l) $n = 4$



(m) $n = 10$ (n) $n = 20$ (o) $n = 50$ (p) $n = 100$

Visual Results

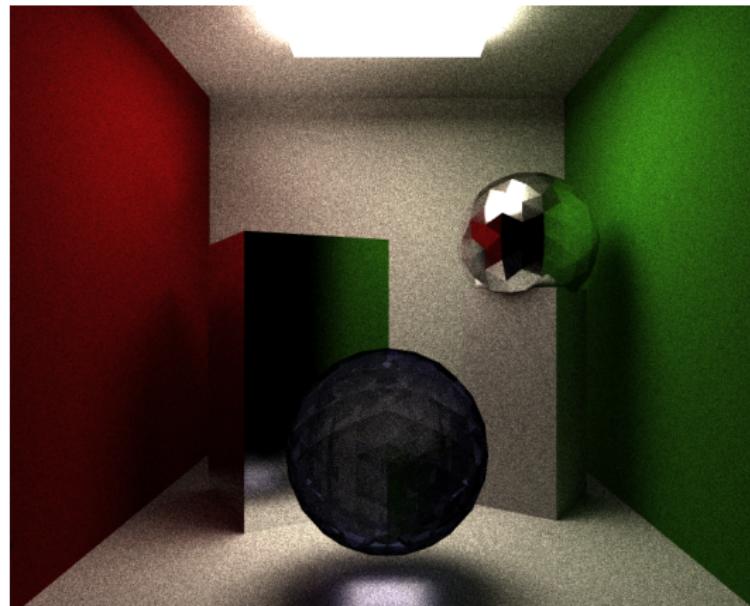


Figure: tracOr_viewer after integrating for 5000 frames.

Visual Results

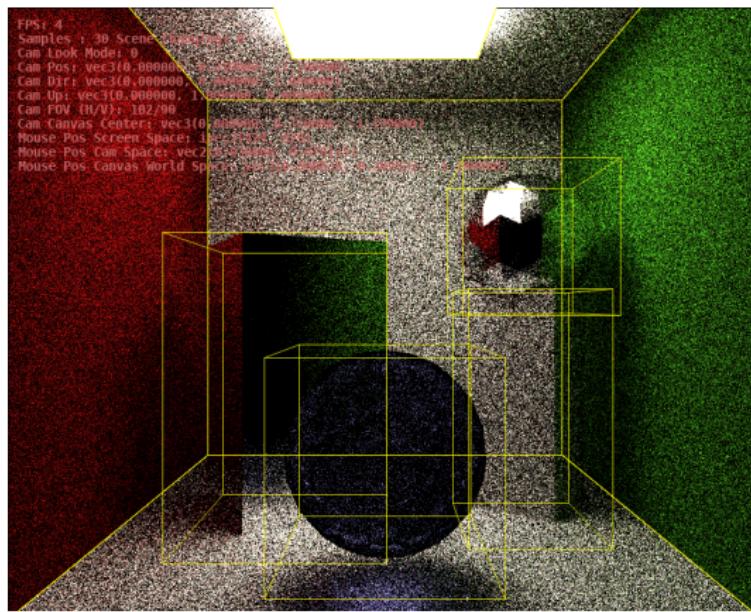


Figure: tracor_viewer debug view.

Results

Visual Results

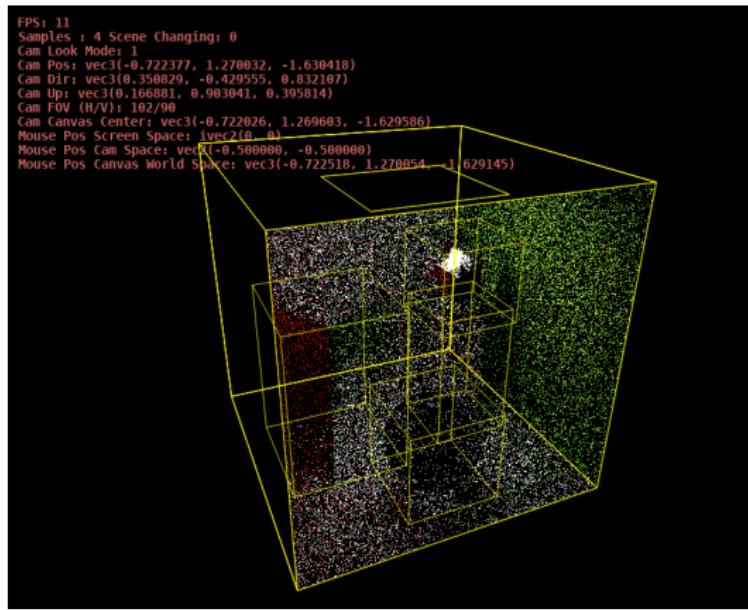


Figure: trac0r_viewer debug view while interactively navigating the scene.

Visual Results

Live presentation!

Introduction

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Real Time Path Tracing Explained

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Evaluation

Research

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Conclusion and Outlook

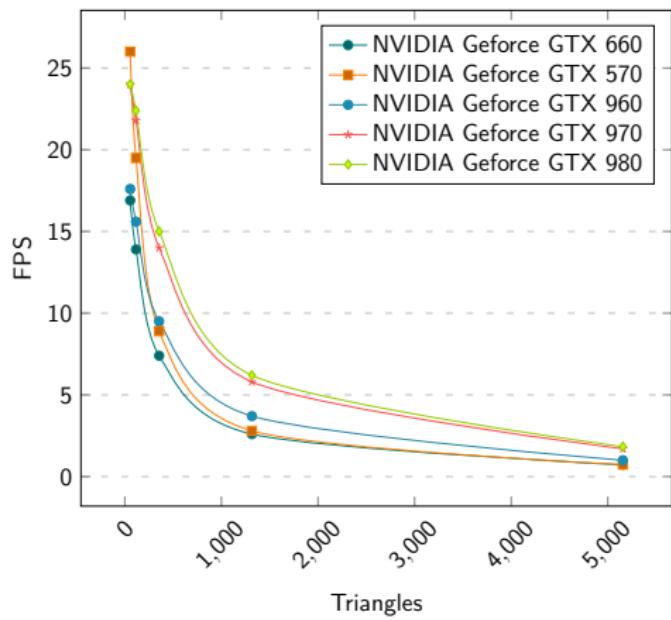
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Evaluation

Evaluation

Evaluation

Performance in correlation to scene complexity

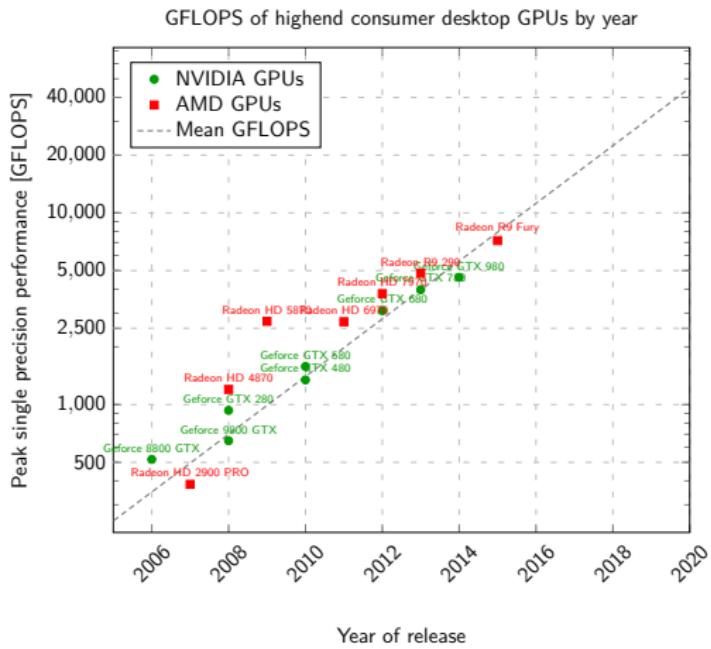


Evaluation

GPU	Average FPS	GFLOPS	Average FPS GFLOPS
NVIDIA Geforce GTX 660	8.3	1881.6	4.4×10^{-3}
NVIDIA Geforce GTX 570	11.6	1405.4	8.6×10^{-3}
NVIDIA Geforce GTX 960	9.5	2308	4.1×10^{-3}
NVIDIA Geforce GTX 970	13.5	3494	3.9×10^{-3}
NVIDIA Geforce GTX 980	13.9	4612	3.0×10^{-3}

Table: Tested GPU performance and GFLOPS.

Evaluation



Conclusion

- ▶ Recall the goal: When will real time path tracing be viable on commodity hardware?

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- ▶ Data and research suggests viability in ≈ 4 years

Outlook

Many venues for improvement:

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- ▶ Image filtering: Bilateral filter

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 - ▶ Convergence: Bidirectional path tracing + Multiple Importance Sampling
 - ▶ Image filtering: Bilateral filter
 - ▶ Research: Who knows?
- ⇒ Real time path tracing possible within 4 years

Introduction

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Outlook

Real Time Path Tracing Explained

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Research

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Conclusion and Outlook

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Fin

Thank you for your attention.