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An Investigation of How Lighting and Rendering Technology Affects Filmmaking Relative to Arnold's Transition to a GPU-Based Path-Tracer

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Abstract

Computer Graphic (CGI) technology enables artists to explore a broad spectrum of approaches and styles, from photorealistic to abstract, expanding the boundaries of traditional aesthetic choices.

Recent years have witnessed of 3D-CGI production shift towards greater physical fidelity driven by technological developments as well as consumer demand for realistic visuals; this trend can be found across various creative fields like film, video games, and virtual reality experiences with high-quality textures, lighting, rendering, and physics simulations providing enhanced levels of immersion for users.

Arnold is one of the famous rendering engines assisting artists to be more creative while producing photorealistic images. Moreover, Arnold renders the engine as one of the main path-tracing renderers and contributes significantly to more fantastic photorealistic productions. Also, Arnold renders not only Support CPU render but also support GPU rendering to take full advantage of faster computation times and real-time interactivity, among many other advantages. Because of that, this study investigates how new technology like developed GPUs helps artists and filmmakers better comprehend 3D rendering solutions that impact their workflows.

On the other hand, philosophically exploring the relationship between making a creative decision and technology within 3D photorealistic rendering reveals an intricate yet dynamic relationship that informs the creative processes of both independent artists

and small studios alike. This interaction serves as a reminder that Art is driven forward by its creator's creative energy rather than simply technological capabilities; artists and studios can continue pushing limits by embracing this complex dialogue between creativity and tech, opening new paths within digital Art's fast-evolving realm.

Introduction

Individual 3D Artists and small animation and VFX studios that produce digital art face a delicate balance between artistic choices and technological development in this rapidly shifting realm of digital art. At the core of this dance lies GPU and CPU rendering technology's effect on creative methods and results in 3D photorealistic rendering, significantly affecting artistic methodologies and developments in 3D photorealism. Also, deciding between GPU and CPU rendering for freelancers and small studios is more than technological; it raises philosophical questions regarding how technology affects the artistic process and what constitutes art itself.

Additionally, this decision has lasting ramifications on democratizing art and making high-end 3D-CGI (three-dimensional computer graphics) products available to more people.

Freelance Artists and small studios can leverage technological innovations to produce increasingly intricate yet visually attractive work on tight budgets, encouraging more diversity within the arts.

Small art Studio or freelancer artists can tap the power of GPUs to enhance creative processes, increase productivity, and remain competitive by taking advantage of them in different ways. Here is how a GPU could work to the benefit for their:

Firstly, GPU rendering can dramatically shorten rendering times for high-quality images or animations, giving artists more time to iterate quickly on projects for improved outcomes and more work produced.

Secondly, Real-time visualization allows artists to observe results quickly and make more effective decisions, especially on game engines like Unity or Unreal Engine. GPU rendering may also play an integral part.

Thirdly, Cost-Effectiveness For small companies and freelancers alike, GPU rendering offers far lower costs than CPU render farms; furthermore, they can test render images before spending much money and waiting overnight to see the result.

Fourthly, GPU technology enables small art businesses to enhance their creative processes, boost efficiency and remain competitive within their industries, ultimately helping them fulfill their dreams while expanding their businesses.

On the other hand, the CPU offers similar quality at higher performance for industry visual standards and has shown promising results with subsurface scattering (SSS), particularly human skin and caustics, where GPU currently cannot fully support such shaders. Due to their vastly differing capabilities, GPU and CPU render present producers and directors with difficulty choosing which engine best meets their product and budget requirements - especially for small businesses and freelancers with tight budgets.

In conclusion, this research helps artists make better decisions in choosing a CPU and GPU, rendering benefits for small businesses, and saving money and budget to select a bet to affect the audience significantly.

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Background of study

Overview of Photorealistic (Photorealism, or Photorealistic 3D images) and narrative.

Photorealistic 3D Rendering is a computational graphics methodology that endeavors to generate imagery strikingly resembling real-world photographs (Cardoso, J. 2013).

There are various existing visual styles in which CG render engines can render. Specific projects necessitate photorealistic depictions that can be easily confused with actual photographs, whereas other projects are stylized in distinct manners or intended to generate more illustrated or cartoonish appearances. According to Birn (2013), the credibility of the lighting in your work must be convincing to the viewers, regardless of whether you choose a photorealistic visual style.

On the other hand, narrative refers to the storytelling aspect of visual art. It is how artists, animators, and filmmakers convey a story or message through optical elements such as characters, environments, and actions. A strong narrative can evoke emotions and engage the audience, regardless of the level of photorealism. (Abbott, 2008).

It is framing these not just as technical attributes but things that can affect a narrative and aesthetics that impress and convey meaning for a human audience.

Photorealistic Techniques 3D Rendering

Various techniques and algorithms are employed to create photorealistic 3D renderings. Some of the most widely used methods include:

Ray Tracing

By tracking a light source's path through a scene and computing the interactions between light beams and objects, a computer technique known as ray tracing imitates the behavior of light. This method produces accurate reflections, refractions, and shadows, making realistic visual representations. However, ray tracing may not be the best choice for real-time applications because of its high processing cost. Shirley and Morley (2008) state that.

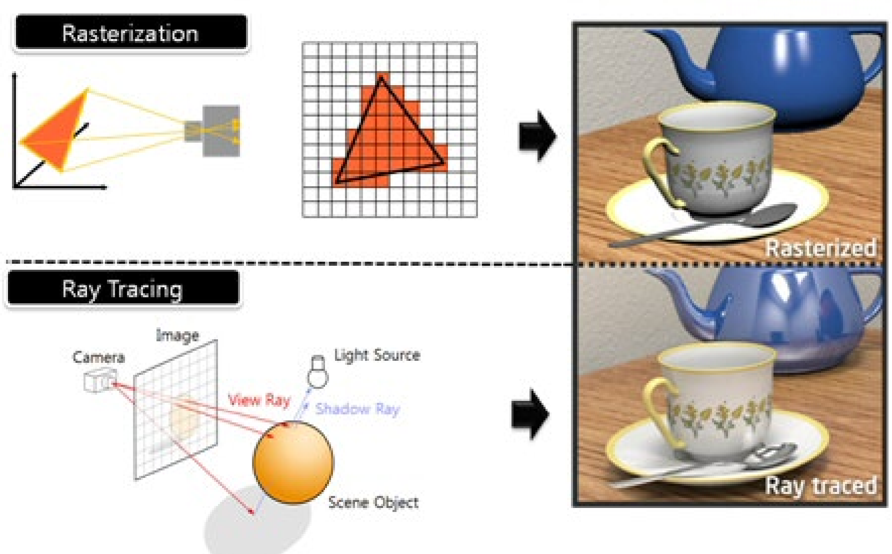


Figure 1.1: Ray tracing vs Path tracing, credit: pixelsham.com)

Rasterization

Rasterization is a quick and less intensive computational method that converts 3D designs to 2D photographs by mapping polygon vertices onto an array of pixels in two-dimensional space. Although it does not provide realistic results as ray tracing, it is also widely utilized for real-time applications like video gaming (Akenine-Moller Haines & Hoffman 2018).

Global Illumination

Global illumination algorithms simulate how light interacts with objects and bounces around a scene, producing more realistic lighting and shading effects. Standard Global illumination methods include radiosity and photon mapping. (Bekaert, Bala, & Dutre, 2018)

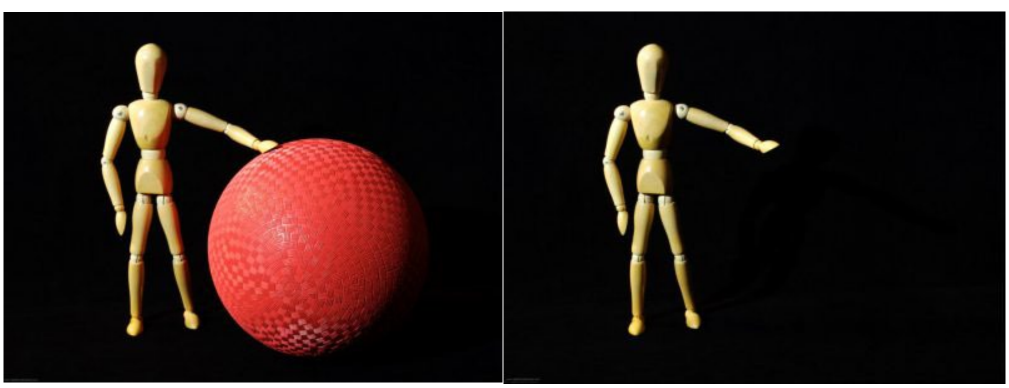
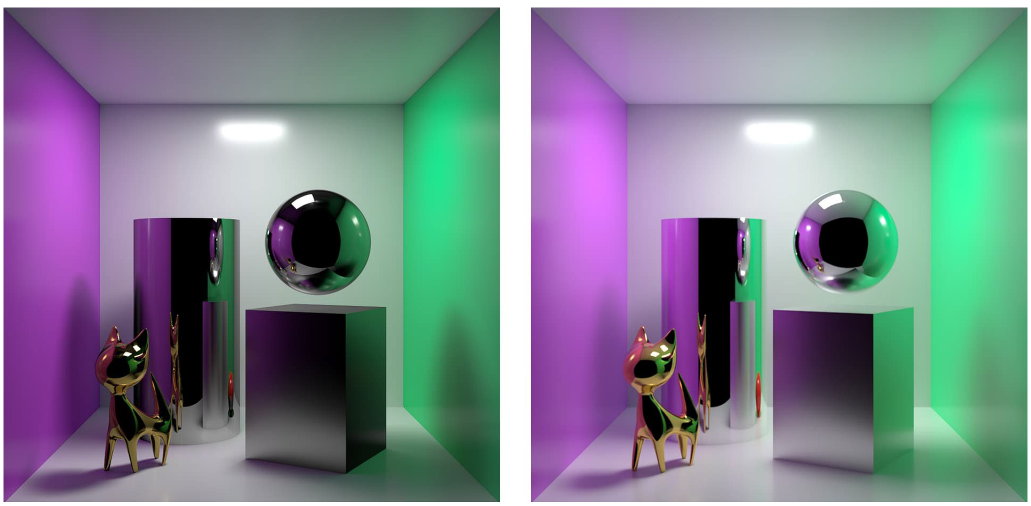


Figure 1.2: Real image for global Illumination, Source: https://www.fxguide.com/fxfeatured/the-art-of-rendering/?highlight=Arnold, Note red flowing into the figure's shadows.

“What is Path Tracing”

Path tracing is a more advanced rendering technique combining ray tracing elements and global illumination. It simulates the random paths of light rays in a scene, resulting in highly realistic images with accurate lighting, shadows, and reflections. However, path tracing can be computationally demanding and require powerful hardware or cloud-based rendering solutions. (Pharr, Jakob, & Humphreys, 2016)



Ray Tracing **Path Tracing**

Figure 3.1: Ray tracing and path tracing comparison image, Source: (https://forums.unrealengine.com /t/ray-traced-reflection-brightness-compared-to-path-tracing/509942)

skin qualities from sub-surface scattering

Sub-surface scattering (SSS) is essential to creating lifelike depictions of skin textures and visual characteristics within computer graphics. This phenomenon involves the optical behavior of translucent substances such as skin. Jensen, Marschner, Levoy & Hanrahan (2001).

Light can penetrate surfaces before scattering within material structures before emerging at various points, as Jensen et al. (2001) described. Sub Surface -Scattering (SSS) is the effect that creates visually pleasing, scattered skin surfaces - an attribute that plays an essential part in creating photorealistic three-dimensional depictions of people or other living beings.

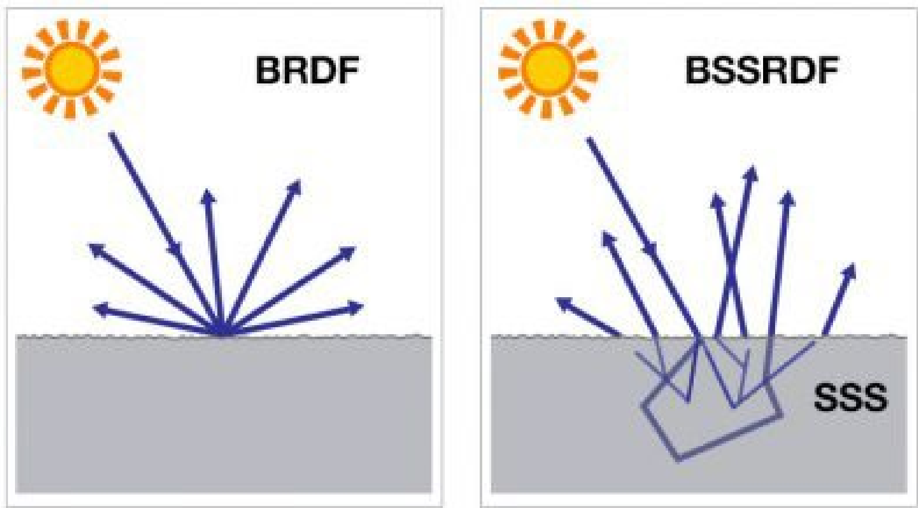


Figure 1.3: “BRDF” vs. “BSSRDF”, (Source: https://en.wikipedia.org/wiki/Bidirectional_scattering_distribution_function)

Scholars have recently developed methodologies and frameworks that accurately simulate subterranean diffusion within computer-generated imagery. BSSRDF (Bidirectional Surface Scattering Reflectance Distribution Function) is an industry-standard model which captures both inbound and outbound light at surfaces, thus accurately representing their light behavior within translucent materials (Donner & Jensen, 2005).

Figure 1.4: (BRDF and BSSRDF on the skin shader, Source:

https://cs184.eecs.berkeley.edu/sp20/lecture/15-71/advanced-topics-in-material-mode)

Subsurface Scattering (SSS) rendering algorithms have significantly boosted the aesthetic appeal of skin in various digital media, such as films and video games, leading to more engaging virtual experiences, according to Jimenez and Scopigno (2019).

Transmission

Transmission refers to light passing through transparent or semitransparent materials like water and glass. Its exact replication is essential to creating photorealistic renderings of scenes incorporating translucent objects or elements (Pharr, Jakob & Humphreys 2016).

Figure 1.5: Transmission shader sample photo, (Source:

https://help.autodesk.com/view/ARNOL/ENU/?guid=arnold_for_katana_tutorials_ka_Shading+Glass+and

+Liquid_html)

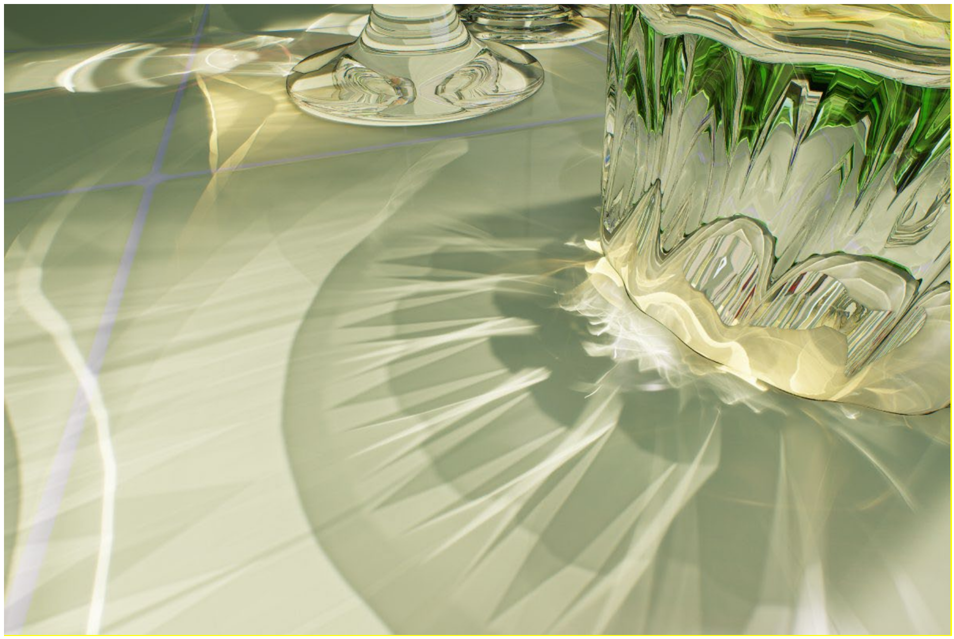


Figure 1.6: Caustics result photo,) Source: https://developer.nvidia.com/blog/generating-ray-traced-caustic-effects-in-unreal-engine-4-part-1/)

"Caustics"

Caustics in 3D rendering refers to distinct patterns of concentrated light caused by reflection and refraction from surfaces that bend light rays, such as lenses, mirrors, or water surfaces. According to Pharr, Jakob, and Humphreys (2016), intricate light patterns are essential in creating photorealistic renderings because they enhance the overall appearance and credibility of settings.

Chapter 2

Ray Tracing and Arnold Render Engine

Arnold is an increasingly popular rendering engine with a specific Ray tracing methodology, rapidly growing since Sony Pictures Image Works was first introduced. Since then, thanks to Sony Picture Image Works' efforts, more professional filmmakers and video game studios are beginning to embrace Arnold in large-scale animation and visual effects productions and feature films. (Wikipedia contributors, 2023)

However, “Uma Pictures”, “ILM”, “Digital Domain”, “Frame store”, and numerous other animation companies are taking full advantage of the Arnold system and adopting this product too! Marcos Fajardo, an immigrant from Spain living in America, created Arnold and remains its chief originator at Solid Angle Europe, based out of Europe. (Wikipedia contributors, 2023)

1997-2000 (Short Animation)

In 1997, young Fajardo, who was 24 years old, decided to develop his rendering program; therefore, the basic framework for the Arnold render engine was laid out that year.

When Fajardo was hired, “Blue Sky Studios” was the first 3D animation company to use path Tracing in every rendering project based on the Fajardo render engine. In this way,” Bunny's “short animation film benefited from using Ray tracing in 1998. (Seymour ,2012).

Figure 2.1: “Monster House”, (Sony Pictures Image works, Source: www.imdb.com)

After 8 years in 2006 “Sony Pictures Image works” released “Monster House” that is a first feature long movie, which is use Arnold render engine with developed path tracing, this movie doesn’t have a motion blur because of some Artistic decision to be similar of stop-motion animation technic. Also,” Monster House” avoids noise of sampling in the light and final render images. Moreover, they add a Depth of field on the compositing layer. (Kovashka et al., 2016)

Figure 2.2: The Blue-Sky Bunny,1998, Source: Newenglandfilm.com/magazine/1999/10/nothing-but-blue-sky-for-bunny

2001 (First Oscar by using an Arnold)

“50 Percent Grey's” short animation film was nominated for an Academy Award (Oscar) in 2001, and this is an unprecedented honor for Fajardo because Ruairi Robinson used 3D Studio Max by himself at that point while Gonzalo Rueda (one of the Fajardo’s friends) using an Arnold render engine for rendering that short animation. (Seymour,2012).

Figure 2.3: 50 Percent Grey's short animation, Source: fxguide.com)

A new revolution for artists was that they could use an Arnold to produce a 3D animation by using Ray tracing for companies with a lower rendering budget.

“Fifty percent gray” rendered with Global Illumination and Completely in Ray traced on a small company with a few computers sharing a frame rendering. Seymour (2012).

Sub-surface scattering in Arnold (2001-2009)

In 2001 Fajardo read a paper about sun surface scattering, which Henrik Wann published, and he was excited about that. He is involved with understanding the new situation because there was heavy math on that. Also, he tried to find a way to add that to Arnold as soon as he understood that the paper added that to Arnold after 30 minutes.

That was the first step: when Fajardo was hired at “Sony Pictures”, they agreed to use an Arnold renderer for “Cloudy with a Chance of Meatballs” Movie. (Seymour, 2012).

Figure 2.4:(Cloudy with a Chance of Meatballs Movie, Sony Picture

https://www.npr.org/templates/story/story.php?storyId=112635896)

2012 (Focus on Support)

In 2012, Solid Angels (Arnold Render engine Company) had sixteen employees, Also Fajardo, as the head of this Company, still needed to hire new engineers to help and work on the new projects that were coming from the companies such as Sony Pictures, “Frame store”, “Whisky tree”, “Image works”, “Luma Pictures”, “Digital Domain”, and “ILM”. (Seymour (2012).

Moreover, Arnold Renderer, as render engine involved in a few other great films, including “Thor”, “Alice in Wonderland”, “Captain America”, and “Captain America”.

Fajardo believed having excellent support for the licenses is more important than just selling without supporting the team. Because of that, he tried to work on the support of big company clients. (Seymour ,2016).

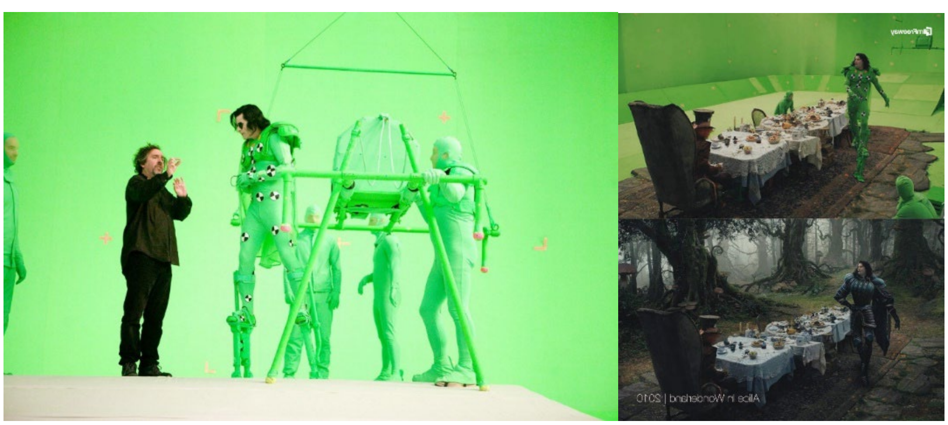


Figure 2.5: (Alice in Wonderland, https://twitter.com/FilmFreeway/status/1399802223471775745)

After 2012 (revolution of joining)

The recent year has witnessed substantial developments in CGI for the widely used and adaptable Arnold Ray Tracing Rendering engine. In 2016 Fajardo Sold Arnold to Autodesk; this acquisition by Autodesk improved Arnold's compatibility with 3D animation and modeling software from Autodesk, including Maya and 3ds Max (Seymour (2016).

The physically based shading system, improved sampling algorithms, improved rendering volume performance, and many other improvements are included in the 2017 version of Arnold 5.0 (Fleischmann, 2017).

As a result of Arnold's consistent progress, it has become a de facto industry standard for visual effects. It has been a critical contributor to the creation of films like "Gravity," "Blade Runner 2049," and "Avengers: Endgame". (Seymour, 2016)

Figure 2.6: Left (Gravity2013, Warner Bros, Source: Warnerbros.com/movies/gravity)

Chapter 3, Path tracing and Render Man

How Path Tracing began

As part of Kajiya's research from (1986), path tracing's increased precision depiction of light behavior, in this way, artistic can achieve higher visual realism in 3D-CGI; this indelible impactful statement about modern narrative techniques used across film and gaming industries since 2000.

Moreover, Path tracing allows visual effects practitioners to create virtual environments that are both authentic and immersive, as noted by Dutre et al. (2006).

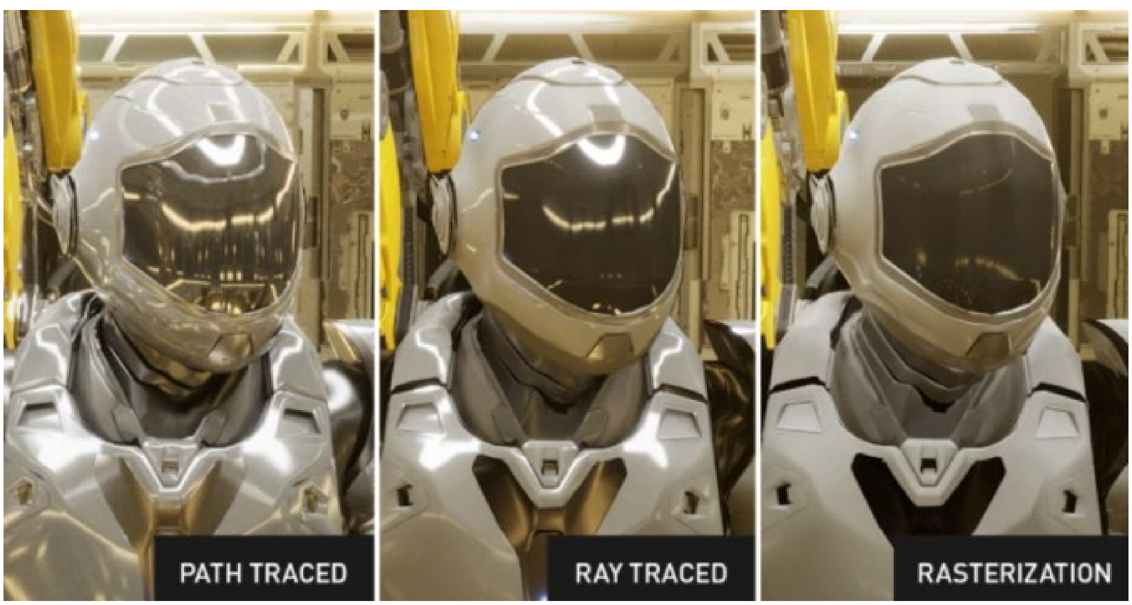


Figure 3.1: (Comparing Path tracing, Ray tracing and Rasterization, Source: https://blogs.nvidia.com/blog/2022/03/23/what-is-path-tracing/)

Path tracing has seen widespread application within film and 3d animation, as evidenced by films like Avatar (2009) and "The Jungle Book" (2016) that utilize this technique.

Path tracing provides visual effects practitioners a means of producing more natural settings with realistic creatures seamlessly integrated with live-action footage as seen with this approach, such as being employed to produce scenes like those found in Avatar 2009. (Seymour, 2012).

Film production companies use this technique effectively to create realistic environments with realistic creatures seamlessly integrated within live-action footage via path tracing techniques. In this way, they can involve an audience in the movies and make a believable story; therefore, in this way, artists can affect the film's audience, noted Dutre et al. (2006).

Render Man 1988-2000

Generally, Photorealistic RenderMan (PR Man), developed by Pixar, is now one of the best renderers available and is utilized in all the studio's big films.

In 1988, the Pixar Animation Company decided to release RenderMan Interface Specification marked as the first public appearance of Render Man. During their early 1980s work on “Star Trek II: Wrath of Khan” (1982), which included breakthrough Genesis Sequence, Loren Carpenter and Robert Cook of “Lucasfilm's” computer and graphics development division invented the REYES renderer. Moreover, the algorithm of PRMAN fundamentally uses REYES, the initial of Render Everything You Ever Saw. It also supports GI (Global Illumination) and Ray tracing in rendering. (Seymour, 2012).

Figure 3.8: (Render man Logo, Source: https://www.studiodaily.com/2014/05/pixar-revamps-renderman-offers-free-non-commercial-license/)

Since the birth of 3D-CGI and VFX, Pixar's RenderMan has been used to create breathtaking images for films including: "The Abyss", "Jurassic Park", "Terminator II", "Toy Story 3", "Wall-E", and "Cars". (Seymour, 2012).

RenderMan has worked on over 84 VFX and 23 animation movies yearly since 2001, 10 times more than ten years before. Since 1996, all Academy Awards nominees have used Pixar RenderMan to create stunning visual effects, with 47 out of 50 candidates choosing it over other programs this decade! (Seymour, 2012).

Since 1999, Pixar has received five technological Oscars, and PRMan features compositing, a new Raytracing hider, Radiosity cache storage, and realistic shading. Version 16 of hybrid renderer software allows physical rendering using solitary Ray Tracing without REYES algorithms. RenderMan now produces photon maps for global Illumination, precise environment reflection, interreflection, refraction, and colored shadows utilizing ray tracing. This work expands RenderMan's Ray Tracing capability. (Seymour, 2012).

Figure 3.2: (Wall E, Disney and Pixar film Company Source: www.pixar.com)

Figure 3.3: (Cars, Disney and Pixar film Company, Source: https://www.pixar.com/feature-films/cars)

Render Man from Monster Inc to Monster University

Pixar Animation Studios has developed, and historically movies named Monster Inc, produced in 2001, and Monster University, produced in 2013. Each of these animated movies has a massive effect on the CGI world.

Comparing both movies, especially in the 3d photorealistic subject, we find many renovations during the 12 years Pixar released these animation movies. Moreover, using the difference in rendering styles to increase the aesthetic appeal of each film is a subject that we can point to them. This study tries to understand these differences which impact visual quality.

Figure 3.4: (Pixar, Monster Inc, 2001, Source: www.pixar.com)

Monsters Inc movie in 2001 added more realistic simulations and improved visual quality (Pharr Humphreys Hanrahan and Pharr 2016). Also, Global illumination (GI) techniques such as Radiosity and Ray Tracer created realistic lighting effects and shadow effects; later, Pixar company developed using advances in rendering technology for further realistic simulations and improved visual quality (Pharr Humphreys Hanrahan and Pharr 2016).

Technology for Rendering: Technology for Rendering: Technological advancements were an integral component of both movies. Since Monsters Inc. to Monsters University, Pixar's proprietary rendering engine Render Man underwent several modifications and improvements that led to enhanced performance and better visuals (Christensen et al., 2018).

To Compare these photos below, you can find a huge difference, such as developed GI (Global Illumination), clarity of shaders, and lighting subsurface scattering.

Figure 3.5: (Mike, Pixar, Monster University, 2013, Source:www.pixar.com)

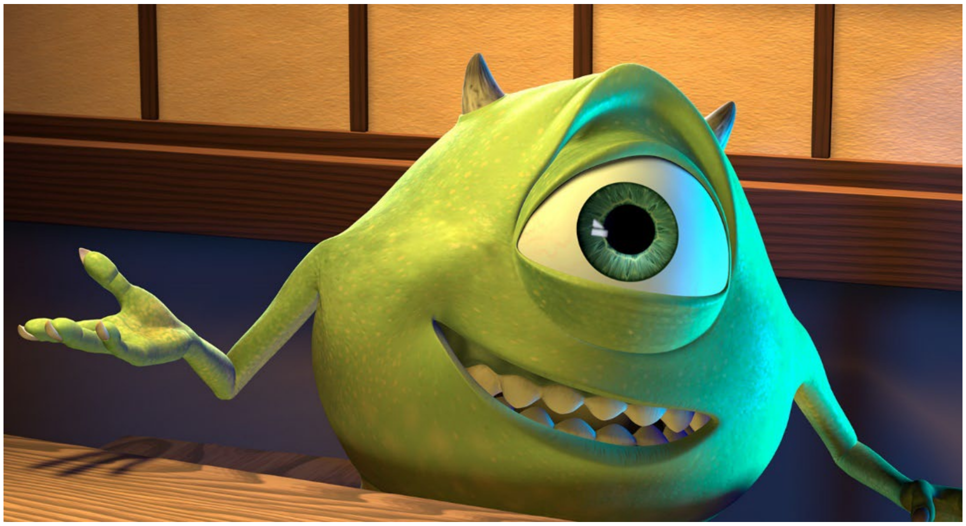


Figure 3.6: (Mike, Pixar, Monster Inc, 2001, Source: www.pixar.com)

Shading and Texturing Techniques: Pixar used Perlin noise to create lifelike shading effects and textures on characters as well as their backdrop (Perlin, 2002). Monsters University expanded upon this technique with advanced texturing methods like subsurface scattering and displacement mapping that recreate more realistic surfaces, especially skin and fur (Burley, 2012).

Figure 3.7: (Sulley, Pixar, Monster University, 2013, Source: www.pixar.com)

Figure 3.8: (Sulley, Pixar, Monster University, 2001, Source: www.pixar.com)

Character Modeling and Rigging Techniques: Monsters Inc. pioneered innovative character rigging techniques, which allowed Sulley to wear many hairs. Monsters University later took this further by employing cutting-edge simulation and rigging technology for more dynamic animation of characters (McLaughlin et al., 2011)

Figure 3.9: (Pixar, Monster University,2013, Source: www.pixar.com)

Monsters University used volumetric rendering and simulation technology to produce more realistic atmospheric and water phenomena (Stam, 2009). Meanwhile, Monsters Inc relied on particle systems and fluid dynamics simulations to produce similar realistic effects like fire and smoke.

Since the release of Monsters, Inc. and Monsters University, advances in photography-realistic rendering techniques have produced more immersive, visually pleasing films that provide audiences with an enhanced cinematic experience far beyond what was available.

Differing rendering in photorealism between "Monsters University" and its predecessor "Monsters, Inc." could be due to advances in rendering technologies, material representations, and lighting techniques during their 12-year span - modifications which contributed to greater visual accuracy and realism for "Monsters University".

Chapter 4, GPU History 1951-2010

History of GPU Rendering

GPUs (graphics processing units) have become one of the cornerstones of computer system architecture today. Their original purpose was to receive binary data from CPU and convert it to visual representations for output on displays; but now GPUs are also widely utilized for complex calculations like artificial intelligence, machine learning and big data analysis. (Wikipedia, 2021)

GPU (Graphic processing Unit) History 1951-1995

Massachusetts Institute of Technology (MIT) created the Whirlwind flying simulator for the American Navy in 1951. This creation was the first move to the future of using a GPU for modern Computers. (Hague, 2013)

Modern graphics processing units (GPUs) trace their roots in video shifters and address generators developed during mid-1970s video technology research projects, such as Arcade systems which featured graphics processing units (GPUs) with specific functionalities on their circuit boards. Also, RCA's Pixie video chip in 1976 could generate video signals with a resolution of 62x128. (Hague, 2013)

Figure 4.1: (The Namco Galaxian arcade system's graphics hardware, Source: https://en.wikipedia.org/wiki/Graphics_processing_unit#:~:text=In%201994%2C%20Sony%20used%20the,%22the%20world's%20first%20GPU%22.)

In 1981 “IBM” released personal computers that used monochrome and color display adapters (MDA/CDA); those computers' components were custom video display devices, not GPUs. (Wikipedia, 2021)

In 1983 “Intel” company produced the first “ISBX 275 Video Graphics” Controller, which was Multimodule Board was a technological breakthrough. This device could show one color at 512x512 pixels or eight colors at 256x256 pixels. (Wikipedia, 2021)

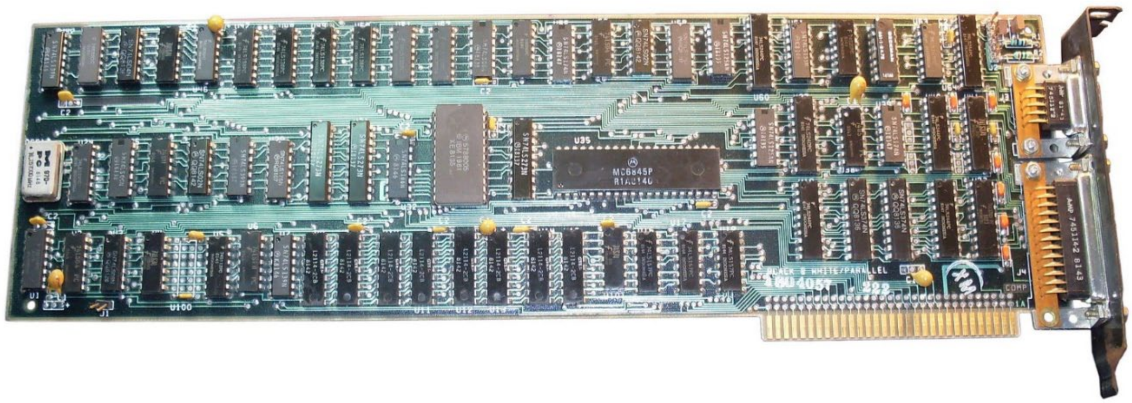


Figure 4.2: (IBM Monochrome Display Adapter,

Source:https://en.wikipedia.org/wiki/Graphics_processing_unit#:~:text=In%201994%2C%20Sony%20used%20the,%22the%20world's%20first%20GPU%22.)

One of the pioneer Company In 1985 was Array Technology Inc, founded in Canada and subsequently rebranded as ATI Technologies. The Wonder series of graphics boards and chips produced by this corporation is anticipated to maintain a significant GPU market share over a prolonged duration. (Wikipedia. (2021). ATI Technologies.)

Figure 4.3: (ATI Technologies logo,

Source:https://en.wikipedia.org/wiki/Graphics_processing_unit#:~:text=In%201994%2C%20Sony%20used%20the,%22the%20world's%20first%20GPU%22.)

In the early 1990s, a considerable number of graphics hardware companies surfaced, which later underwent either acquisition or dissolution. During this period, “NVIDIA” emerged as one of the prosperous companies. By the end of 1997, the corporation had obtained a market share of around 25% in the graphics industry.

“S3 Graphics” released the “Porsche911” inspired “S3 86C911” in 1991. The term reflects operational efficiency gains. InfoWorld, 1992. This card's success and imitators drove all major graphics card vendors to include 2D acceleration into chips by 1995. APIs improved graphic card integration in the 1990s. (InfoWorld, 1992)

Figure 4.4: (S3 Graphics in 1991,

Source:https://en.wikipedia.org/wiki/Graphics_processing_unit#:~:text=In%201994%2C%20Sony%20used%20the,%22the%20world's%20first%20GPU%22.)

Real-time Computer Graphic 1990-1997

In the 1990s, arcades, PCs, and consoles used real-time 3D graphics. This increased interest in hardware-accelerated 3D graphics. Fifth-generation consoles like the

"Nintendo 64", "PlayStation," and "Saturn," and arcade system boards like the “Sega Model 1” and “Namco System 22” introduced mass-market 3D graphics technology. (InfoWorld, 1992)

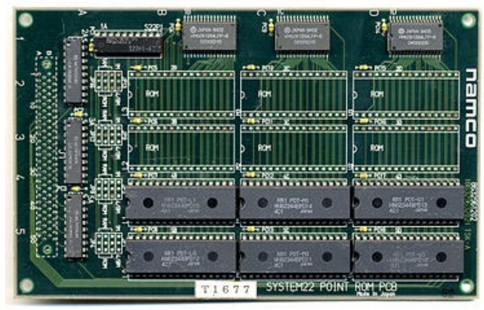


Figure 4.5: (SYSTEM22 POINT ROM PCB,

Source:https://en.wikipedia.org/wiki/Graphics_processing_unit#:~:text=In%201994%2C%20Sony%20used%20the,%22the%20world's%20first%20GPU%22.)

Fujitsu, a company that try to develop "Sega Model 2" gaming machine, tried to combine T&L and LSI into a single answer for home computers in 1995. (Vlask, undated). So, in 1997, Fujitsu made the first 3D geometry engine for desktop computers called the "Pinolite." (Fujitsu, n.d.).

GPU History 2000-2010

The GeForce 3 (also called NV20), made by "Nvidia," was the first chip with color options that could be changed. The handling of individual pixels and geometric edges has been better by using short programs that can take in more picture patterns as inputs.

The chips in the "Xbox game system" and the "PlayStation 2" were in direct competition. (Dreijer, n.d.).

Figure 4.6: (Radeon 9600 Pro, with DVI and ADC ports, Source:https://en.wikipedia.org/wiki/Graphics_processing_unit#:~:text=In%201994%2C%20Sony%20used%20the,%22the%20world's%20first%20GPU%22.)

As a result of “Nvidia GeForce 8” the creation of generic stream processing units, Graphic Process Units have become more flexible as computing machines. The use of parallel GPUs has become a potential option to CPUs for computing. This step has led to the rise of a field of study called GPU computing, also sometimes called GPGPU because it looks at general-purpose computing on GPU. (Wikipedia, 2021)

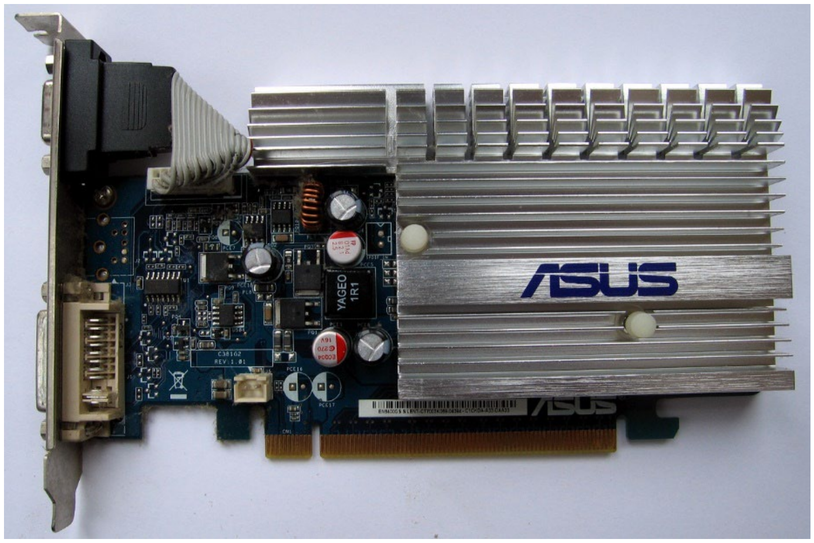


Figure 4.7: (NVidia GeForce 8400 GS "Rev 1.0" Source:

https://en.wikipedia.org/wiki/Graphics_processing_unit#:~:text=In%201994%2C%20Sony%20used%20the

,%22the%20world's%20first%20GPU%22.)

Chapter 5. Methodology

The methodology for this investigation will involve a combination of quantitative and qualitative methods. Quantitative data will be collected through measurements of rendering times, memory usage, and GPU utilization. Qualitative data will be collected through subjective evaluations of the visual quality of the renderings. The research design will involve comparing the quality of renderings produced using GPU-based rendering technology to those produced using CPU-based rendering technology.

Research Design

This research uses Arnold Maya's CPU and GPU rendering methods to explore the most effective techniques for producing high-quality 3D photorealistic renderings. The study will compare both approaches' performance, quality, and efficiency, aiming to provide valuable insights and guidelines for artists and professionals in the animation and visual effects industries helping them to improve, not only productivity but efficient ways to take creative decisions.

Research Questions

The study will address the following research questions:

What is the impact of Arnold's transition to a GPU-based path-tracer on the filmmaking process, and how does this affect the creative decisions in the pursuit of quality of lighting and rendering in films?

Tools and Software

To carry out a comprehensive study of Arnold Maya's CPU and GPU lighting and rendering methods, the following tools and software will be utilized:

Autodesk Maya 2023.2

Autodesk Maya is a leading 3D modeling,3D Animation, and rendering software used widely in the animation and visual effects industries. In this study, Autodesk Maya will be the primary platform for creating and manipulating 3D scenes, lighting setups, and materials. (Eric Keller, Todd Palamar, Anthony Honn, 2010).

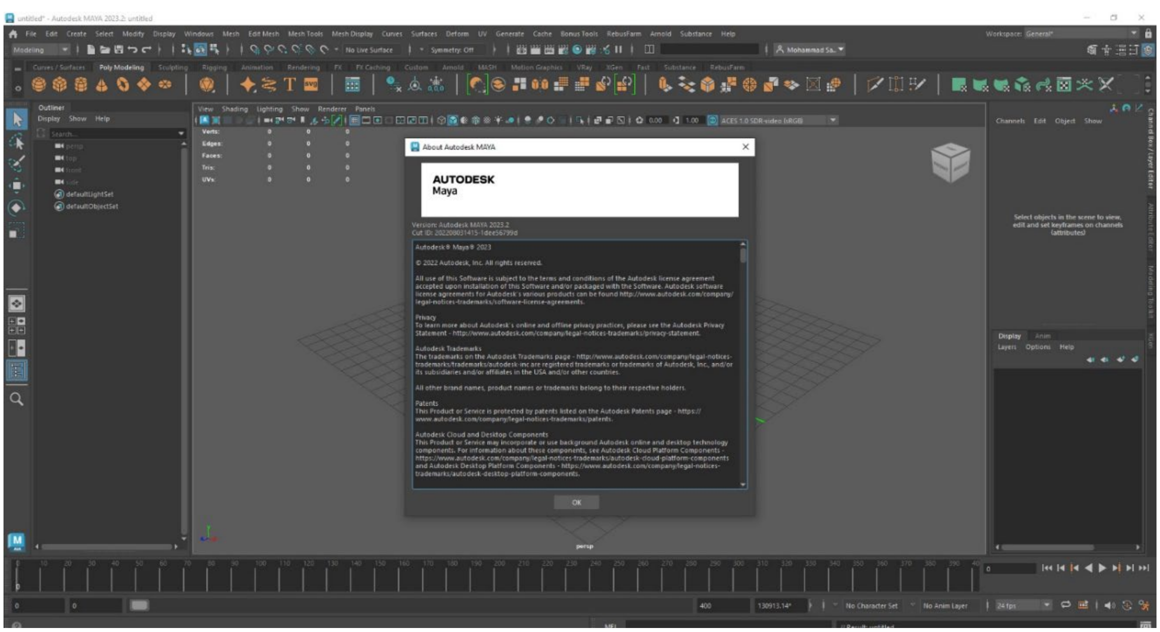


Figure 5.1: (Screen Shot MAYA 2023.2, Source: Autor,2023)

Autodesk Arnold v 7.1

Arnold Renderer is a high-quality rendering engine integrated into Autodesk Maya. The study will focus on Arnold's CPU and GPU rendering capabilities to evaluate their performance, quality, and efficiency in producing photorealistic renderings. (Murdock,2021).

NVIDIA GPUs

Implementing NVIDIA's latest RTX 40 series and 30 series graphic cards, such as the RTX 4090, RTX 3060, and RTX 3090Ti, has significantly impacted the landscape of research computing. These high-performance GPUs offer unparalleled processing power and efficiency capabilities, making them ideal for Rendering complex 3D scenes and large-scale simulations. (NVIDIA, 2022)

Figure 5.2: (NVIDIA, RTX 4090, Source:www.nvida.com)

Image Quality Assessment Tools (“MSU, VQM Tool”) v14.1

The “MSU, VQM software” is a useful tool to check the noises on the Image and Videos. This program's primary application is to analyze the image and video pixel by comparing each pixel on one or two images with the original image pixel. MSU software was used for this research to find an accurate result of noise reduction, or the amount of noise that is GPU or CPU has on the final images. (MSU Quality Measurement Tool: Basic Information, n.d.)

Chapter 6, Results

Performance Comparison

Rendering Speed

In the 3D animation and visual effects industries, rendering speed is crucial. Autodesk Arnold Render Engine, a high-quality renderer in Autodesk Maya, has long been a favorite among pros. Historically, Arnold relied on the CPU for rendering tasks, utilizing the computer's processing power for complex calculations. (Murdock, 2021).

However, since the introduction of GPU rendering, artists have seen substantial advances in rendering performance. GPU rendering leverages the parallel processing capabilities of modern graphics cards, offering faster and more efficient rendering compared to its CPU counterpart. This development has allowed artists to meet tight deadlines while optimizing their workflow without compromising quality. The book "GPU Zen 3" by Wolfgang Engel and Carsten Detacher provides insights into GPU rendering and its use in the 3D animation and visual effects industries, covering topics such as parallel processing capabilities of modern graphics cards, optimizing workflow with GPU rendering, and achieving high-quality results with real-time rendering techniques. It is a valuable resource for artists looking to use GPU rendering.

Increased number of faces

In this trial, the render time for both the CPU and GPU goes up when the number of items (face count) in the Maya scene goes up. However, GPU render times consistently remain significantly lower than CPU render times across all face counts. This demonstrates the

efficiency and performance advantage of using GPUs for rendering complex scenes, significantly as the complexity increases.

Number of Faces	CPU Render time (s) Ryzen 9 3900x	GPU Render time(s) RTX 4090
160,000	50	18
320,000	54	19
640,000	62	20
1,280,000	78	21
2,560,000	110	24
5,120,000	183	30

Table 6.1: (results of increasing number of faces, Autor)

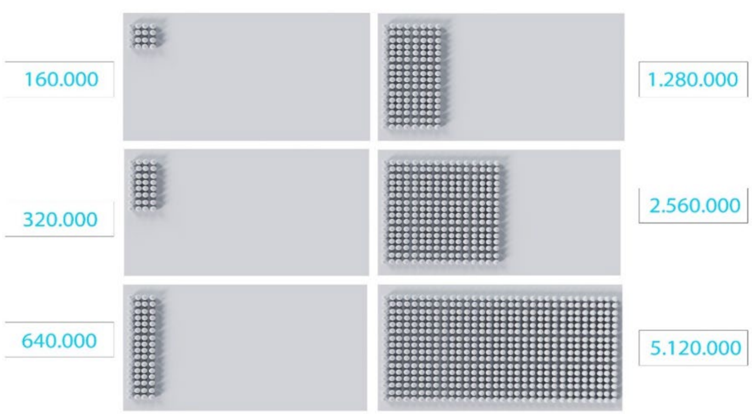


Figure 6.1: (Image rendered number of faces. Source: Autor,2023)

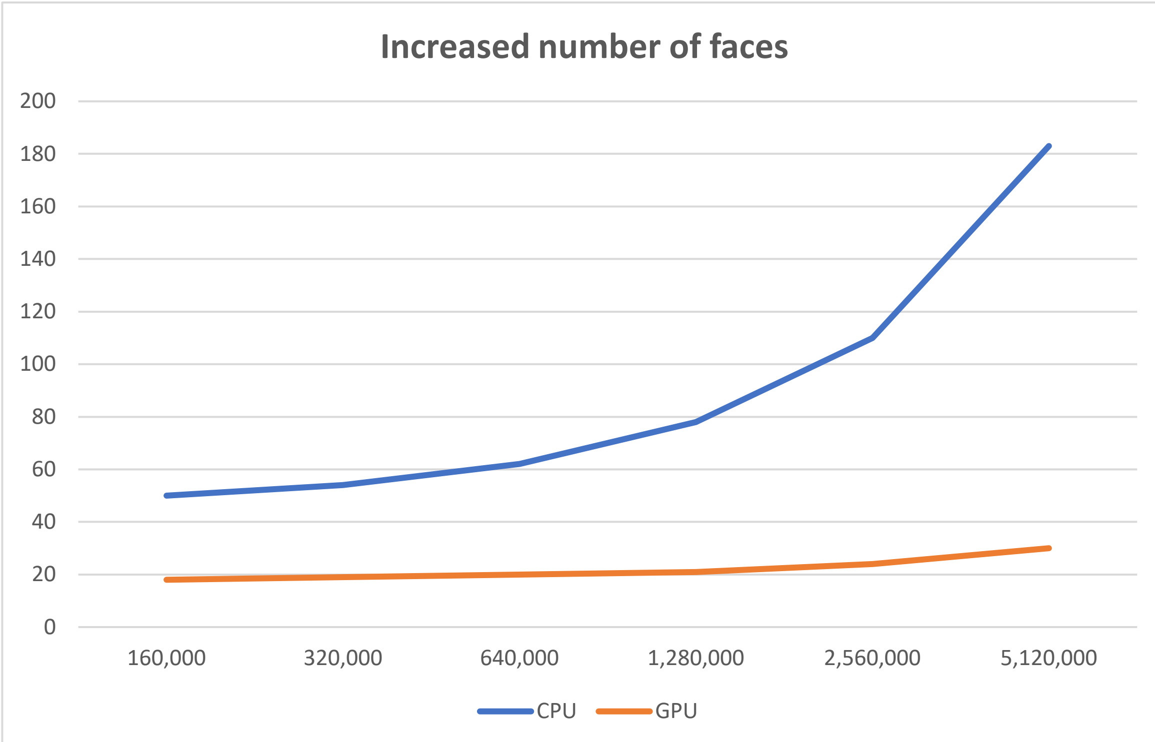


Table 6.2: (Graph of increasing number of faces , Source: Autor,2023)

The experiment included six diverse levels of complexity, with face counts ranging from 160,000 to 5,120,000. The sample of the experimental is below:

As the number of faces in the scene increased, CPU render times increased, ranging from 50 seconds for the most explicit scene (160,000 faces) to 183 seconds (about 3 minutes) for the most complex scene (5,120,000 faces).

This result shows that the number of faces affects the time rendering more than GPU rendering because GPU render times are raised with scene complexity. However, the render times were consistently lower than the CPU's, ranging from 18 seconds for the simplest to 30 seconds in the scene with more faces.

Textures and materials

Complex scenes often involve advanced shaders and visual effects, such as subsurface scattering, volumetrics, or motion blur. These effects require more intricate calculations, putting extra strain on the GPU and increasing render times. (Autodesk,2022)

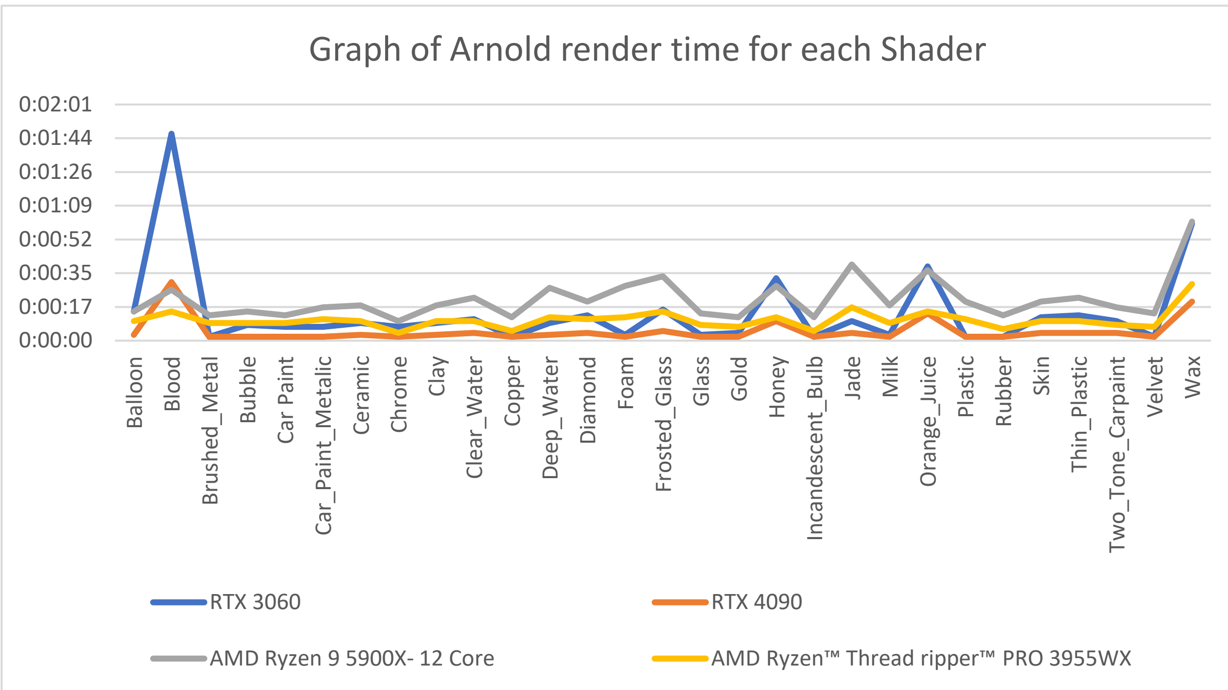


Table 6.3: (Graph of different shader render time, Source: Autor,2023)

There are some noticeable differences when comparing the shader render times using the "RTX 4090" and "AMD Ryzen Thread ripper PRO 3955WX".

The "NVIDIA RTX 4090" generally has a much faster render time than the "AMD Ryzen thread ripper PRO 3955WX". The "NVIDIA RTX 4090" can calculate faster than the CPU on the complex shaders for rendering and other intensive tasks.

Table of render time for each Arnold shader

Shader Name	“RTX 3060”	“RTX 4090”	“AMD Ryzen 9 5900X”- 12 Core	“AMD Ryzen™ Thread ripper™ PRO 3955WX”	Image Size
Balloon	0:00:15	0:00:03	0:00:15	0:00:10	1024*1024
Blood	0:01:46	0:00:10	0:00:26	0:00:15	1024*1024
Brushed Metal	0:00:02	0:00:02	0:00:13	0:00:09	1024*1024
Bubble	0:00:08	0:00:02	0:00:15	0:00:09	1024*1024
Car Paint	0:00:07	0:00:02	0:00:13	0:00:09	1024*1024
Car Paint Metallic	0:00:07	0:00:02	0:00:17	0:00:11	1024*1024
Ceramic	0:00:09	0:00:03	0:00:18	0:00:10	1024*1024
Chrome	0:00:07	0:00:02	0:00:10	0:00:04	1024*1024
Clay	0:00:09	0:00:03	0:00:18	0:00:10	1024*1024
Clear Water	0:00:11	0:00:04	0:00:22	0:00:10	1024*1024
Copper	0:00:02	0:00:02	0:00:12	0:00:05	1024*1024
Deep Water	0:00:09	0:00:03	0:00:27	0:00:12	1024*1024
Diamond	0:00:13	0:00:04	0:00:20	0:00:11	1024*1024
Foam	0:00:03	0:00:02	0:00:28	0:00:12	1024*1024
Frosted Glass	0:00:16	0:00:05	0:00:33	0:00:15	1024*1024
Glass	0:00:03	0:00:02	0:00:14	0:00:08	1024*1024
Gold	0:00:04	0:00:02	0:00:12	0:00:07	1024*1024
Honey	0:00:32	0:00:08	0:00:28	0:00:12	1024*1024
Incandescent Bulb	0:00:02	0:00:02	0:00:12	0:00:05	1024*1024
Jade	0:00:10	0:00:04	0:00:39	0:00:17	1024*1024
Milk	0:00:03	0:00:02	0:00:18	0:00:09	1024*1024
Orange Juice	0:00:38	0:00:10	0:00:36	0:00:15	1024*1024
Plastic	0:00:02	0:00:02	0:00:20	0:00:11	1024*1024
Rubber	0:00:02	0:00:02	0:00:13	0:00:06	1024*1024
Skin	0:00:12	0:00:04	0:00:20	0:00:10	1024*1024
Thin Plastic	0:00:13	0:00:04	0:00:22	0:00:10	1024*1024
Two Tone Car paint	0:00:10	0:00:04	0:00:17	0:00:08	1024*1024
Velvet	0:00:02	0:00:02	0:00:14	0:00:07	1024*1024
Wax	0:01:00	0:00:15	0:01:01	0:00:29	1024*1024

(Table 6.4: Table of different shaders CPU and GPU render time, Source: Autor,2023)

At the same time, the "AMD Ryzen thread ripper PRO 3955WX" is a high-end processor (for this experiment in 2023) better suited for general computing tasks.

Moreover, the "NVIDIA RTX 4090" just needed three seconds to render the Balloon shader. Also, The AMD Ryzen thread ripper PRO 3955WX, by contrast, completed the task in 10 seconds. While the "AMD Ryzen thread ripper PRO 3955WX" required 26 seconds to render the Blood shader, the "RTX 4090" required 10 seconds.

These differences in render time become more pronounced as the complexity of the shader increases, with the "RTX 4090" consistently outperforming the "AMD Ryzen thread ripper PRO 3955WX".

Higher resolution output

Complex scenes are often rendered at higher resolutions to preserve the details and maintain visual fidelity (Möller et al., 2018)

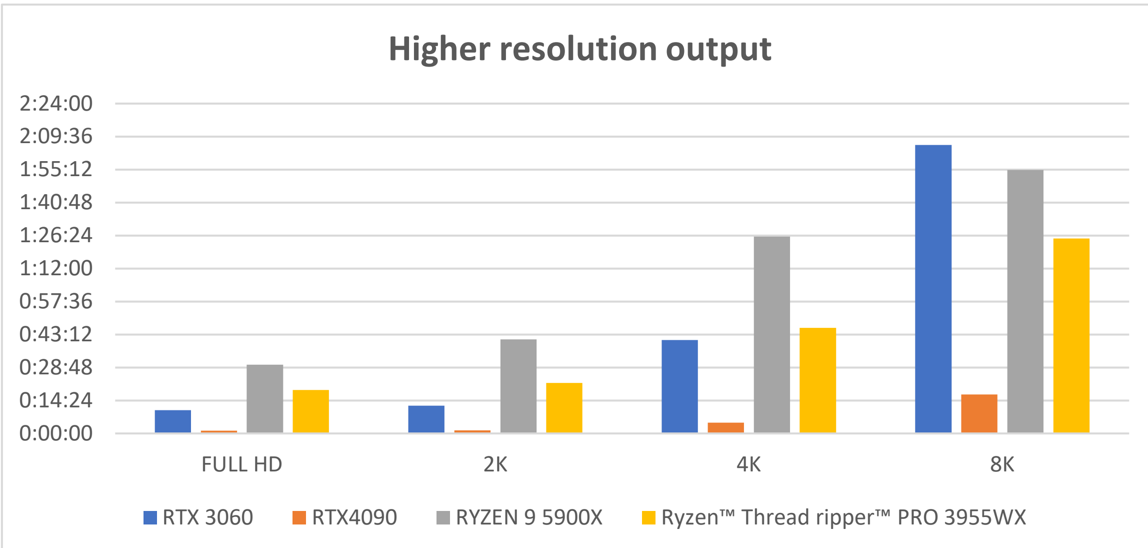


Table 6.5: (Graph of high-resolution output render time. Source: Autor,2023)

resolution	"RTX 3060"	"RTX 4090"	"AMD Ryzen 9 5900X- 12 Core"	"AMD Ryzen™ Thread ripper™ PRO 3955WX"
1080*1920(Full HD)	00:10:13	00:01:13	00:30:00	00:19:00
2048*1080(2K)	00:12:10	00:01:22	00:41:00	00:22:00
4096*2160(4K)	00:40:46	00:04:46	01:26:00	00:46:06
8192*4320 (8K)	02:06:00	00:17:00	01:55:05	01:25:05

Table 6.6: (Table of high-resolution output render time, Source: Autor,2023)

Render times for the "NVIDIA RTX 4090" and the "AMD Ryzen Thread Ripper PRO 3955WX" were affected when the image resolution was raised, as shown by the presented statistics.

For instance, Rendering a 1080p resolution (1920 x 1080) resolution on the "RTX 4090" takes around 1 minute and 13 seconds, while doing the same on the "AMD Ryzen Thread ripper PRO 3955WX" takes nineteen minutes.

In another example, the "RTX 4090" processes the 8K resolution image in seventeen minutes while on "AMD Ryzen Thread ripper PRO 3955WX" takes one hour, twenty-five minutes, and five seconds.This result shows "NVIDIA RTX 4090" is faster than the CPU that I used.

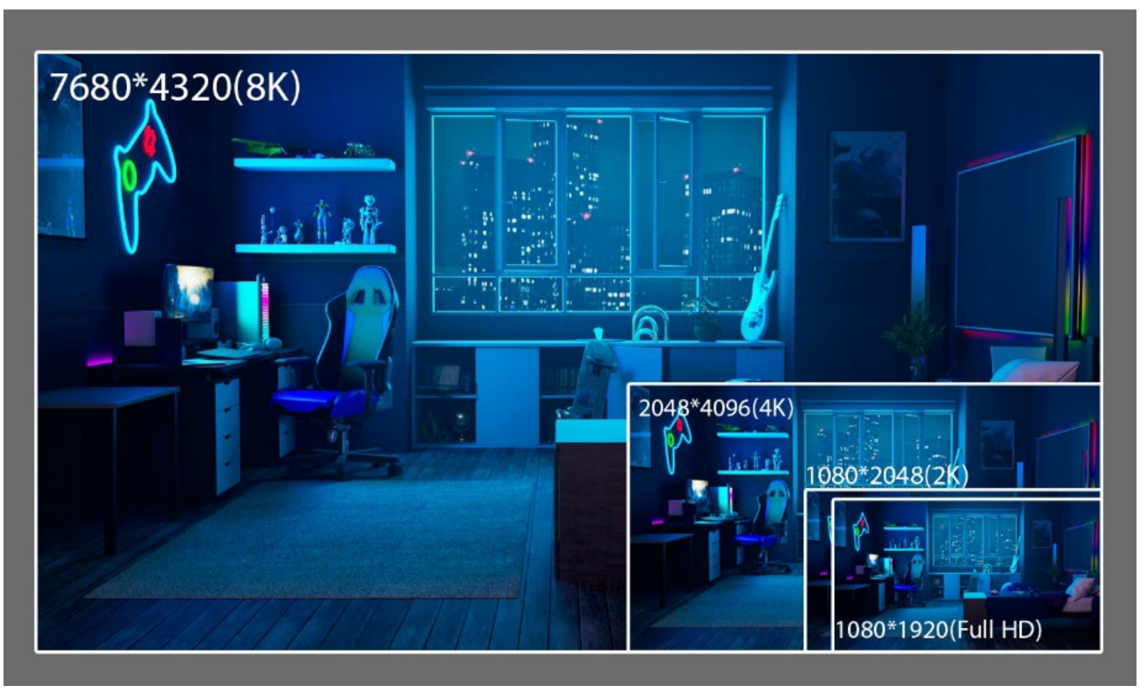


Figure 6.2: (Image rendered resolution render time Source: Autor,2023)

Quality Comparison

One of the most critical aspects of creating high-quality 3D renders is ensuring that the final image is clear and free of noise (Autodesk. Arnold, 2022). In this article, I will discuss my in-depth approach to reducing noise in Arnold Renderer, utilizing its built-in AOVs (Arbitrary Output Variables) and a video quality measurement tool to systematically identify and address the sources of noise in the rendered images.

Noise Reduction by using Arnold noise workflow.

The Arnold Renderer offers a selection of AOVs (Arbitrary Output Variables) that artists can use to examine various components of a rendered image (Autodesk. Arnold, 2022). Analyzing these AOVs, we identify specific noise sources and make appropriate adjustments. (Arnold Renderer | Autodesk | Press Release: Arnold 5.3, n.d.)

Arnold's documentation highlights the following “AOVs” as particularly useful for pinpointing noise sources: “Specular-Direct”, “Diffuse-Direct”, “Diffuse-Indirect”, “Specular-Indirect”, “Subsurface-Scattering” (“SSS”),“Transmission”, and “Light Sampling”. (Arnold Renderer | Autodesk | Press Release: Arnold 5.3, n.d.)

Transmission/Light Sampling

This article explores noise reduction techniques in Autodesk Maya, using the Arnold renderer for CPU and GPU rendering. It focuses on the impact of raising sampling rates, using denoisers, and comparing the performance of an “Nvidia RTX 4090” GPU and an “AMD Ryzen 9 5900X” CPU.

To evaluate the noise contribution of each AOV, artists must render the scene and examine the results. (Autodesk. Arnold, 2022).

Suppose they find no noise in a specific AOV. In that case, they can reduce the corresponding component that does not contribute to the overall noise in the final image. For instance, if artists detect noise in the Specular Direct AOV, it implies that they need to increase light sampling to reduce the noise in the final image. This systematic approach allows them to effectively target noise sources and improve the quality of their rendered images.

Despite the practicality of the AOV-based method, it can be challenging to detect the subtle disturbance in specific pixels visually. In these situations, a more precise technique was required to assess the noise levels in rendered images. For this purpose, I utilized the MSU Video Quality Measurement instrument, a robust piece of software that enables objective evaluation and comparison of video and image quality. This instrument enabled me to measure the noise levels in my CPU and GPU-rendered images and analyze them.

Noise result from MSU Software

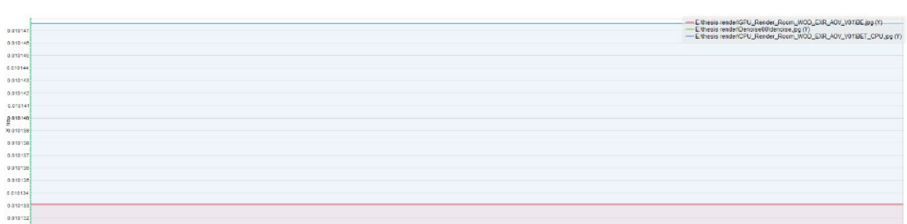


Figure 6.3: (Result of noise reduction, Source: Autor,2023)

Arnold Workflow for noise reduction

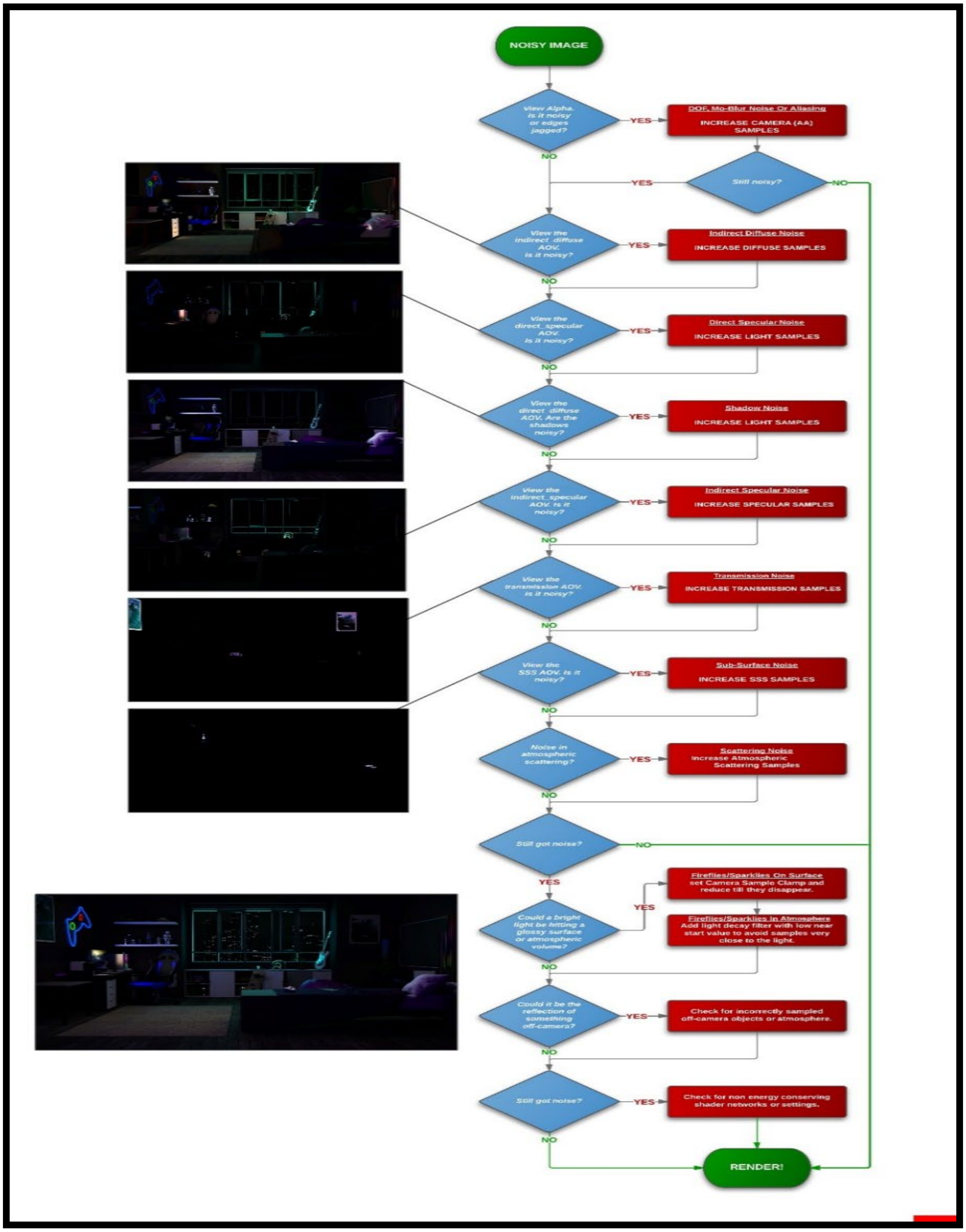


Figure 6.4: (AOVs, Noise reduction, Source: Autor,2023)

The table exhibited previously illustrates a comparison of three different images. The red line represents a GPU-rendered image with noise evaluated using AOVs, the green line represents a GPU-rendered image with the "Optix denoiser", and the blue line represents a CPU-rendered image. According to the results, the GPU render with denoiser displayed the lowest noise levels, followed by the GPU render, and then the CPU-rendered image, which displayed the highest noise range. This analysis demonstrates that GPU rendering produces a final image with lower noise levels than CPU rendering. As a result, I chose a GPU-rendered image with noise reduction as the main image to contrast the results of CPU and GPU rendering.

Table of comparison noise

	RED /GPU	**Green GPU /Denoiser**	**Blue/CPU**
Noise found (less good)	0.010133	0.010131	0.010148

Table 6.7: (Noise reduction results by MSU software, Source: Autor,2023)

Further Investigation

In the future, expanding the scope of the thesis on the comparison between Arnold CPU and GPU rendering will be crucial to provide a more comprehensive understanding of their capabilities and limitations.

One essential step would be to explore other CPU and GPU combinations, allowing for a more extensive evaluation of the performance and quality of various rendering systems.

Another significant aspect to investigate further is the rendering of complex materials and geometries, such as hair, feathers, Fog, Fire, and caustics.

These intricate elements pose unique challenges that may be addressed differently by CPU and GPU rendering systems.

This information can then inform best practices in utilizing the appropriate rendering solution for specific tasks, ultimately improving efficiency and output quality. Furthermore, understanding how these complex materials interact with light in different rendering systems can help developers refine their algorithms and techniques, resulting in more accurate and realistic simulations.

Conclusion

The findings of this study include two distinct aspects: the technical, on the one hand, and the creative, on the other.

The technical portion of this study uncovered some information on Arnold GPU rendering that may be advantageous, including quicker render times, less noise in the rendered image, and handling complicated scenes.

These results aid the artist in making wiser choices regarding their work. To generate high-quality images and animations rapidly, for instance, artists can benefit from render speed by improving their artistic expression, streamlining their processes, and making better-informed decisions that align with their objectives and available resources.

Furthermore, shaders with improved GPU rendering performance could be crucial in enabling artists to create realistic lighting, shading, and textures, raising the visual quality of their work. Additionally, obtaining a high-resolution photograph quickly might help them see more detail and manage noise to create a high-quality 3D photorealistic image.

The democratization of art (art philosophy) and the accessibility of high-quality 3D rendering to a broader audience are profoundly impacted by these options, such as render time, quality, high-resolution picture, and optimum shader performance. Artists and small studios may use technological advancements to produce more intricate and aesthetically attractive work, even on a restricted budget.

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