



RAY-TRACING ON GPU: LIGHT SAMPLING ALGORITHMS

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- M.Sc. candidate in Software Development at the **University of Granada**.
- Master's specialization in Visualization, Immersive Environments and Video Games.
- Software Engineer at **Institut Straumann**. CAD (Computer-Aided Design) and CAM (Computer-Aided Manufacturing) technologies in Orthodontics.

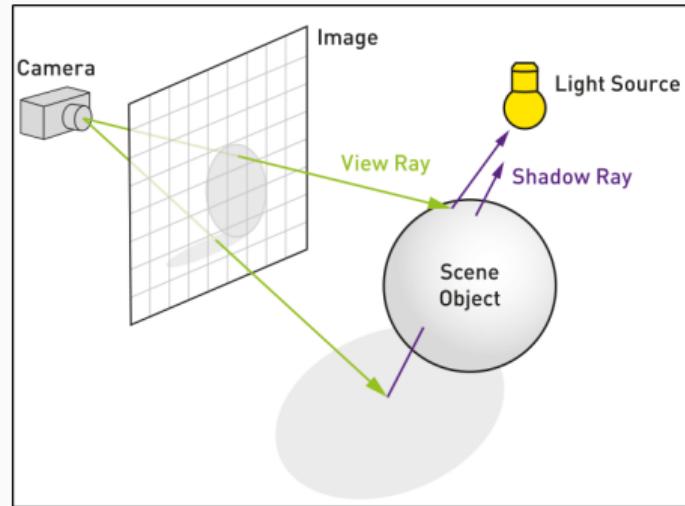


To my tutor, **Dr. Carlos Ureña Almagro**, who took me under his wing and whose profound knowledge and success motivated me to start and finish this project.

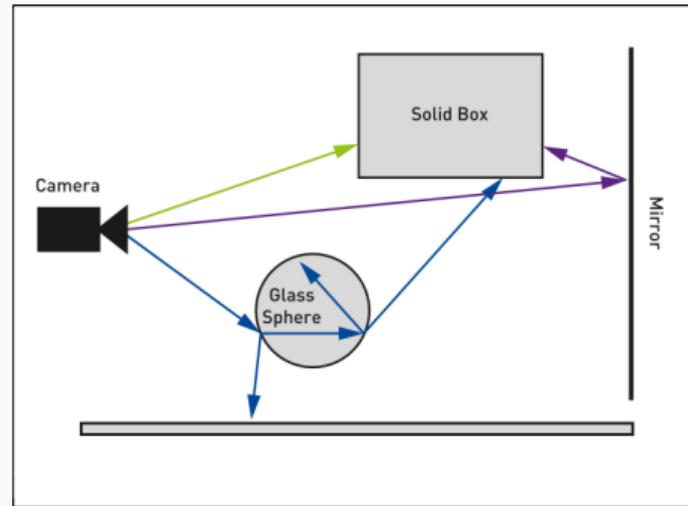
To my professor, **Dr. Alejandro José León Salas**, whose moral support and encouragement allowed me to proceed despite every obstacle I met.

To **all professors** at the **University of Granada** who motivate every student to put in additional efforts to reach perfect results.

1. Ray-Tracing Evolution.
2. Motivation and hardware improvements.
3. Goals.
4. Development of Ray-Tracing frameworks on CPU and GPU.
5. Ray-Tracing comparison. CPU vs. GPU.
6. Basic Light Sampling on GPU.
7. Conclusion.



Ray casting. The process of finding the closest object along a ray. *Source: "Ray tracing Gems I."* [Haines and Shirley, 2019]



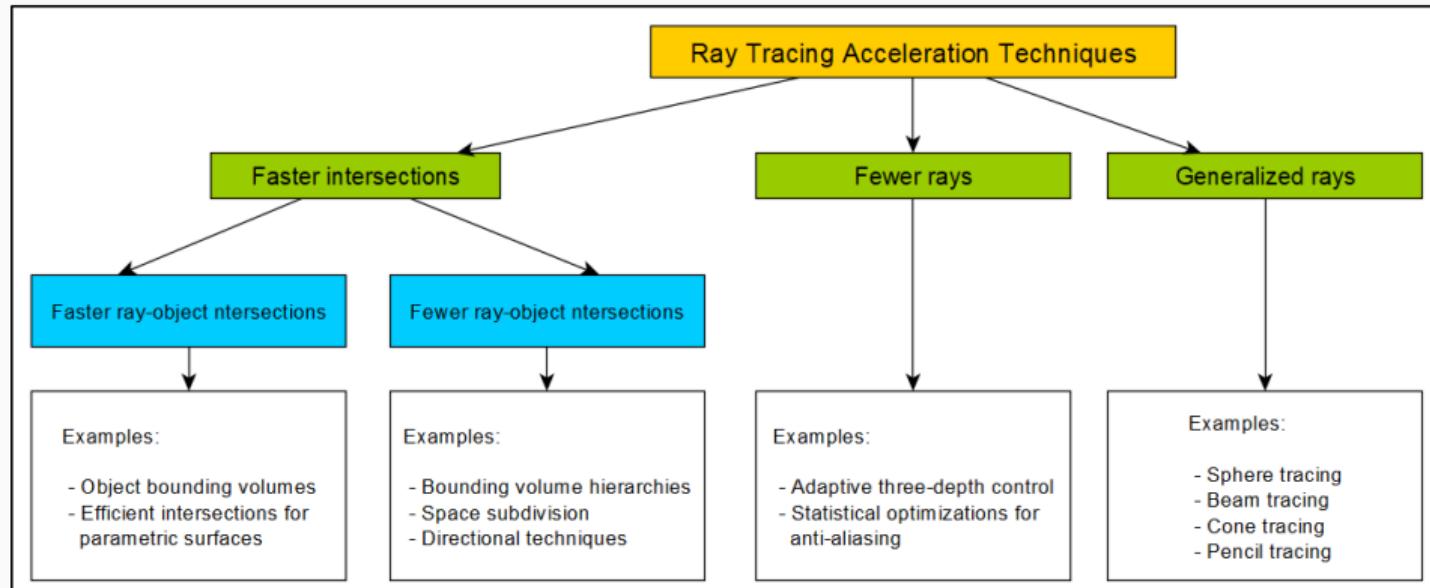
Ray-Tracing uses the ray casting mechanism to recursively gather light contributions from reflective and refractive objects. *Source: "Ray tracing Gems I."* [Haines and Shirley, 2019]

Ray-Tracing isn't a new technology. It has been evolving since the 1960s. Some of the most significant milestones are:

- [Appel, 1968]: Some Techniques for Shading Machine Renderings of Solids.
- [Whitted, 1980]: An Improved Illumination Model for Shaded Display.
- [Cook et al., 1984]: Distributed Ray-Tracing.
- [Goral et al., 1984]: Modeling the Interaction of Light Between Diffuse Surfaces.
- [Kajiya, 1986]: The Rendering Equation.
- [NVIDIA, 2009]: OptiX Ray-Tracing Engine.
- [Laine et al., 2013]: Wavefront Path Tracing on GPU
- [NVIDIA, 2018]: Turing RTX Architecture.
- [NVIDIA, 2022]: Deep learning super sampling (DLSS).

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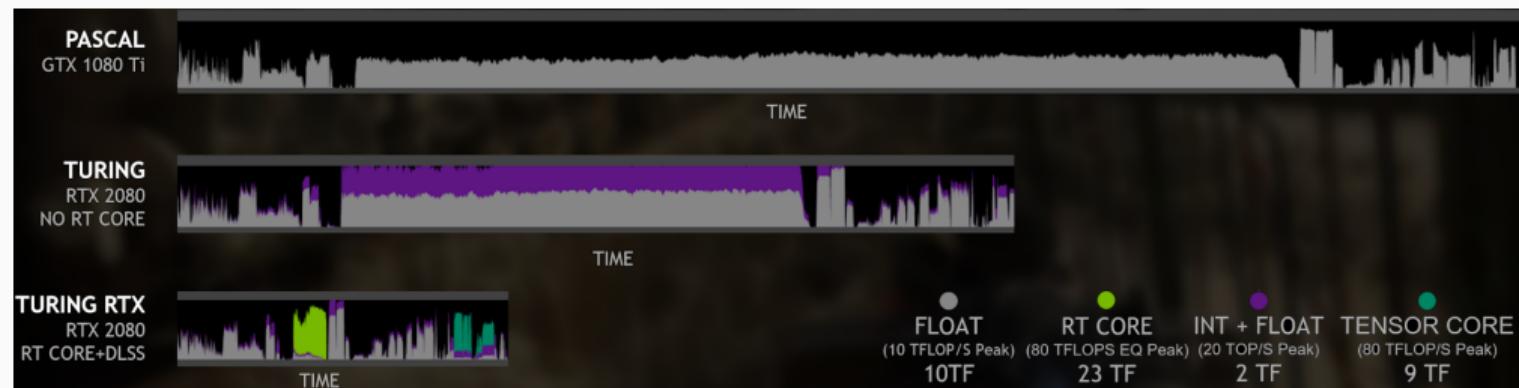
A broad classification of acceleration techniques. [Arvo and Kirk, 1989]

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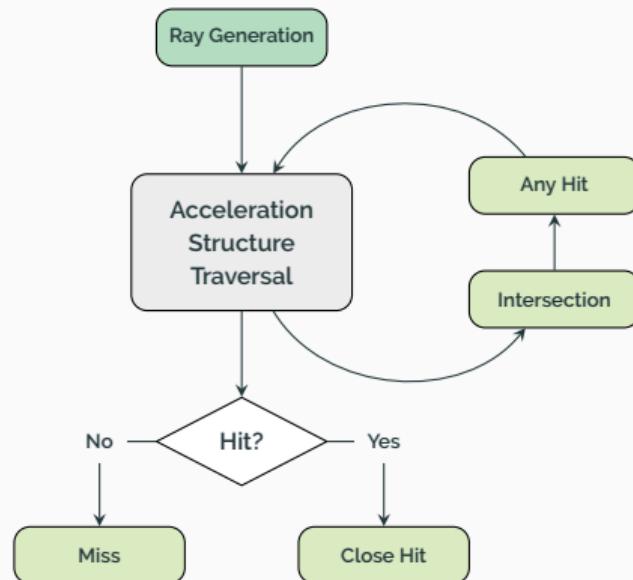
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GeForce RTX 2080 vs. GeForce GTX 1080 performance improvement. Source: [NVIDIA]:

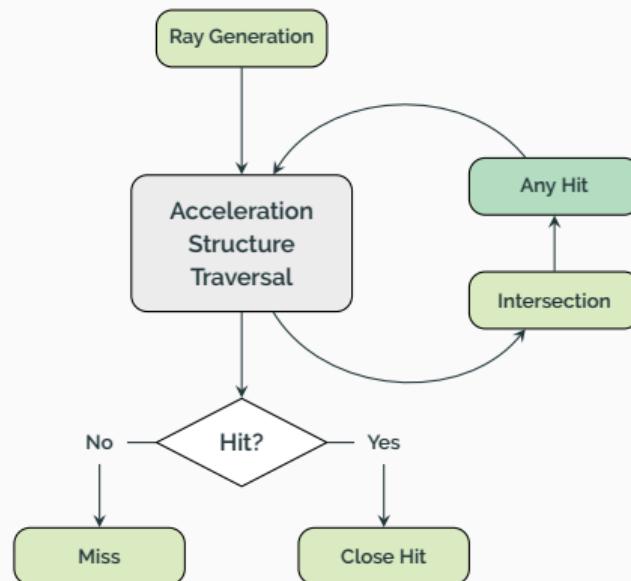
- Ray Generation shader. «Main loop» and entry point to the ray tracer.

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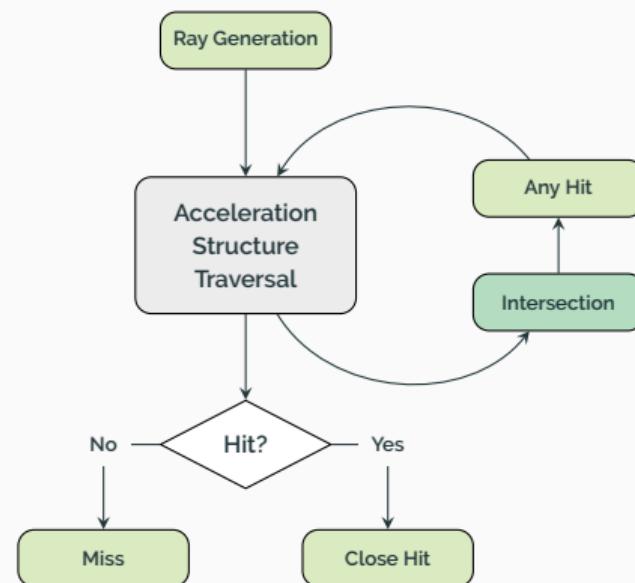
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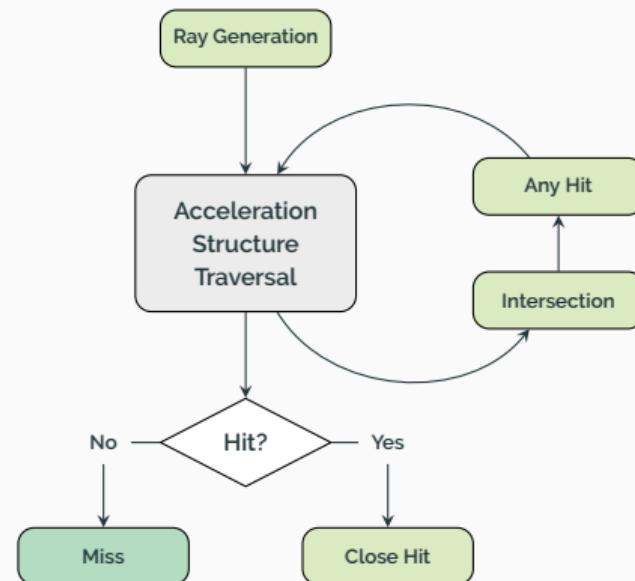
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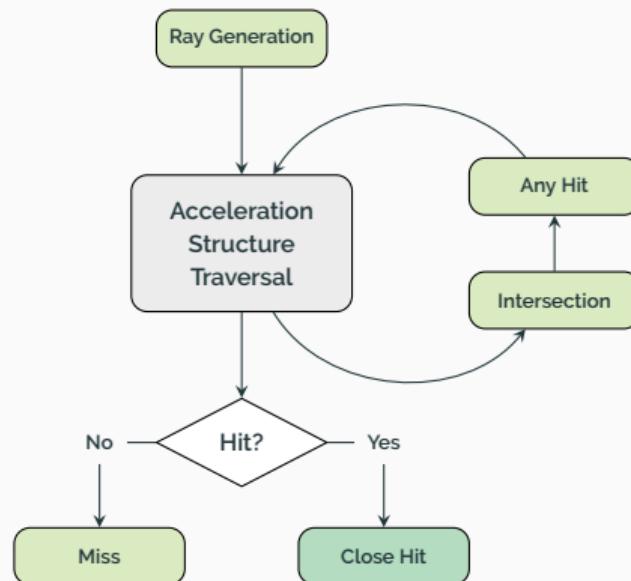
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- **Close Hit** shader. Runs once per ray to shade the final (closest) hit.

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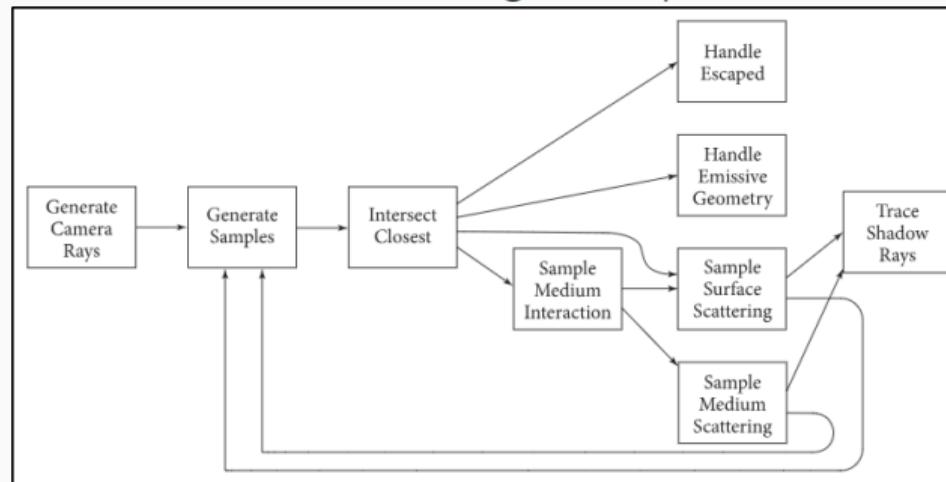
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- Evaluate light sampling algorithms on the GPU.
- Prepare basis for future research in the field of Ray-Tracing and Simulation.

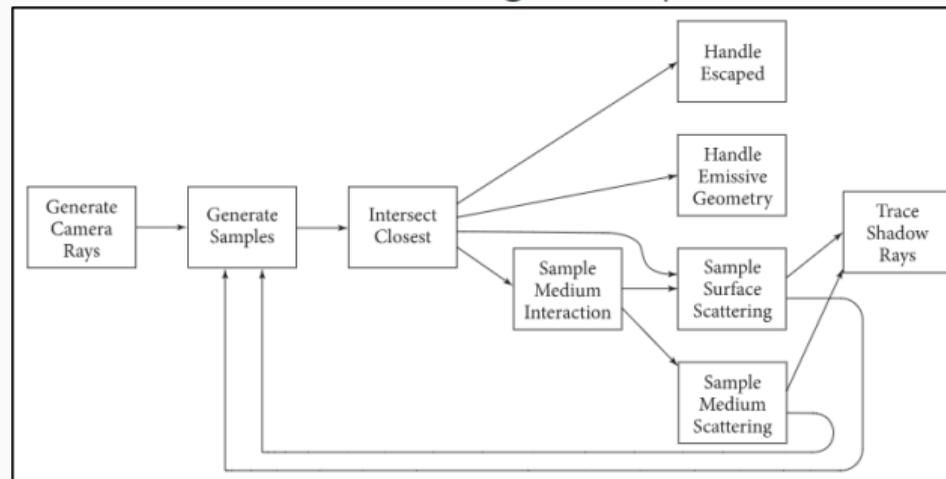
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- [Knoll et al., 2019] and [Meister et al., 2020]: RTX-based Ray-Tracing improvements.

To develop the Ray-Tracing using Vulkan, we need to have an RTX-compatible GPU. The following hardware and software were used:

- **System:** XMG Neo 17 (Laptop)
- **OS:** Windows 10
- **CPU:** Intel i9-14900 HX
- **RAM:** 64 GB
- **GPU:** NVIDIA GeForce RTX 4070 (with Ray-Tracing cores)
- **GPU Ram:** 8 GB
- **Compiler:** MSVC 19.41 (Visual Studio 2022)
- **CMake:** 3.30.2
- **DirectX Support:** 12.1

We use VCPKG to manage the third-party libraries in the project and support all popular platforms: Windows, Linux, and macOS. The libraries used in the project are:

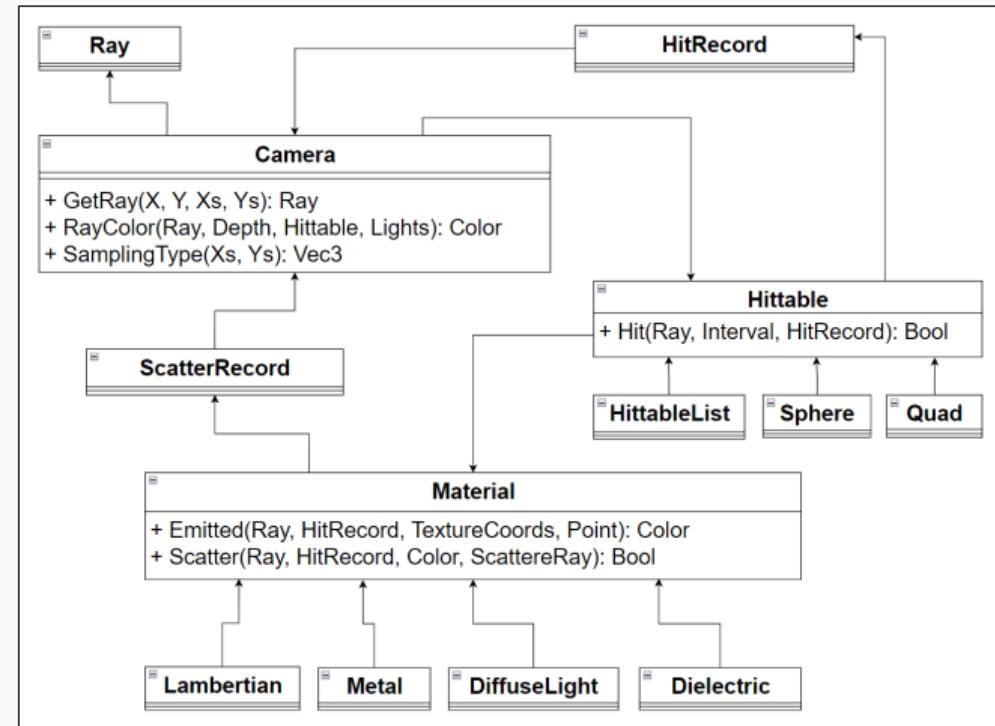
- **C++**: main programming language.
- **GLSL**: shading language.
- **Vulkan SDK**: official Vulkan SDK.
- **GLFW**: window creation and input handling.
- **GLM**: mathematics library for graphics software.
- **Dear ImGui with Docking**: graphical user interface library.
- **Spdlog**: fast C++ logging library.
- **Stb**: single-file public domain image loader for C/C++.
- **Tinyobjloader**: tiny but powerful single-file object loader.

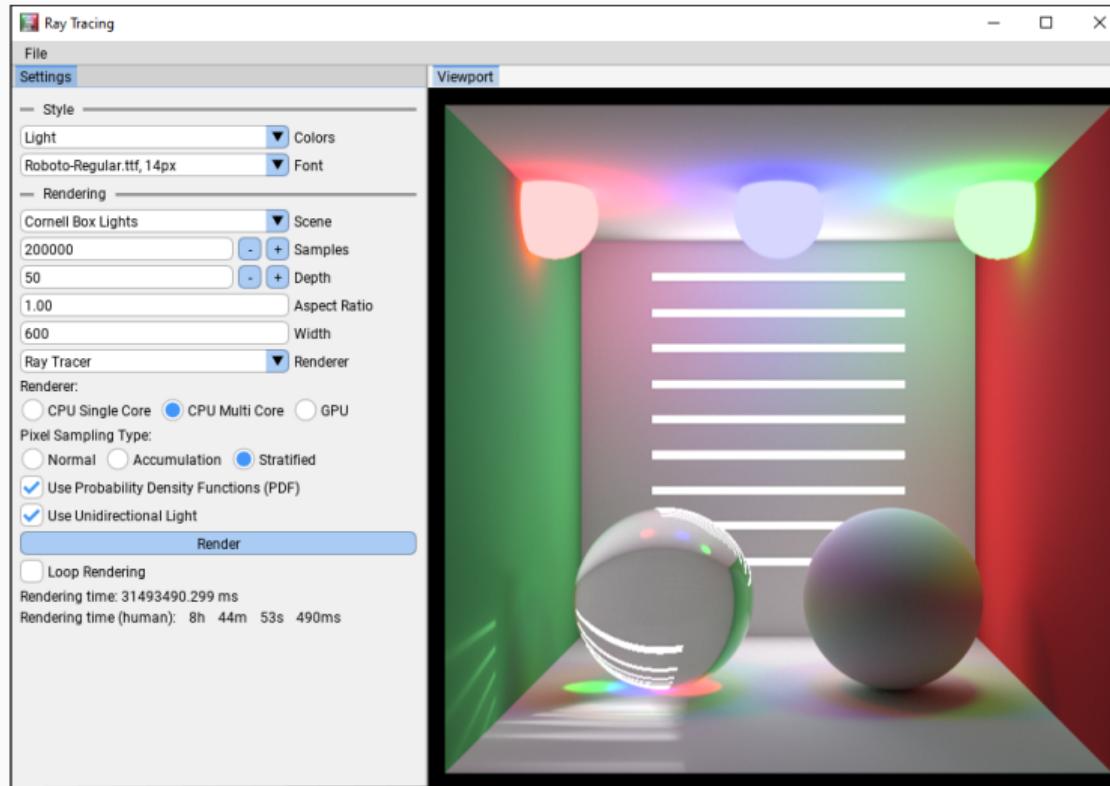
RAY-TRACING FRAMEWORK

Ray-Tracing framework by Peter Shirley (In One Weekend series).

- Camera.
- Hittable - object.
- Hittable List - group of objects.
- Material.
- Ray.
- Hit Record - hit properties.
- Scatter Record - ray behavior.

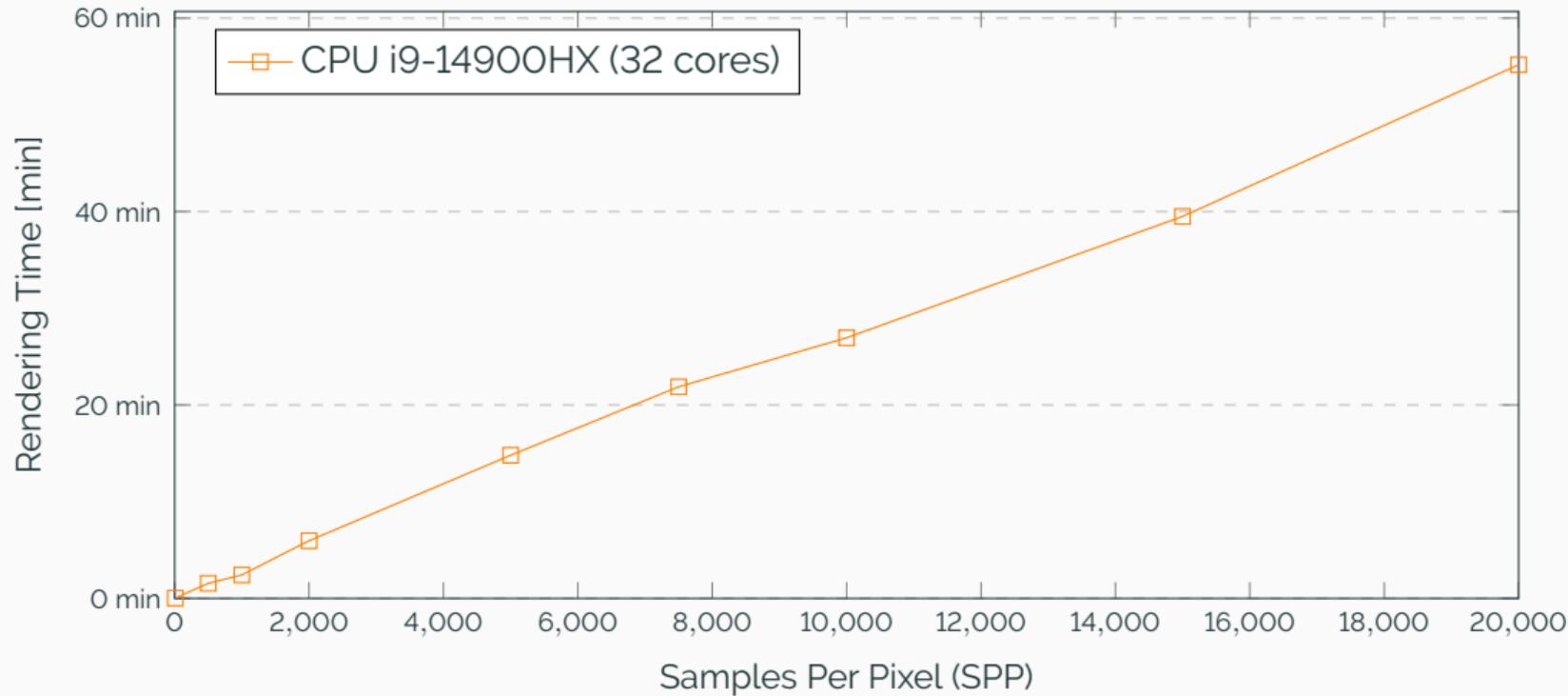
RAY-TRACING ON CPU





Samples per pixel	Rendering Time CPU (ms)	Rendering Time CPU (human)
10	2'000 ms	2s
50	9'000 ms	9s
100	19'000 ms	19s
250	42'000 ms	42s
500	94'000 ms	1m 34s
1000	146'000 ms	2m 26s
2000	358'000 ms	5m 58s
5000	888'000 ms	14m 48s
7500	1'313'000 ms	21m 53s
10000	1'617'000 ms	26m 57s
15000	2'370'000 ms	39m 30s
20000	3'311'000 ms	55m 11s

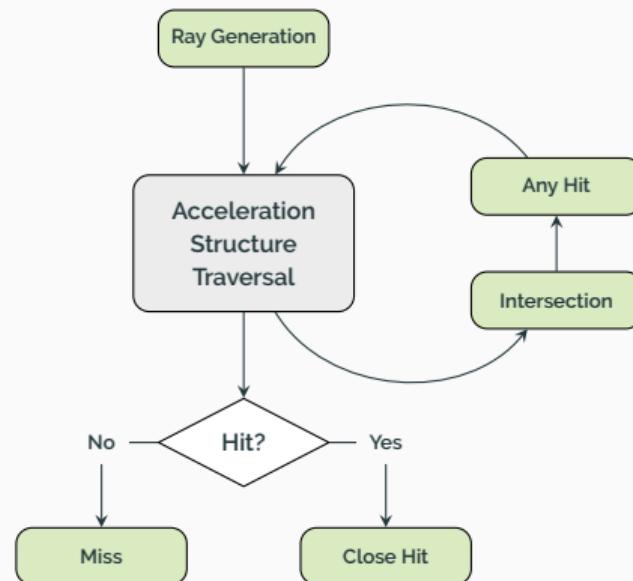
Ray Tracing performance on CPU.



- **Ray Generation Group:** Ray Generation shader.
- **Miss Group:** Miss shader (background).
- **Close Hit Group for Triangular Data:** Close Hit shader (meshes).
- **Close Hit Group for Non-Triangular Data:** Close Hit and Intersection shaders (procedural objects).

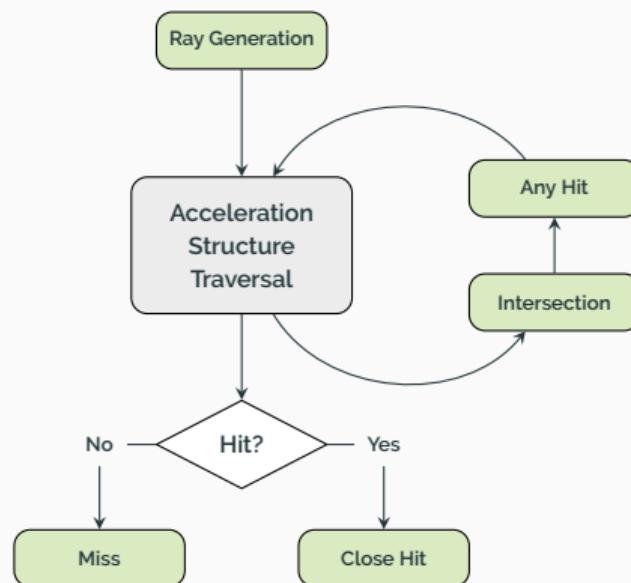
Side Note: Any Hit shader can typically be used to efficiently implement alpha-testing (transparency) and shadow rays. It is not used in this project, so we don't have it in the pipeline.

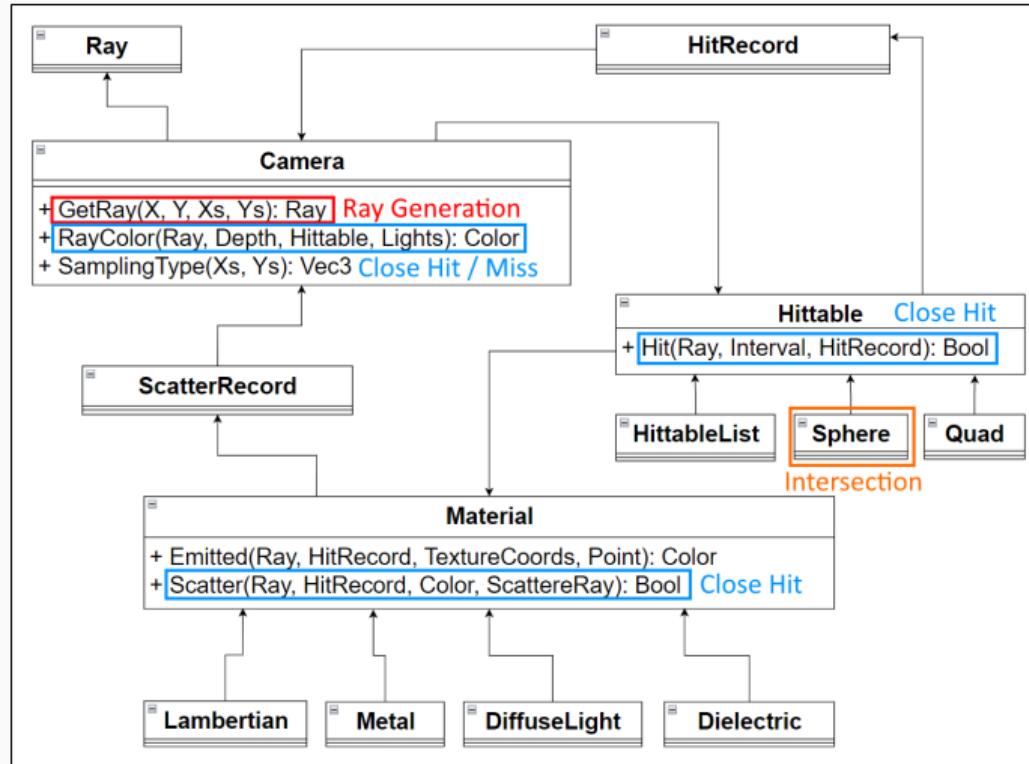
RAY-TRACING SHADERS



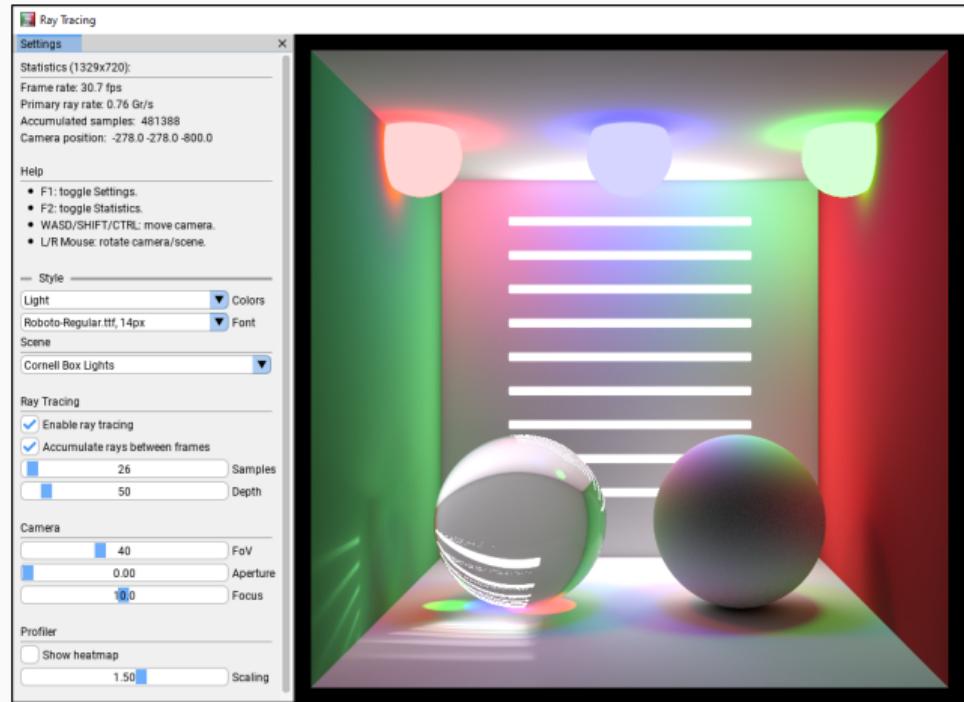
- Camera.GetRay \Rightarrow Ray Generation
- Hittable.Hit (Sphere.Hit) \Rightarrow Intersection
- Camera.RayColor \Rightarrow Close Hit/Miss
- Material.Scatter \Rightarrow Close Hit
- HitRecord \Rightarrow Ray Payload
- ScatterRecord \Rightarrow Ray Payload

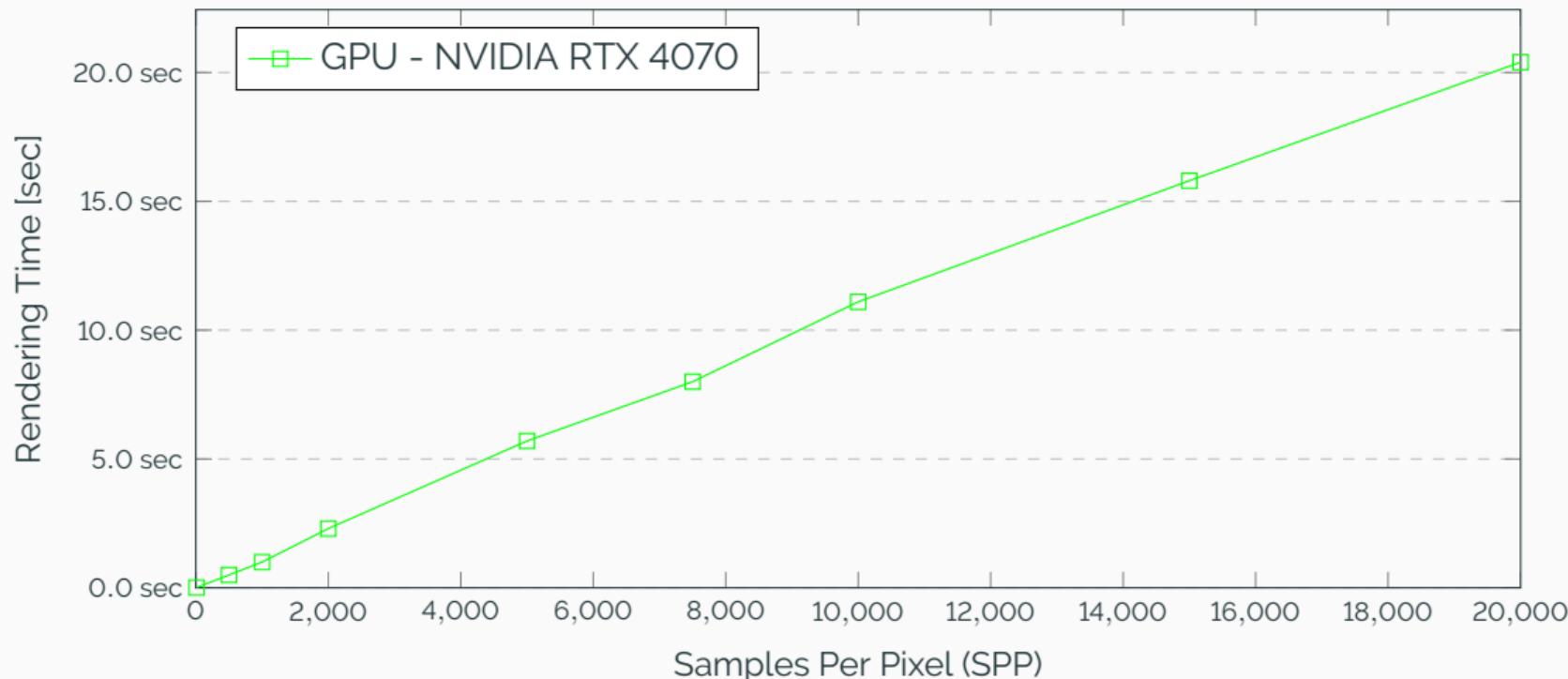
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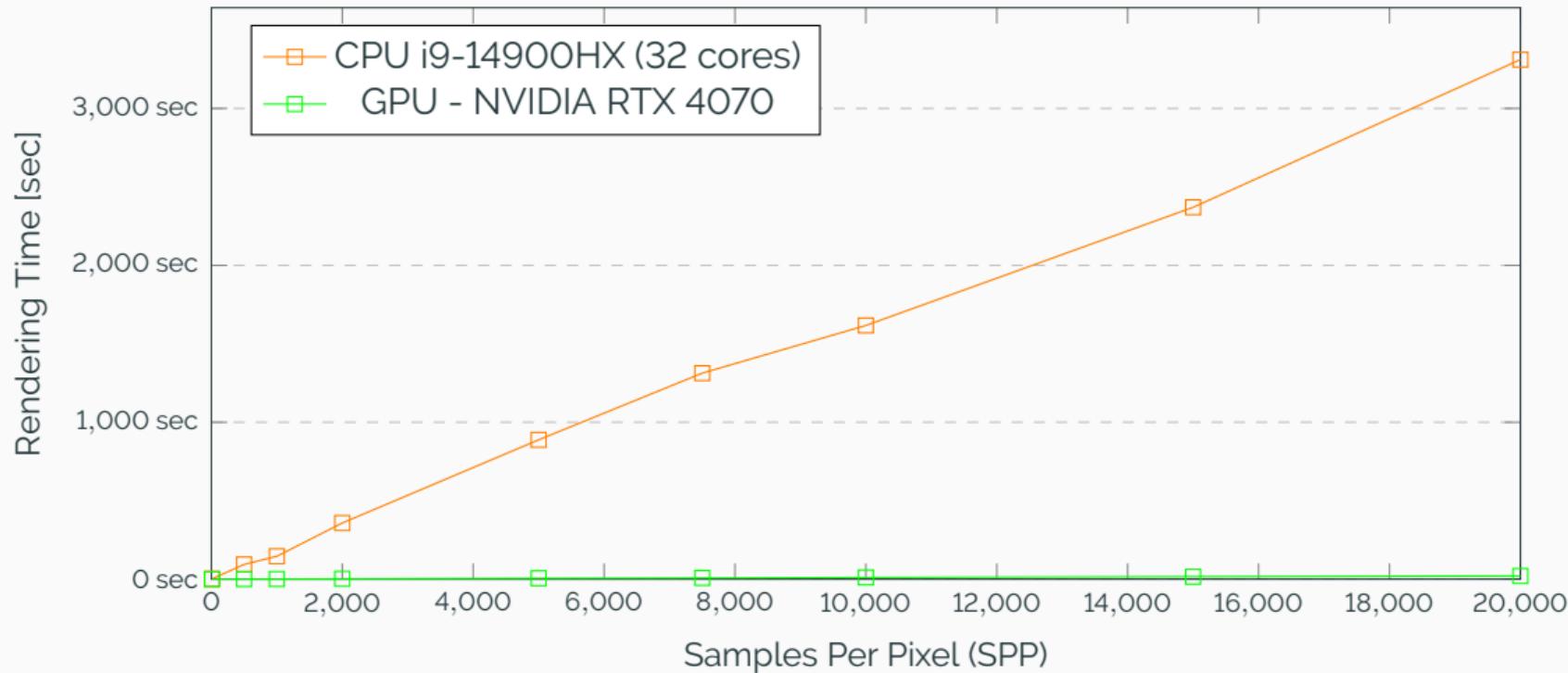




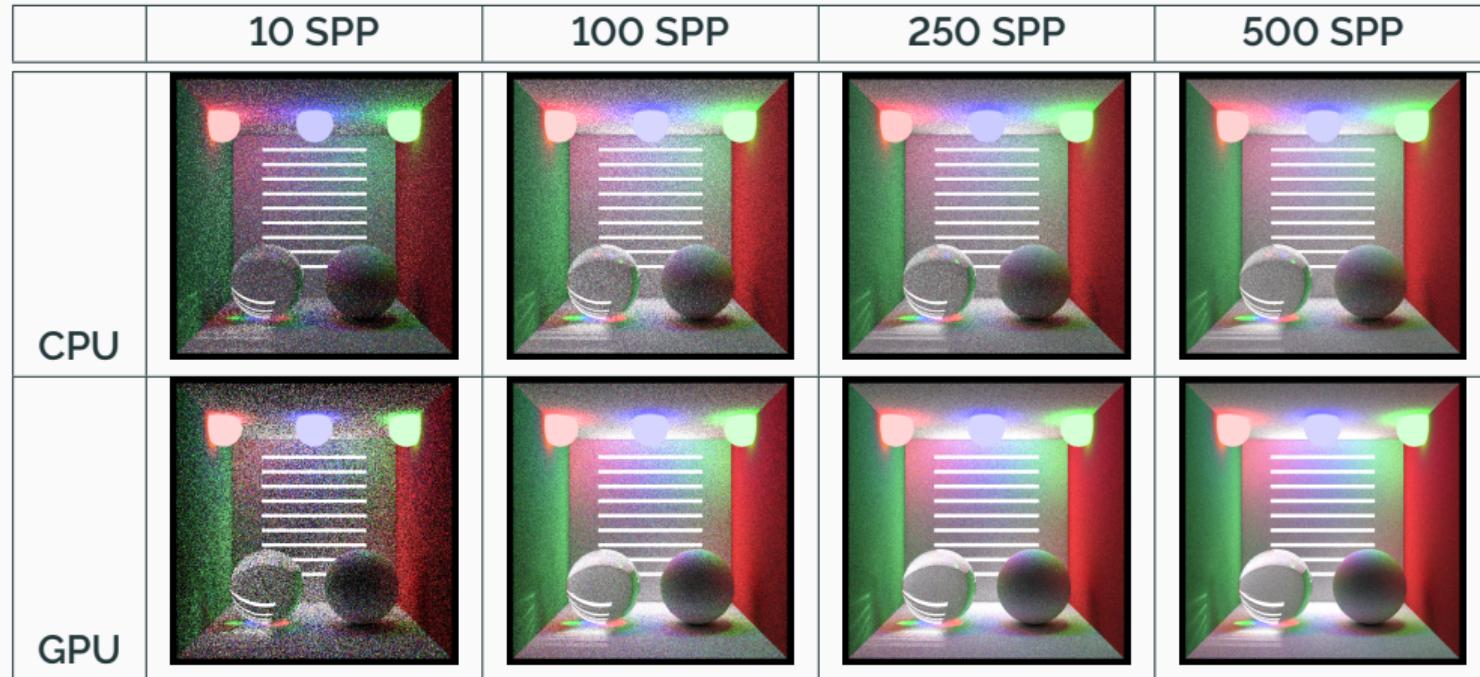
On the test scene (Cornell Box with multiple light sources) we can see Caustics effect, coloured shadows and refraction in the right places. The GPU implementation matches the CPU implementation visually.



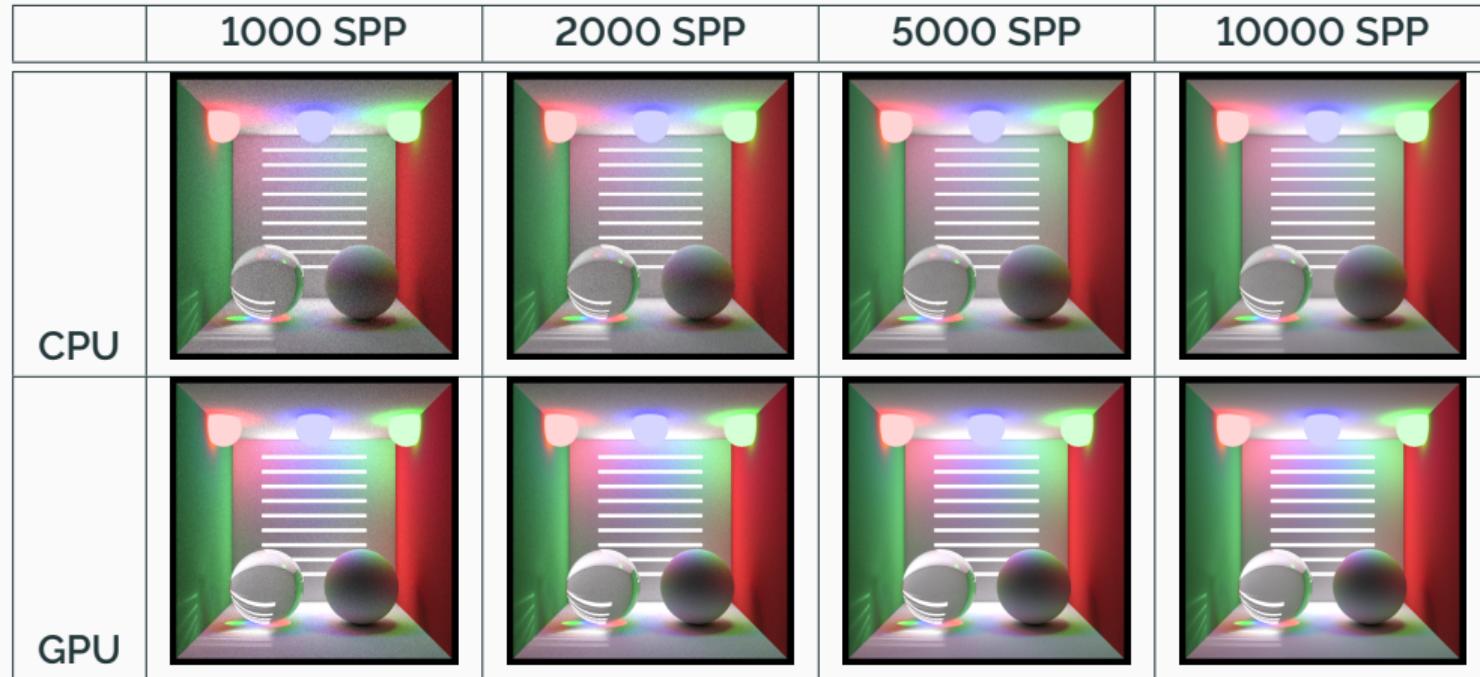




The immediate drop in rendering time on the GPU. The rendering time is still linear.



The quality of the ray traced images rendered by CPU and GPU (part 1). SPP - Samples Per Pixel.



The quality of the ray traced images rendered by CPU and GPU (part 2). SPP - Samples Per Pixel.

DEMO

<https://www.youtube.com/watch?v=koZc1S7LPkQ>

Time to implement light sampling on the GPU. We need to make the following improvements:

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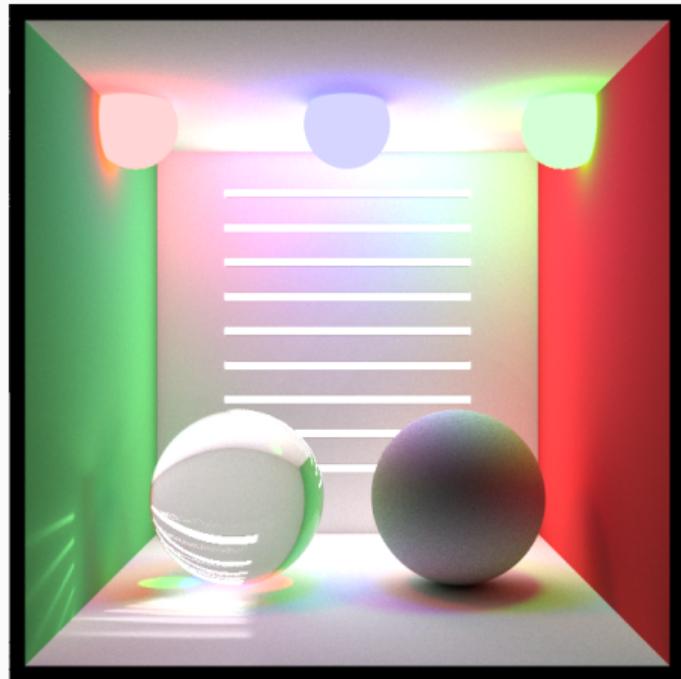
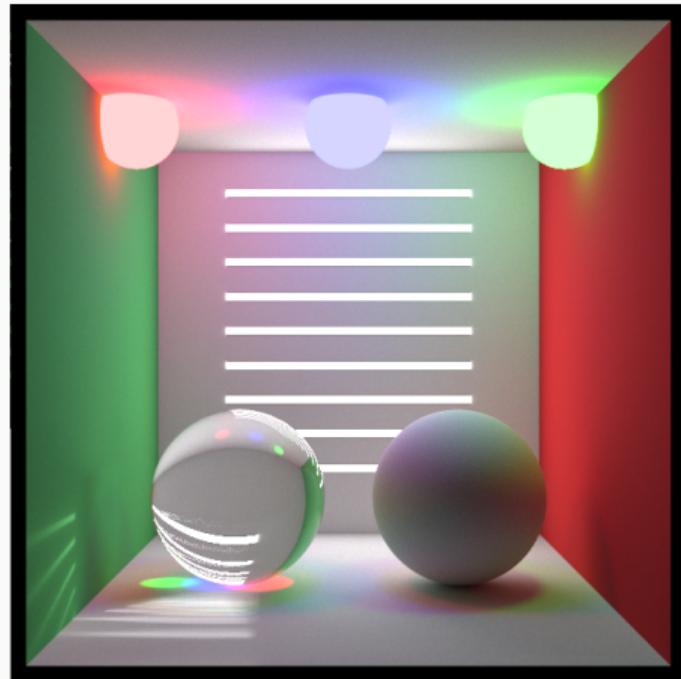
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- Change **Ray Generation** shader to process PDF values from the scattering functions and geometries.
- Improve **Close Hit** shaders, for procedural and triangle meshes, to calculate the PDF value for a specific emitting light source.

LIGHT SAMPLING ON GPU RESULTS

LIGHT SAMPLING ON GPU

Random scattering on a hemisphere without PDF scattering (left) and with PDF scattering (right).



- We created two independent software systems for testing various Ray-Tracing technologies on CPU and GPU.
- The Ray-Tracing framework on the GPU is significantly faster than the CPU version.
- The image quality is comparable between the CPU and GPU versions. The main requirement: implement similar pixel sampling algorithms.
- Ray-Tracing on the GPU is already a mature technology, and it is possible to achieve real-time Ray-Tracing with the algorithmic improvements.

The source code of the Ray-Tracing frameworks on CPU and GPU and all supplementary materials are available on the public GitHub repository and published under the Open Source MIT License at the following URLs:

- <https://github.com/d-k-ivanov/ray-tracing>

In case of any issues or questions, the author can be contacted via emails **d.k.ivanov (at) live.com** or **divanov (at) correo.ugr.es**.

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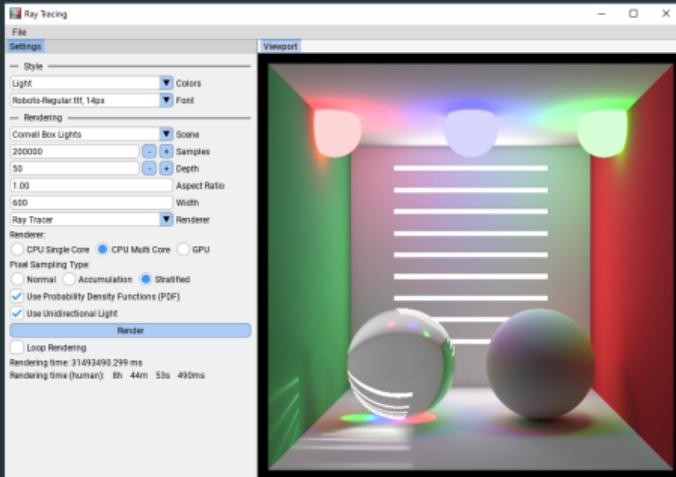
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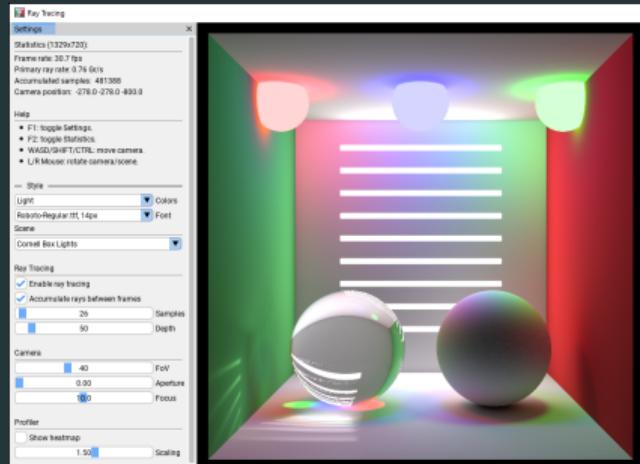
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- Add Material Definition Language (MDL) support and concepts from Physically Based Rendering (PBR).

QUESTIONS?



Ray-Tracing on CPU.



Ray-Tracing on GPU.