International Journal of Research in Circuits, Devices and Systems

E-ISSN: 2708-454X
P-ISSN: 2708-4531
IJRCDS 2022; 3(2): 86-90

www.circuitsjournal.com
Received: 13-04-2022
Accepted: 17-05-2022

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Real time ray tracing in modern 3D video games

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Abstract
Ray Tracing is a technology which simulates lighting that closely matches that of the real world. It makes frames more natural and adds an effect of realism. Most of the 3D Video games of the past decade used digital techniques to provide shadows, reflections, and depth perception, however even though they might do sufficiently good enough it is still not going to be perfect. Unlike rasterization which primarily relies on pixel processing and interaction of distinct colors of the various polygons, Ray Tracing tracks the beam of light rays from the origin to where it bounces off another surface and that ray is bounced off of another surface thus the number of rays in the frame increases. This makes Ray Tracing extremely intensive and performance demanding as many numbers of highly intensive frames have to be rendered in a truly short span of time. Since it tracks the beam of light, it provides the perfect simulation for the future of the 3D video gaming industry. Now that there are finally sufficient hardware resources that can run this technology without any bottlenecks, many upcoming game titles are adding ray tracing support to their titles and even the modern game engines like UE 5, Unity are adding compatibility for this technology. This goes to say that Ray Tracing is definitely here to say.

Keywords: Real time ray tracing, global illumination, lighting in gaming

1. Introduction
Ray-Tracing has been the dream for graphic designers. It is the only technology available in the market which can offer a sense of photorealism which rasterization cannot reach. But the true hurdle was more on the hardware side. Since the properties of millions of light rays have to be taken into account as light bounces off of surfaces in reality. To create a similar effect in 3D graphics the light rays are actually traced by the GPU and the image is displayed based on how the light bounces off the 3D surfaces. This is truly a revolutionary piece of technology in the field of graphic 3D lighting. In this article we will discuss about the Ray Tracing APIs (Application Programming Interface), Ray Tracing, The Nvidia RTX architecture and applications/engines supporting this technology and even modern 3D video games implementation of this technology [4].

1.1 What is Ray Tracing
It is technological advancement in the field of 3D lighting and rendering illumination in a simulated graphic environment. It uses the physics of light's refraction and reflection properties and traces the light considering all these factors into account and estimates the trajectory and properties of the following light ray [3, 4].

1.2 Scope
This study on Real Time Ray Tracing in Modern 3D Video Games aims to go into the details of why ray tracing is essential for the future of 3D graphics, the way it is revolutionizing the modern 3D graphics industry and how it is being beneficial to video games, advancements in video game industry using real time ray tracing and what it means for the future in the 3D graphics lighting in video games, how it is implemented using the latest modern hardware and how modern software are adding compatibility for this new cutting edge technological advancement in video games, its merits and hurdles and finally its potential in the years to come.

2. History of Ray Tracing
The phenomenon of Ray Tracing was first introduced by Albrecht Dürer (1471–1528) in 1525 [8].

Then Arthur Appel in 1968 then used this concept and was able to predict whether the light would create a shadow [9]. Then in 1971, Goldstein and Nagel were able to create shaded images of some objects by applying the idea of photographic in reverse [10]. This slowly paved the way for Turner Whitted to finally demonstrate the idea of light bouncing back off of surfaces due to refraction and reflection [11]. This inspired many graphic designers to finally push Ray Tracing limits to what it is today.

How does Ray Tracing Work?

Ray Tracing in current generation 3D video games make use of extremely fast (GPUs) Graphical Processing Units to actually simulate the effect of actual global illumination and interaction of light with other surfaces considering the refraction and reflective properties of light.

When a light ray is emitted from a source it goes it goes on its trajectory until it encounters another surface where it gets reflected and then the reflected ray goes on until it encounters another surface, thereby increasing the number of light rays in 3D graphic environment constantly. These light rays have to be rendered real time in video games unlike movies where there is plenty of time for rendering particular scenes and which is where the technology was first used mainstream whereas in video games everything has to be done in real time [5].

This requires simultaneous calculation of the reflected light rays, their strength, the surfaces in the 3D graphical plane and how it interacts and the strength of the reflected ray but this can be done with modern processors as they have extremely fast computational performance. The main hurdle, however, is the graphical simulation and rendering since there are millions of light rays in a single frame. And moreover, Ray tracing requires excessive amounts of extremely fast memory to store the 3D graphic environment frames, this is done using the GDDR6 SDRAM (Graphics Double Data Rate 6 Synchronous Dynamic Random-Access Memory) video memory which has bandwidth speeds of up to 16 Giga bytes per second [6].

3. Real Time Ray Tracing in Nvidia GPUs

The main intensive work in any sort of Ray Tracing is the computation and calculation of intersection. Every Ray of light which is cast from the camera (minimum one is mandatory for each pixel of every frame and the number increases if there are other optics simulated in the same 3D graphic environment).

First and foremost, the Ray Tracing software needs to calculate whether the object and rays from the light source intersects. If it intersects then light rays are cast from that object which was intersected, this cycle continues until the light ray which originated completely leaves the 3D graphic plane (its value and intensity are also modified based on other lighting conditions) or if it reaches and intersects with an extremely powerful light source. The concept of denoising does reduce the total number of light rays in the graphic frame, still the number is enormously huge [22].

The way Nvidia has overcome this challenge is thanks to their development of RT (Ray Tracing) Cores as a subproduct of their Turing Architecture. They are dedicated for Ray Tracing and tasked with improving ray tracing performance greatly

by increasing the compute performances for the 3D objects which are stored in BVH (Bounding Volume Hierarchy), which is a common data type for the storage of objects in ray tracers [22].

4. What is BVH Traversal and how it is used in Ray Tracing

Bounding Volume Hierarchy is an extremely common ray tracing acceleration technique which utilizes tree-based architecture which contains multiple bounding volumes (objects) that are arranged based on hierarchy where each encompasses a set of 3D objects, each form the leaf nodes of the BVH tree. Similarly, the smaller objects and merged together as a larger set and the process goes on recursively [23].

Checking every ray against each and every intersection in the 3D frame is not efficient, it also has high computational cost and the key to solve it using Bounding Volume Hierarchy which greatly improves efficiency and performance [24]. The BVH is assembled in various types of tree architecture such that each light ray needs to be checked with the Bounding Volume Hierarchy using DFS (Depth First Search) algorithm for traversing through the tree created instead of using the primitive brute force approach of checking every ray with every other ray. Before the initialization of any 3D frame, a structure known as the Bounding Volume Hierarchy Building is to be instantiated using the source data. The following 3D frame will be constructed based on a new Bounding Volume Hierarchy Building or a modified version of the previous BVH building based on the current 3D graphic scenario [24].

5. Hardware and Software Technologies for Ray Tracing

Initially the compute performances of graphical processing 3D graphical rendering of frames were obtained by using CUDA (which is Compute Unified Device Architecture) cores and programmable shader cores [12, 13].

But in modern generational video cards compute performance in ray tracing is obtained using Nvidia Ray Tracing Cores. Ray Tracing Cores. Ray Tracing core follows the model of ASIC (Application-Specific Integrated Circuit). Ray Tracing cores have additional extra circuits to the CUDA common purposes of pipelined rendering of 3D graphic frames to be used when Ray Tracing Computation comes up [14]. Another development in the field of 3D graphical computations is the Tensor Cores used in latest RTX video cards by Nvidia. Tensor Cores help in Artificial Intelligence and Machine learning related computations [12]. Modern GPUs supporting this technology include RTX 2000 series and the RTX 3000 series and the titan RTX series.

5.1 Hardware used by Nvidia Latest RTX Cards breakdown

- **CUDA**

  CUDA (Compute Unified Device Architecture) acts as a parallel computational platform and at the same time works as an API (Application Programming Interface). Nvidia's main purpose behind designing these CUDA cores was to enable developers to maintain physical resources [26]. Developers C / C++ now have much better access to the resource allocation. The Compute Unified Device Architecture has also supplemented the growth of frameworks like Open ACC (Open Accelerators) which a programming standard for parallel computing & OpenCL (Open

Computing Language) is a low-level Application Programming Interface for heterogeneous computing. They are similar to the parallel processors which are used in CPU manufacturing but in this case, there are more than thousands of CUDA cores [24, 25, 26].

- **RT Cores**
  RT (Ray Tracing Cores) are dedicated hardware components developed by Nvidia for simulating the Real Time Ray Tracing in video games and to handle the intensive computations pertaining to it. Developing dedicated hardware for a specialized task reduces a lot of computational work from the traditional CUDA cores which perform most of the basic computations for video games as described above. The Ray Tracing cores give up the versatility that the CUDA cores possess for much higher raw Bounding Volume Hierarchy traversal calculation and packet tracings for rays. The main task of the RT cores is to greatly improve efficiency and speed in tasks specific to Ray Tracing [27].

- **Tensor Cores**
  Tensor Cores provide Dynamically Adapting Calculation and mixed-precision computing vastly improving throughput but can maintain high accuracy at the same time. It provides an Enhanced AI Inference and an advanced HPC (High Performance Computing) to greatly improve performance in NLP and AI and helps solve advanced computations. It is the hardware component entitled with providing DLSS (Deep Learning Super Sampling) and denoising which greatly reduces the downsides of Real Time Ray Tracing [28].

5.2 Software Supporting Ray Tracing Technologies: APIs

Microsoft along with partnership with Nvidia introduced DirectX Raytracing API (Application Programming Interface) which has added Ray Tracing Support to DirectX 12. DirectX Raytracing (DXR) also has the added benefit of complete integration with traditional techniques like rasterization [4]. Even Vulkan API (Application Programming Interface) introduced Vulkan Ray (VK Ray) which supports the following Nvidia Software Development Kits (SDKs) which includes RTX Global Illumination (RTXGI) Direct Illumination (RTXDI), RTX Memory Utility (RTXMU) and NVIDIA Real-Time Denoisers (NRD) [16].

3D Game Engines

Unreal Engine 4 extends support to NVIDIA technologies such as RTX Global Illumination (RTXGI) Direct Illumination (RTXDI), Deep Learning Super Sampling (DLSS), and more Software Development Kits (SDKs) for rapid integration with Ray Tracing into the Unreal Engine 4 development cycle [4]. Ray Tracing can be enabled in Unity projects using the High Definition Render Pipeline (HDRP) which is a high-fidelity Scriptable Render Pipeline built by Unity to target modern (Compute Shader compatible) platforms can be used with just a couple of clicks, alongside native DLSS integration which was added to unity in Q3 2021 [17].

Ray Tracing Quality and Performance:

The following Images were taken in the AAA game Cyberpunk 2077 from my system which is running on RTX 3060.The screenshot on the left (Figure 1) was taken with RTX set to ultra and we can clearly see how the light rays behave with water in the floor below which adds a depth of photorealism and the subtle neon lighting in the vending machines cannot be recreated in case of rasterization which is used in the image on the right (Figure 2). However, there is a very noticeable performance. Quality set to ultra in all four test cases

Table 1: FPS - Frames Per Second (Higher is Better)

RTX on 1080p DLSS off	RTX Off 1080p DLSS Off	RTX On1080p DLSS On	RTX ON1080p DLSS Off
26 fps	55fps	42fps	72 fps

Images and benchmark taken in Cyberpunk 2077 from a system using

Graphics Card: GeForce RTX™ 3060 GAMING OC 12G (Factory Overclocked to 1837MHz)

Processor: Intel Core i5 10400F(base)

Memory: 16GB DDR4 (clocked at 3000MhZ)

Fig 1: Pictorial representation with RTX set to ultra-images

Fig 2: Pictorial representation with RTX set to ultra-images in clear form

6. How it impacts the Global Video Graphics Card Market?

Currently Ray Tracing in 3D graphics and Video games is becoming a crucial aspect and an essential element in the field of lighting. It is estimated that there are 1.75 billion PC Gamers worldwide in 2020 which is rapid growth from the year 2008 when there were only 1.09 billion [18]. Whilst considering this enormous number of users, it can be stated that the global market for this industry is also steadily increasing and studies show that there were at least 101 million units sold in the third quarter of 2021, and also estimation states that there will be over 3000 million units by the end of 2025, this paves the way for competition between video card manufacturers and adopting latest technologies which are available in the market and adopting them in their products. And Ray Tracing which is adopted by Nvidia in their RTX series of GPUs helped them get their massive market share they have today with over 80% market share compared to AMDs mere 20% market share. Even though the GPUs themselves have similar performance in basic 3D visual rendering, Nvidia's Ray Tracing technology in their GPUs gives them the advantage and helped them get the market lead they have today [19].

6.1 Why is it welcomed by the PC Gaming Community?

Most PC Gamers nowadays are looking for real life alike graphics in video games. One of the issues of video games of the past was they could not recreate the light sources and global shadows, ambient occlusion, reflections as life like. And the key solution to these issues is Real Time Ray Tracing which significantly improves the overall quality of graphics and provides realistic lighting in all conditions mimicking the actual nature of light rays. Hence the entire PC Gaming Community is much more inclined towards support of Real Time Ray Tracing in video games.

6.2 Hurdles Faced

Even though with all this Processor Compute power the processors are currently bottlenecked by the lack of powerful GPU's (Graphical Processing Units) is being the main hurdle in the field of Real Time Ray Tracing. As tracing millions of light rays takes a huge hit on performance as seen in above (Table 1). Another huge factor is the cost of these video cards, the Nvidia RTX ones, which starts at 350 USD and goes up to 1500 USD for the top end variants. But over time video card manufacturers aim to lower costs [20].

6.3 Solutions to overcome hurdles

Since Real Time Ray Tracing takes a huge hit on performance, for people using high native resolutions, Nvidia has adopted a new feature called DLSS (Deep Learning Super Sampling), it works by upscaling a low-resolution suck as 1080p and uses AI (Artificial Intelligence) [23] using the tensor cores which also improves HPC (High Performance Computing) present in the RTX line of video cards [21]. DLSS also provides a 65% boost in FPS as noticed above (Table 1)

7. Future Potential in Video Games

Real Time Ray Tracing definitely has brilliant potential in the years to come. As the only downside of Real Time Ray Tracing is the cost to implement and the performance drawbacks, as hardware components get progressively better and better, there will be a time when hardware performance will catch up to the game engines extensive graphic environments. Once that time comes, Real Time Ray Tracing will have a leading role in the 3D graphic lighting scenarios. Therefore, Real Time Ray Tracing in Modern 3D Video games is definitely here to stay. Also, with respect to the role of Artificial intelligence in gaming and it effects on youths (Including raised issues and challanges) can be found in [29-42].

8. Conclusion

Thus, Real Time Ray Tracing in modern video games is analyzed and examined over its benefits over rasterization and its use of latest hardware to provide the results and modern software adopting this technology with customers also welcoming this technology can be seen as definitely be seen as green light for this technological advancement and also a win for the gaming community, even though currently the technology is considered expensive as technology progresses, costs will be cut down and made more efficient, in the future it will be a crucial aspect of any 3D graphic frame.

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