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Nvidia DLSS 4 AI Audit

1. Introduction

Artificial intelligence has become a new turning point in game development since NVIDIA launched DLSS in 2019. Gamers and developers alike continue to debate what AI means for the future of gaming. Nvidia, known for its technological innovation, debuted DLSS as a solution to efficiency decreases in games and has continued to improve the technology with consecutive DLSS releases. Many consider the newest version, DLSS 4, to have the largest leap in advancements and believe it upholds Nvidia's position as the leading brand for AI-game graphics. While most consumers agree that DLSS 4 improved gaming AI, many feel hesitant to place it above more traditional technologies, as DLSS still has many limitations and only works in specific games. This lends itself to how DLSS was initially trained on images from specific games though recent developments allow Nvidia to reach a larger consumer base with wider training data and applications outside of the gaming field. However, this brings other issues to light, such as the environmental impact of large AI models and potential biases in the data. The topic of Nvidia's DLSS 4 is a complex one, as the product itself constantly changes and people struggle with the implications of AI and the future of the company beyond the gaming sphere.

2. History

Founded in California by Jensen Huang in 1993, Nvidia has been the most influential company for computer graphics over the past 30 years. In the late 80s and early 90s, video games were becoming more and more popular, and consumers wanted to play them at home rather than in arcades. Huang said, "We also observed that video games were simultaneously one of the most computationally challenging problems and would have incredibly high sales volume. Those two conditions don't happen very often." Nvidia produces graphical processing units (GPUs), which process graphical information in parallel and provide significantly faster results than using the central processing unit (CPU). This new way to run video games and other computer graphics applications launched Nvidia into the massive company that it is today.

Nvidia has always tried to be on the cutting edge of technology. In 2008, Nvidia acquired AGEIA Technologies for their PhysX physics engine to integrate into their GPUs. In 2016, Nvidia announced the GeForce GTX 10 series, which significantly outperformed the earlier generations of GPUs, and could better be used for virtual reality. In 2018, they rebranded their

GTX series of cards to RTX. This change was used to promote their new ray tracing technology. Ray tracing simulates the bounces of light off of each object before reaching the camera, which drastically improves the lighting fidelity. However, it is also computationally heavy. With this immense decrease in performance, Nvidia needed to find a new way to improve the efficiency of their cards beyond the traditional methods.

In February 2019, Nvidia released their deep learning super sampling (DLSS) technology. This technology improved game performance (frame rate) by rendering the game at a lower resolution and then upscaling the image using a convolutional neural network (CNN). This model was a decent first attempt to improve performance using AI, but it suffered from several drawbacks. First, the model could only use information from the current frame to be upscaled, so the image quality suffered as a result. Second, the model itself used significant GPU resources, which somewhat offset the performance gains of rendering the game at a lower resolution. Lastly, the model had to be trained on a per-game basis, which was time consuming, so many games did not even implement this feature.

DLSS 2 improved upon the earlier generation significantly in April 2020. This new model used temporal antialiasing upsampling (TAAU), which uses data from previous frames to give the model more context. Additionally, this model used only about half the overhead performance cost of the previous model, further increasing the performance gains. This generation of DLSS also removed the need to train on each game, which increased the number of titles that DLSS was brought to over the next few years. These improvements caused DLSS to increase in popularity among gamers, as it was an easy way to increase performance with very little loss in visual fidelity.

In October of 2022, Nvidia released DLSS 3, which improved the upscaling technology even further. This update promised to increase the performance gains of upscaling as well as increase the visual quality. This generation also saw the addition of new features beyond upscaling; with the launch of Nvidia's RTX 4000 series of GPUs, they also offered frame generation. This technology worked by rendering a frame, holding it for a few milliseconds, interpolating a frame in between entirely using AI, then sending the frames to the player. This model could nearly double frame rate, but it increased the input latency. Additionally, this model added performance overhead for the GPU and was only available on RTX 4000 series cards. The following year, Nvidia announced DLSS 3.5, which introduced ray reconstruction. This technology improved the quality of ray traced graphics while using DLSS. While this mid generation release did majorly improve the model, this was a welcome improvement for players that frequently used ray tracing features.

Earlier this year, Nvidia released DLSS 4 alongside their 5000 series GPUs. Once again, this update to the technology required buying into the latest generation of graphics cards. With this generation, DLSS 4 brought multi frame generation (MFG), which produced not one AI generated frame, but three AI generated frames between each rendered frame. This meant that the new model could theoretically give 4x performance over no frame generation–though with the overhead cost of the model, these gains were really closer to 3x. Additionally, MFG increased latency even more than the older 2x model. While MFG was not received the greatest by consumers, DLSS 4 also offered a new model for their upscaler, which now used a transformer model rather than the older CNN. This new model drastically improved the quality of the upscaler, allowing games to be rendered at much lower resolutions with almost no cost to visual fidelity. This new model was also released to all graphics cards that supported DLSS (RTX 2000, 3000, 4000, and 5000). However, the performance cost was heavy on older generations of cards, as they did not have as many tensor cores. Overall, with this newest generation of DLSS, Nvidia offered a high quality option to upscale games, improving frame rate performance with minimal cost to visual quality.

3. Rhetoric and Representation

While marketing has changed considerably as new releases continue to enhance the gaming experience of DLSS, many marketing statements have remained the same. Since the initial launch of DLSS, Nvidia has touted its smoothness and realism. The company frequently reminds its customers that the AI in “DLSS is always learning” and improving (“DLSS 4” 00:15-00:18, Burnes “*Anthem*”). With the announcement of DLSS 1, there was an advertising push from Nvidia that showcased the ability to generate reflections with ray tracing, including a full demo video on the topic (Burnes “*Anthem*”). With the DLSS 2.0 drop, they reiterated the many abilities of ray tracing and “next-generation realism” with improvements in “image quality and performance” (Burnes “NVIDIA DLSS 2.0”). DLSS 3 was advertised with similar criteria, Nvidia claimed it was “a revolutionary breakthrough in AI-powered graphics” while doubling down on the superior “image quality” and responsiveness in games with DLSS (Lin and Burnes). Up until the launch of DLSS 4 these advertisements did not address the quality of their product against “traditional native rendering” (“DLSS 4” 02:20-02:21), a common comparison from consumers (Silver_Charge_5611, Kavor, Roach). However, with the release of DLSS 4, Nvidia claimed DLSS technology brought “revolutionary performance” and “high[er] quality” pixels exceeding the abilities of native rendering (“DLSS 4” 02:18-02:19 and 05:14-05:45). This is a bold claim that is much refuted by gamers using DLSS 4. In a recent XDA post, Jacob Roach wrote that he has “been able to achieve the performance [he] wants natively” or through combinations of software other than DLSS 4 (Roach). Intel, a competitor of Nvidia with their XeSS software, claims their “AI algorithms deliver [...] close to native quality,” but is still unwilling to claim superiority over the traditional rendering, unlike Nvidia (“Intel® Arc™”). Despite these controversial claims, DLSS 4 has been met with generally positive responses (Mkilbride, Natasha_Giggs_Foetus, lordunderscore) though many find Nvidia’s marketing extreme. Statements like, “if you’re to believe Nvidia’s marketing” and “the application of MFG [(DLSS 4)] is extremely narrow” make clear the "grain of salt" mentality with which consumers must approach Nvidia’s advertising statements (Roach). However, hesitancy to accept Nvidia’s claims is not the sole concern of their customers.

Many reactions to DLSS 4 express concerns for the future of DLSS and AI-gaming products. Consumers worry that DLSS, and its future generations, will create “lazy” programmers, act as “a crutch [...] used to artificially inflate prices,” and destroy developer jobs (nyomarek, Singh, fpshunter). Many buyers also express frustrations when using DLSS because it is difficult or impossible to run on older models, causes distractions while playing heavy-action sequences, and can make games look strange (nyomarek, Georgieva, Roach, Silver_Charge_5611, Seushimare). Other gamers and developers are taking DLSS and AI as an inevitability. Tanveer Singh in a post on XDA argues that DLSS and AI is “the natural lifecylce of hardware advancements” and it “is here to stay” regardless of how consumers feel (Singh). Singh also points out that Nvidia competitors, like AMD, similarly push their AIs in product announcements indicating that “the industry has already transitioned” to AI products (Singh). This is an accurate observation as both DLSS 4 (“enhance,” “boost,” and “maximize” with AI (“NVIDIA DLSS 4”)) and AMD’s FSR 4 (“AI-accelerated upscaling plus frame generation” helps “achieve next-level performance and faster responsiveness” (“AMD FidelityFX™”)), advertise AI as a key component of their products’ superior abilities. Without the improvements AI brings to these products they would stand out less in the market, having both less to offer and fewer controversies.

4. Data

As mentioned before, Nvidia’s DLSS is an AI-driven technology that enhances gaming performance by outputting high-resolution frames using lower-resolution inputs. Like almost any other artificial intelligence model, the core of DLSS’s functionality is the data that it is trained on. It is the backbone of the model and is what enables it to deliver high-quality frames for gaming in real time.

DLSS is trained mainly using extensive visual data pulled directly from video games. These massive datasets consist of both low-resolution and high-resolution frames from various scenes of the video game (Lyon). It is important to note that not only do these datasets contain these still frames, they also include additional necessary rendering information such as motion vectors and depth buffers (Lyon). These extra pieces of information help the model understand how objects move through space and how far away they are from the viewer, allowing DLSS to make more accurate predictions when generating images (Zhang et al.). Together, this collection of data provides the model with rich context to base its visual predictions on.

To teach DLSS how to upscale images, Nvidia also preprocesses this data in house to create ‘perfect frames’, or ultra-high quality versions of those same game images. These frames ultimately act as a cross-reference for the model, indicating what the generated output should theoretically look like (Alarcon). During the actual training process, the model is repeatedly fed the low resolution inputs and motion information, and asked to generate a high-resolution version of the same frame. The outputs are then analyzed against the ‘perfect frames’, slightly adjusted, and repeated to create a large neural network (Alarcon). This process is repeated with thousands of frames, allowing the model to become increasingly effective at generating high-resolution outputs using low quality inputs.

A potential concern that is raised from DLSS and the datasets it is trained on is platform or engine bias. According to their website, Nvidia collaborates closely with game engines like Unreal Engine and Unity for their DLSS plugin, potentially leading to a skewed and biased dataset (Nvidia DLSS). Since larger engines like Unreal and Unity may support a certain type or genre of game, DLSS's performance may be limited when it comes to games created on lesser known engines. If the model is mainly fed information from these select sources, its functionality and use cases can become hindered when dealing with video games that may not conform with the style of these larger engines. That being said, Nvidia doesn't publish a percentage breakdown of where exactly the training data is being drawn from, making it difficult to truly understand how well this platform works across the spectrum of video game genres and styles.

From an ethical standpoint, DLSS raises some important questions about transparency and consent. In 2022, Nvidia did announce enhanced documentation for AI models using 'Model Card++', a feature that outlines things like bias, privacy, security, and general explanations for an AI model (Boone et al.). While this effort is a positive step forward for the company in terms of transparency, it is unclear if Nvidia has created one of these for DLSS. This lack of clarity makes it difficult to understand whether their training data is fully consented to by game developers. It also raises questions surrounding the idea that Nvidia is using artificial intelligence to predict frames, possibly reproducing or altering artistic elements without permission. Video game development is in itself a form of art, where the visual aspects of the game can be considered a form of intellectual property. Hence, the absence of transparency becomes a significant concern, especially when it comes to utilizing the ideas and art of others in this creative industry.

5. Materials and Labor

Nvidia's breakthroughs with DLSS have proved monumental and gained quick popularity for its powerful capabilities. A key point to its fame is the fact that DLSS uses less energy/ computing power on the system once in use - however, the resource and energy consumption behind manufacturing and developing the DLSS technology is easily overlooked.

DLSS is an extensively trained AI model, reportedly trained using a supercomputer. Bryan Cantanzaro (Vice President at Nividia's Deep Learning Research Team) is reported to have mentioned a supercomputer in use for 6 years just to improve the DLSS model and study errors in it's outputs (James, D.). While Nvidia has not officially confirmed this, they revealed their Eos supercomputer in February 2024, showcasing its technology and explaining how it was used by Nvidia's internal teams for AI development and research (Boyle). Additionally, marketing for DLSS throughout the years involves mentions of training on supercomputers, with the current DLSS 4 model ray reconstruction marketed with the following: *"DLSS replaces* *hand-tuned denoisers with an NVIDIA supercomputer-trained AI network that generates higher-quality pixels between sampled rays.”* (Nvidia DLSS).

Although Nvidia has not revealed details, involvement of a supercomputer such as Eos (or a previous variant, such as the DGX SaturnV), is likely. These systems consume large amounts of energy and water to stay online and cooled ("Supercomputing"). Since Nvidia has strict publicity measures for DLSS, it is difficult to estimate the energy consumption involved. One speculation based on studying DLSS 3.5 suggests that while training DLSS is energy-intensive, it consumes less energy than other AI models like LLMs (Abraham).

On the other hand, DLSS requires “tensor core” technology, found exclusively in Nvidia’s RTX GPU series - specifically the RTX 20, 30, 40 and latest 50 series. Although all RTX chips receive updates with new DLSS model releases, this closed ecosystem restricts access to users without a RTX backed setup. Additionally, some DLSS 4 features such as multi-frame generation are exclusive to the RTX 50 series (Nvidia DLSS). This means that even users with a system backed by the fairly recent RTX 30 and 40 series chips would have to upgrade if they wish to harness DLSS 4’s full capabilities. As such, new hardware must be manufactured and sold, instead of upgrading existing hardware that still has significant lifespan left.

Such exclusivity comes with significant environmental consequences. Manufacturing a new RTX chip - like other GPUs - relies on labor-intensive manufacturing, significant energy and water consumption, and mineral extraction of critical natural resources. Production cycles emit carbon emissions and include extracting rare earth metals and critical minerals (as defined by the US government; GAO) such as tungsten, lithium, aluminum and gold.

Each process post extraction is not only energy intensive, but also consumes high volumes of ‘ultrapure’ water - used to clean and cool chips - is refined through ionization and reverse osmosis. Producing 1,000 gallons requires 1,500 gallons of raw water, and in 2024, chip factories globally used as much water as a city of 7.5 million people (James, K.).

Furthermore, as part of the effort to diversify the raw material supply chain, the mining processes increasingly occur in regions with little to no regulatory frameworks overseeing the process. Mineral exploration has expanded to low-income regions like the DRC, Zambia, and Angola, where labor and resource exploitation, unsafe labor conditions and poor compensation are common (UN, p.25).

Meanwhile, replacing RTX chips prematurely creates electronic waste. Older models, often still functional, end up in landfills or inefficient recycling processes, where toxic materials can leach into soil and water. Even if recycling metals are scrapped, only a fraction of valuable metals (such as gold) are recovered, and much of the process involves labor in developing regions under poor working conditions. As of 2022, 5 billion kilograms of e-waste used in small devices like phones and laptops was generated globally, with only 22% formally documented and recycled (UNITAR). That is around the weight of 250 million stainless steel spoons, with only 55 million recovered.

Though Nvidia offers some recycling programs, many components still end up in landfills or low-efficiency recovery plants, often in developing countries where laborers may be exploited, and exposed to unsafe working practices ("How to Recycle Our Products"). Nvidia has published environmental and social governance reports, but these focus mostly on its internal operations, and do not report suppliers' metrics ("NVIDIA Sustainability Report"). With a multitude of components contributing to DLSS and RTX chip production, it is difficult to track exact metrics and environmental impacts. There is little transparency about the upstream supply chain, where most of the labor-intensive and ecologically damaging processes occur. The company's Responsible Mineral Policy makes efforts to avoid conflict zones, but it doesn't directly address the broader issues of regulatory gaps, corruption, and exploitation in global mining operations ("Responsible Minerals Policy.").

As DLSS becomes more popular, especially in gaming, demand for RTX chips will grow. But as mineral reserves deplete and energy becomes scarcer, questions remain about how ethical and efficient continued production can be (Zewe). To ensure responsible development, Nvidia must increase transparency and provide more detailed reporting on the labor, materials, and energy behind DLSS.

6. Outputs and Consequences

NVIDIA is a company that provides GPUs and software development platforms for accelerated computing solutions. Its greatest, or most well-known, impact has come through its introduction and popularization of modern GPUs, which were revolutionary for gaming graphics. It's fast and detailed, and displays intricate backgrounds and designs clearly. But GPUs have grown and developed, and have come to help in fields like machine learning, oil exploration, scientific image processing, statistics, linear algebra, 3D reconstruction, medical research and even stock options pricing determination (Olena).

Despite the success of GPUs, NVIDIA has expanded and recently released technology that gives businesses the tools and infrastructure to apply AI, including deep learning models, to anything they offer or do. Businesses can apply AI into their practices and products faster. Many of them that have used NVIDIA's technology have improved the planet and society. In the Healthcare industry, institutions have been able to use technology for drug discovery, surgery, medical imaging, and wearable devices ("NVIDIA Sustainability Report"). A startup named SimBioSys created a system that helps surgeons more clearly identify tumors by converting MRI models to 3D models of breast tissue. Researchers at the Wellcome Sanger Institute used NVIDIA's AI to help create technology that helped them analyze thousands of cancer genomes every year, and to look for a cure (Cook). In terms of climate action, its AI has the potential to optimize solar and wind farms, enhance power grid reliability, advance carbon capture, and more ("NVIDIA Sustainability Report"). Even in its current stages, it has helped. A robot in Hong Kong named Clearbot uses AI for a boat that automatically cleans trash from water. The Greyparrot Analyzer, using machine learning and embedded cameras, distinguishes between trash and objects that can be recycled (Cook).

There have been many benefits that have come from NVIDIA's contributions. But their modern, high-speed technology requires large amounts of energy and resources. A GPU requires raw materials and the manufacturing of chemical components, which are toxic to the environment. GPUs have rare earth materials like tantalum and palladium that are usually found in Southeast Asia and are called "conflict materials" because of the unfair labor practices that are often used for them to be acquired and their serious environmental impact, like the release of potent greenhouse gases that make up about 50% of emissions (Koski). In addition to the mining practices and need for these materials, the chemical components necessary in the making of GPUs, such as copper clad laminates or other heavy metals, leak into the surrounding environment, water, and food chain. They eventually reach people, and can cause kidney dysfunction, nervous system disorders, and several other health effects (Koski).

In addition to the resources NVIDIA requires for its products, it has failed to support different groups of people equally. In 2024, only 23% of its employees were women, and 75.6% were men. 50.4% of people employed were in the Americas. The racial makeup of these employees was 55.9% Asian, 30% white, 5.3% Hispanic, 1.6% Black, and less than 1% for other races ("NVIDIA Sustainability Report"). All of this was according to their official report on Diversity and Inclusion in their Corporate Sustainability Report, on which it lists its strategies for recruitment for diversity, but it needs to change its approach to hire more women, more people outside of the Americas, and more people outside of two dominant races in its workforce.

There are ways to help recycle materials, decrease environmental impacts, and make NVIDIA's workforce more equal. But it needs to recognize these problems are serious and prioritize making an effort to change the negative impacts of the technology that allows it to prosper.

7. Conclusion

Nvidia fails to take accountability for many aspects of DLSS, resulting in mixed responses from those familiar with the software. The recent expansion of fields Nvidia's AI may be implemented in holds promise for breakthroughs in the technology and provides hope to researchers; however, adopting DLSS technology into the mainstream, that is, non-gaming fields, raises questions about biases and environmental impacts. Within the world of gaming other problems have long been in discussion. Consumers and developers worry about the repercussions DLSS will have on the field long-term with many complaining the current technologies are painted as far more advanced than they truly are. Despite these concerns, Nvidia and its competitors continue to boast that DLSS, and similar products, are the future of gaming, highlighting AI as an important and influential component. Nvidia's stance on AI aligns with its reputation for innovation in the technological sphere and benefited the company with the positive feedback DLSS 4 received earlier this year. DLSS 4 made noticeable improvements to previous models and, though many concerns remain, Nvidia has maintained its position as a company at the forefront of advancement. The future of Nvidia, and gaming as a whole, remains unclear as

AI implementation continues to develop and the company, as well as consumers, grapple with the potential of this technological revolution.

8. Website (Visual Component)

An in-depth look at the development and implications of Nvidia's DLSS 4:

Patrick-Leary.github.io/AI-Audit

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