

ARTISTICALLY ENHANCED IMAGES: A STUDY ON ACCESSIBILITY AND CREATIVE STYLE IN VIDEO GAMES

Mihai-Lucian VONCILĂ¹

Eren MURAT²

Dragoș-Bogdan TUDOR³

Ioan-Lică MARIN⁴

Mihai UDUBAȘA⁵

Oana Irina TURCU⁶

Nicolae TARBĂ⁷

Costin-Anton BOIANGIU⁸

Abstract

This paper presents a novel approach to postprocessing video games by integrating accessibility enhancements for individuals with various types of color blindness (deuteranopia, protanopia, and tritanopia) and vision deficiencies while simultaneously enabling artistically inspired visual transformations. By leveraging real-time shader modifications and advanced image processing techniques, the solution ensures improved color perception, smart edge highlighting, and consistent multi-frame style rendering. The proposed framework addresses the gap between user-centric accessibility optimizations and creative customization in gaming, aiming to broaden both the inclusivity and the aesthetic range of interactive entertainment experiences

Keywords: Accessibility, Color Blindness, Deuteranopia, Protanopia, Tritanopia, Postprocessing Shaders, Artistic Style Transfer, Edge Enhancement, Real-Time Rendering, Video Game Graphics

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¹ PhD Stud., Eng., Faculty of Automatic Control and Computers, National University of Science and Technology POLITEHNICA Bucharest, 060042 Bucharest, Romania, mihai_lucian.voncila@stud.acs.upb.ro

² Faculty of Automatic Control and Computers, National University of Science and Technology POLITEHNICA Bucharest, 060042 Bucharest, Romania, eren.murat@stud.acs.upb.ro

³ Faculty of Automatic Control and Computers, National University of Science and Technology POLITEHNICA Bucharest, 060042 Bucharest, Romania, dragos_bogdan.tudor@stud.acs.upb.ro

⁴ Faculty of Automatic Control and Computers, National University of Science and Technology POLITEHNICA Bucharest, 060042 Bucharest, Romania, ioan_lica.marin@stud.fsa.upb.ro

⁵ Faculty of Automatic Control and Computers, National University of Science and Technology POLITEHNICA Bucharest, 060042 Bucharest, Romania, mihai.udubasa@upb.ro

⁶ Faculty of Automatic Control and Computers, National University of Science and Technology POLITEHNICA Bucharest, 060042 Bucharest, Romania, oana_irina.turcu@stud.fsa.upb.ro

⁷ PhD Stud., Eng., Faculty of Automatic Control and Computers, National University of Science and Technology POLITEHNICA Bucharest, 060042 Bucharest, Romania, nicolae.tarba@upb.ro

⁸ Prof., PhD., Eng., Faculty of Automatic Control and Computers, National University of Science and Technology POLITEHNICA Bucharest, 060042 Bucharest, Romania, costin.boiangiu@cs.pub.ro

1. Introduction

One of the main visual impairments that affect people playing video games is color blindness. This color deficiency affects approximately up to 8% of the male population, and 0.5% of the females [1], with the most common being forms of deuteranopia and protanopia. This impairment makes it hard to view certain important elements that would lead to finishing important tasks, such as health bars, quest markers, or team colors.

Thus, one of the main challenges that game developers face is that of having to balance player experience alongside graphic fidelity, and performance to cater to the various needs of many people in regard to accessibility. It has been shown that standard visuals often fail to accommodate those with color vision deficiencies or low-contrast perception [1, 2].

Thus, it is important to provide such people with aid in recognizing certain visual cues. That being said, research shows that even subtle changes in hue, saturation, or luminance can significantly change gameplay clarity [1], making the task of providing such benefits in these scenarios even more challenging. Similarly, there is a need to use other techniques, such as edge enhancement in order to accommodate other forms of visual impairment [3].

On a more whimsical note, there is also the desire to magically shift the visual aesthetic of a game into something reminiscent of a famous artist's style, with the end goal being the expansion of inclusivity and delight in modern video games.

In order to address both the accessibility issue and the performance issues, developers can integrate various changes at different points in their rendering pipeline, without having a major impact on the overall performance of the game [1, 4, 5]. Recent research has implemented shader-based solutions that adapt color palettes, highlight edges, and even add contextual outlines for improved object differentiation, showcasing that player satisfaction is maximized when accessibility is a problem that is tackled from the start rather than later [6].

While many accessibility-driven modifications stay close to the original aesthetic of a game, there is a growing trend of creative re-skinning, where entire scenes are transformed to emulate specific art styles [7, 8]. Pioneering work in image style transfer, particularly the neural style transfer approach introduced by Gatys et al. [9], has paved the way for real-time stylization in gaming contexts [8].

Of course, retexturing entire worlds with various styles can introduce performance overhead. Other works on real-time rendering describe how dynamic load balancing and pipeline optimization such as shader execution reordering help maintain stable frame rates even under heavy workloads [10]. In addition, research on interactive evolutionary computation has demonstrated that procedural shader generation can enable non-experts to create visually appealing results [11].

Finally, deep learning–based frame interpolation methods have been verified in studies such as Bao et al.’s DAIN (Depth-Aware video frame Interpolation) [12] and Mengistu [13], which together confirm that generating intermediate frames via optical flow and convolutional autoencoders can effectively boost apparent frame rates while preserving image quality. Together, these findings support the view that combining advanced load balancing, shader optimization, and deep learning interpolation not only elevates gaming’s visual appeal but also enhances functional clarity and responsiveness for a diverse audience.

In this paper, we present two different techniques that try to address these accessibility issues. First directly at the pipeline level, by using color correction shaders, and enhancing edges, and secondly in the Unreal Engine 5, by combining this approach with post-processing volumes, and a variety of filters to test performance impacts.

2. Literature Review

This section provides an overview of existing research and methodologies relevant to accessibility-focused rendering and artistic style transfer in video games.

2.1. Color Blindness

Deuteranopia, Protanopia, and Tritanopia are three forms of color vision deficiencies (commonly referred to as “color blindness”) that result from the reduced or absent function of specific cone cells in the retina.

A widely adopted solution is to apply color transformation matrices based on the specific type of color blindness being addressed. These matrices can be incorporated directly into pixel shaders. A general approach for modifying the color vector C_{in} to produce color-blind-friendly output C_{out} is to employ the accurate M_{cb} generated based on the target deficiency (e.g., protanopia, deuteranopia, tritanopia). According to [1], the computational overhead for such matrix multiplications remains minimal, especially with modern GPU pipelines [4].

In addition to static matrices, dynamic adjustments can be provided so that users may tweak brightness, contrast, or even saturation to better suit their preferences. Our demonstrator application employs a set of user-facing parameters (e.g., slider bars for hue rotation) to ensure seamless real-time color adjustments, making the game experience more inclusive [6].

2.2. Major Visual Impairments

Though color blindness tends to be one of the most common disability issues when talking about visual impairment, it is not the only one that needs to be addressed, as other more severe forms of impairment require a more in-depth implementation in order to properly address them. In recent years, a multitude of papers have dealt with the idea of addressing accessibility issues, in the case of visually impaired people, mostly through audio and haptic feedback [14-19].

Even though all these solutions are beneficial and are of use for people suffering from visual impairments, due to the technology still emerging, and the fact that the vast majority of people wouldn't have access to it, we chose a more accessible approach and tried to address issues at the graphics pipeline.

2.3. Edge Enhancement Techniques for Visual Clarity

Visual clarity is not merely a function of color fidelity. Many players with partial vision or age-related conditions benefit from enhanced edges and outlines that better delineate in-game objects [1, 2]. Such techniques often draw on well-known image processing algorithms, sometimes reimaged and optimized for real-time rendering in shader code [4].

2.3.1. Edge Detection Operations

Classic filters such as the Sobel and Laplacian operators are integral to many shader-based edge detection routines:

$$\nabla I = \sqrt{\left(\frac{\partial I}{\partial x}\right)^2 + \left(\frac{\partial I}{\partial y}\right)^2} \quad (1)$$

where $\partial I/\partial x$ and $\partial I/\partial y$ represent partial derivatives of the image I in the x and y directions, respectively. Papers [2, 4] highlight that GPU-based edge detection requires optimizing the kernel computations to avoid excessive pixel-by-pixel overhead.

2.3.2. Shader-Based Outlining and Depth Cues

Contour-based methods can be combined with in-depth information to accentuate important gameplay elements, particularly those in the foreground. An example technique might use a depth-aware Sobel operator:

$$\text{EdgeStrength} = \alpha \times \nabla I + \beta \times \nabla Z \quad (2)$$

where ∇I is the color gradient and ∇Z is the gradient of the depth buffer, with α and β weighting their contributions [1, 2]. By blending color-based and depth-based edges, developers can produce more robust outlines that remain visible even under complex lighting conditions [3].

2.4. Artistic Style Transfer in Real-Time Rendering

While the forays into accessibility improvements often concentrate on color correction and edge detection, contemporary developments also venture into creatively transforming the game's aesthetic. Inspired by seminal work in image style transfer, developers can now emulate the styles of renowned artists, sometimes even combining accessibility layers with these transformations [7, 8].

2.4.1. Neural Style Transfer Foundations

Gatys et al. [9] introduced the concept of neural style transfer, where a style image's aesthetic is extracted via feature correlations (Gram matrices) at certain convolutional layers in a deep neural network. Chen et al. [8] extended this to ensure multi-frame consistency, which is vital in video games where rapid scene changes can cause distracting flicker.

At the heart of neural style transfer lies the concept of comparing style representations (gram matrices) between a style image and the in-game frame [9]. The style loss function can be expressed as:

$$L_{\text{style}}(a,x) = \sum_{l \in L} w_l \frac{1}{4N_l^2 M_l^2} \sum_{i,j} \left(G_{ij}^l(x) - G_{ij}^l(a) \right)^2 \quad (3)$$

where G^l is the Gram matrix at layer l , and a and x refer to the style and output image representations, respectively [3, 6]. By carefully selecting layers l and weights w_l , real-time frameworks can generate consistent multi-frame style transformations, thus ensuring that a player's journey looks visually cohesive [9].

Performance optimization strategies, such as streamlined network architectures or partial GPU computation, are vital to maintaining real-time frame rates [9, 11].

In the case of multi-style frame consistency, Ruder et al. [7] emphasize that ensuring consistency from one frame to the next requires tracking the style transformation across time. This can be done by retaining partial style information in a recurrent buffer or via motion vectors. The outcome represents a visually cohesive experience.

3. Proposed Method

In this section, we will describe the proposed algorithms, which are split into two different frameworks. Firstly, we have an algorithm that is applied at the shader level in order to perform color corrections and enhance edges. Secondly, the method is expanded in combination with a filtering approach that is designed to be used in the Unreal 5 Engine.

3.1 Shader-Based Color Correction and Edge Enhancement

3.1.1. Algorithm

The first method we propose uses a combination of edge detection, color filtering for common color deficiencies, and a specialized anti-aliasing method called Directionally Localized Anti-Aliasing (DLAA) [20] to reduce flicker and refine object boundaries. Our method is implemented using ReShade [21], a tool that overlays custom shader passes on modern graphics APIs (DirectX, Vulkan, OpenGL). Processing occurs at the end of the render pipeline so it can capture the full scene, including textures, depth buffers, and final color buffers, without significant modification to the underlying application

The first step in our algorithm is correcting color deficiencies. This is performed by reading colors from the back buffer followed by simulating different types of color deficiencies based on a selection.

Next, we compute normals for various pixels in the scene. This is performed in order to aid with detecting edges at further steps. This calculation can be summarized as:

$$N=(\|(Vc-Vn)\times(Vc-Ve)\|,d) \quad (4)$$

where d is the depth of the current texel, Vc is the pixel, while Vn , and Ve represent the top and right neighbors of said pixel.

Separately, the algorithm computes a sum of local depths, and local normals based on all the neighbors of the current texel. Based on these computations, it tries to identify edge pixels. A pixel is classified as an edge if both its depth sum and its normal sum exceed user-defined thresholds. This strategy captures sharp transitions in-depth and normals while also allowing adjustable tolerance levels. Detected edge pixels are marked with specific colors.

Once edges are identified, two distinct sources of boundary information can occur: actual geometric edges in 3D space and color-based edges arising from abrupt changes in the color buffer. Both of these need to be addressed in order to provide an appropriate result.

Firstly, we aim to address abrupt color changes in the image. At this stage, we apply a pre-filter to the detected edges, in order to identify potential abrupt shifts in colors when

transitioning from an object to its edge. These abrupt changes are marked and sent to the DLAA method in order to determine how much to smooth out each edge.

Secondly, we identify potential texture zones existing in the scene that contain strong colors, or in other words either a high contrast or high brightness. These zones are similarly marked, as before, and sent to another DLAA processing step in order to deal with them appropriately.

Finally, the original image is blended with the recomputed textures, based on different user-specified parameters that mix the image using various alpha values for transparency, and other settings related to drawing the edge values. These parameters are used, because testing shows that packed scenes can become overloaded with detected edges, such as those containing foliage, or densely grouped objects.

3.1.2 Visual Results

Figure 1 illustrates the raw edge detection result applied to a 3D scene. At this stage, the algorithm marks strong geometric or color boundaries by examining depth differences and pixel gradients. The benefit is that critical scene outlines become more visible, aiding users

who struggle with object delineation. Similarly, the edges alone could be used in aiding visually impaired people, without the need for other elements being overlapped later.

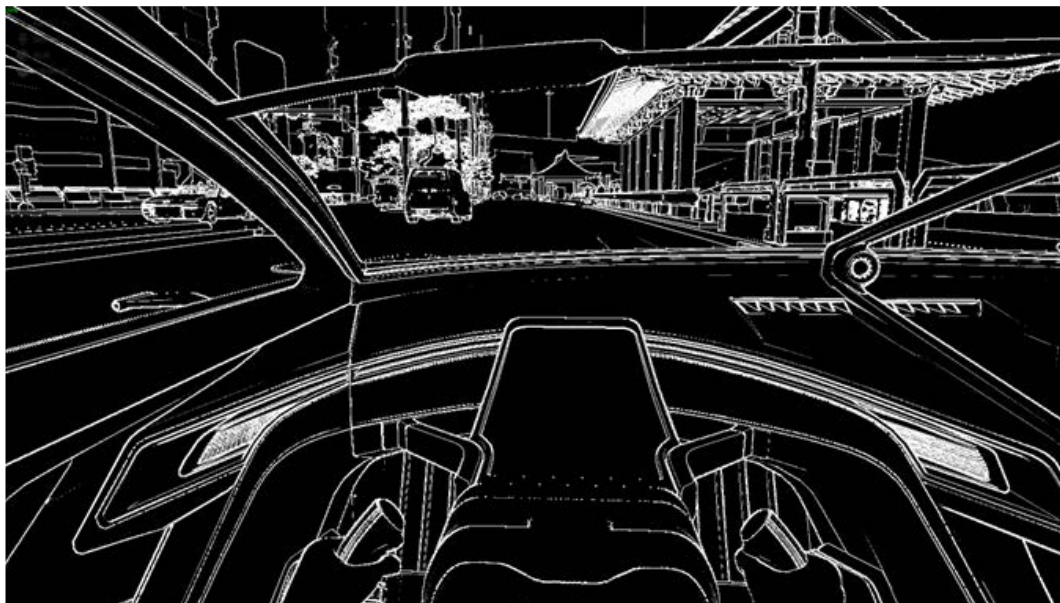


Figure 1. The illustrative process of edge detection in a video game scene

Figure 2 shows the edge detection overlay superimposed on the original scene. This reveals how the newly generated outlines fit into the existing visuals, and the potential improvements to object perception.



Figure 2. Overlapping the edge detection results in the original video game frame

Figure 3 displays the refined edge detection once the alpha parameter has been integrated. By tuning the opacity of the edge overlay, visually busy areas do not become overwhelming, striking a better balance between highlighting boundaries and maintaining scene readability.



Figure 3. Overlapping the edge detection results in the original video game frame

Figure 4 demonstrates the DLAA filter layered on top of the edge detection effect. This additional step removes flickering or overly sharp edges caused by 2D textures on flat surfaces. The benefit is smoother outlines and reduced artifacts, creating a more cohesive and visually comfortable scene for players.



Figure 4. Overlapping the edge detection results in the original video game frame

Figure 5 displays the result of a simulated deuteranopia filter on a video game frame, alongside its applied correction of the simulated filter. More visual information becomes

available for a deuteranopia-suffering person, especially in the blue haze surrounding the distant city.

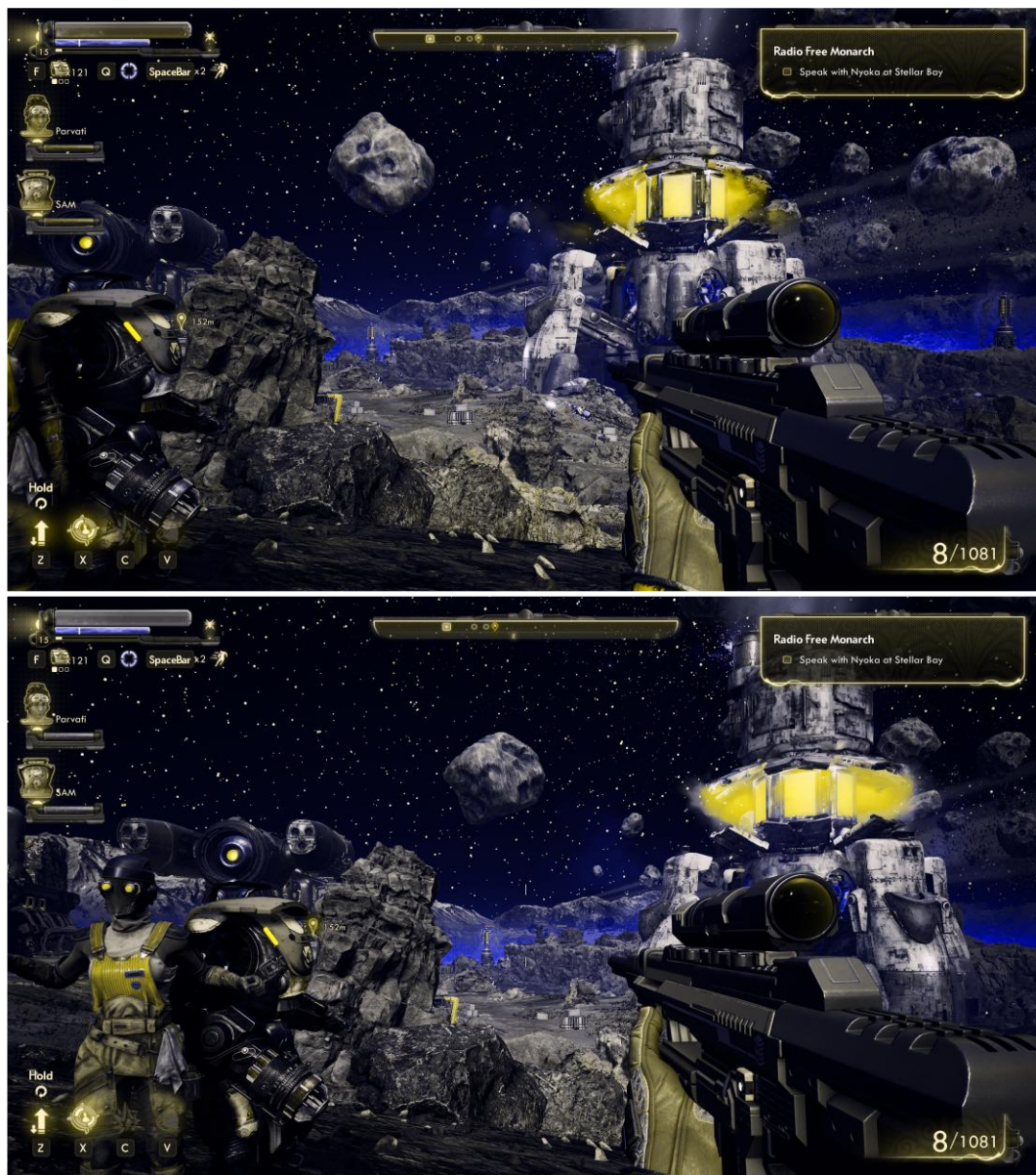


Figure 5. Deuteranopia filter: original (top), corrected (bottom)

The above figures showcase some of the improvements, such as edges in scenes becoming clearer, and certain difficult-to-distinguish objects (like a 2D fish texture rendered on a flat quad) becoming more visibly outlined after applying DLAA. Users with color blindness can enable and calibrate color filters to make critical gameplay elements easier to see, while

users with partial sight can rely on edge detection and anti-aliasing to reduce visual confusion. In summary, the method underscores that combining tolerance-based depth-edge detection with color perception filters and DLAA yields a practical, minimal-overhead strategy to improve visual clarity. By incorporating these strategies in a modular way, small development teams can feasibly enhance accessibility without diverting excessive resources from core game features.

3.2. Shader-Based Color Correction and Edge Enhancement

Our second approach involves changing the image style of certain frames using Unreal Engine 5, more specifically some of its post-process materials [22], and a custom cel-shading setup [23], allowing developers to achieve a certain stylized aesthetic.

3.2.1. Style Transfer Benefits

Even though there aren't many studies that would support the claim that changing the overall style of an image would be beneficial for people suffering from visual impairments, it can be argued that certain styles would be more appropriate in certain scenarios compared to others. Similarly, when people tend to design games for the visually impaired, they tend to make them less complex, in order to accommodate them [6], while this technique would allow for designing a variety of games without compromising.

First of all, changing the visual style in an image can lead to a reduction in overall visual clutter, especially in images that contain photorealistic details, which would be either overwhelming or simply not understood by people with visual impairments, helping them to better focus on certain key elements without needing to worry about understanding certain background elements.

Secondly, changing the artistic style can also lead to better contrast in certain areas of an image, which is something that has been proven to work [6], and that we also employ in our first shader method.

Another argument to be had is that simplifying certain visual elements by altering the overall style of a scene can lead to better consistency in some of the key elements, such as enemies, hazards, or other aspects of gameplay that would lead to a richer overall experience.

3.2.2. Proposed Styles and Filters

Our method mainly involves placing a post-process volume in an Unreal Engine 5 scene, followed by applying the original shader implementation described in Section 3.1, with

small alterations, such as varying DLAA, not including it, or not overlapping edges, combined with optionally applying some post-processing filters at the end of the pipeline.

One such filter, that can be optionally applied is a Kuwahara filter [24], which can be observed in Figure 6. Conceptually, each pixel is examined within a local window divided into four overlapping subregions. Each subregion's variance is computed, and the output color is sampled from the subregion of lowest variance, yielding an intentionally painterly or smudged effect. Symbolically:

$$C_{K(p)} = \min_{\Omega_i \in N(p)} (\text{Var}(\Omega_i)) \quad (5)$$

where Ω_i are the subregions in the window $N(p)$ centered on pixel p . Although originally meant for noise reduction, the method inverts that concept to stylize each frame by blending pixel values from the smoothest local subregion. Setting a small window size, usually less than 3, helps induce a slightly wavy line effect reminiscent of hand-drawn art.



Figure 6. Kuwahara Filter example

Another approach would be one that is only applied for certain areas of the image, such as shaded, or low brightness ones, for which we can apply a Hatching filter. In this case, after edge detection, we apply a threshold to the lighting buffer, applying the style to shades appearing only under a certain brightness level, as seen in Figure 7.



Figure 7. Hatching Filter example

Figure 8 showcases a look that is meant to mimic an older retro style and is built on top of both pixelation and monochrome techniques. A fog effect is introduced by sampling the depth buffer so that pixels that are farther from the camera trend toward a neutral (often grayish or white) fog color:

$$C_{\text{final}} = (1-F) \times C_{\text{mono-pixel}} + F \times C_{\text{fog}} \quad (6)$$

Where $C_{\text{mono-pixel}}$ is the pixelated monochrome color, C_{fog} is the fog tint, and F is a function of distance from the camera. Typically, F increases with depth, creating that characteristic low-visibility effect in distant objects.



Figure 8. Retro Filter example

The Moebius look and feel style, applied to the scene in Figure 10, with results seen in Figure 11, which was inspired by Jean “Moebius” Giraud’s fluid linework and flattened color palettes, involves two core elements: stylized color, which is meant to make the scene have a flat, banded shading style, and outline effect, where edges are better outlined, similar to the Hatching Shader approach. A subtle Kuwahara filter, with a small window size, can then inject a slight wobble in the edges, mimicking hand-drawn imperfections.



Figure 9. Retro Filter example



Figure 10. Retro Filter example

For this paper, these techniques are integrated using a post-process volume placed within the scene, allowing the rendering pipeline to apply these transformations just before the image is finalized. Because it operates at the end of the pipeline, the underlying assets (meshes, textures, lighting) remain unaltered, thus preserving the standard production workflow for pre-made or Marketplace assets.

By comparing performance metrics with and without these post-process steps, only minimal frame rate and latency costs were observed, a roughly 5% decrease in frames per second, with no statistically significant change in average latency. This confirms that advanced stylization can be practically integrated into a modern engine. Thanks to the modular nature of Material Instances, developers can fine-tune threshold values or color quantization intervals and quickly iterate on an artistic vision.

4. Conclusions

4.1. Summary of Findings

Our paper addresses two different facets of video game rendering: accessibility for color-blind or low-vision players and creative consistent multi-style frame rendering. Through our integrated shader pipeline, which carefully combined real-time color correction, edge enhancement, and artistic transformations, we found that real-time GPU strategies can meet both goals without severely impacting performance.

Based on the comparative performance results, the artistic post-processing techniques required to achieve the Moebius-inspired look caused only a minor reduction in average FPS (from 110 to 105) and 1% lows (from 100 to 95), indicating a small, acceptable overhead. Crucially, latency remained effectively unchanged, suggesting that the visual enhancements can be integrated without substantially affecting the responsiveness of the game experience.

The tests were performed using the following hardware specifications: (OS) Windows 11 23H2 (CPU) Ryzen 9 7900 (GPU) Radeon RX 6700 XT (RAM) 64GB DDR5@6000MHz.

4.2. Future Directions and Expanding the Framework

Some of the future directions that can be achieved for our framework could include:

- Extending to other more aggravated forms of visual impairment, such as blindness, and its variations that are not properly addressed in the current approach.
- Offering options for dynamic font resizing: This can be done either for people suffering from dyslexia or simply for people with reading issues in general.

- Multi-Platform & VR approaches: Due to the increased resources needed to render frames in VR performance can be more affected, and for an immersive experience more fine-tuning could be required.
- AI-Assisted Style Refinement, to both improve the overall artistic feel of certain scenes and maybe allow for further visibility improvements.

4.3. Final Remarks

Modern game graphics inhabit a tricky intersection of art, physics, and occasionally the bizarre wizardry known as shader math. Our work shows that by channeling clever matrix algebra, local gradient operators, and style objectives, developers can conjure a genuinely inclusive and artistically unique experience. Our solution allows for more players to enjoy a game, the visuals stay fresh across frames, and performance remains stable enough that players can keep clicking heads (or swords, or spells) to their heart's content.

In the end, accessibility and visual innovation need not collide. Instead, they can complement each other in a unified pipeline that respects both the user's functional needs and the designer's aesthetic ambitions. By taking advantage of these relatively low-cost GPU enhancements, studios of all sizes, AAA behemoths, and indie devs alike can bring their unique visions to a broader audience and, in doing so, elevate the entire medium of interactive digital art.

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