Unity Thesis - Report

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Unity Game Engine

Thesis Topic :

A dynamic grass system in Unity using shaders and prefabs to create realistic, interactive vegetation in real-time environments.

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Acknowledgment

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I am also grateful to my college for providing the necessary resources, laboratory facilities, and technical support to carry out this project successfully.

Lastly, I extend my gratitude to my family and well-wishers for their continuous motivation during the project development.

Abstract

This project presents the design and implementation of a dynamic grass rendering system using prefabs and shaders in Unity. Grass is one of the most crucial natural elements in outdoor environments, yet achieving realism while maintaining performance remains a challenge in real-time graphics.

In this work, grass blades are created as prefabs and enhanced using custom shaders to simulate natural behaviors such as swaying in the wind and reacting to player interactions. Optimization techniques such as Level of Detail (LOD), GPU instancing, and culling are integrated to maintain high performance.

The outcome of this project is a visually immersive, interactive grass system suitable for modern video games and simulations. The system demonstrates how prefabs and shaders can be combined effectively to achieve realism without compromising efficiency.

Introduction

Grass rendering has always been a significant challenge in the field of computer graphics and game development. While large landscapes enhance immersion in games, static textures or low-detail vegetation often reduce the realism of virtual environments.

The goal of this project is to design and implement a dynamic grass system that reacts naturally to environmental factors like wind and player interactions. Unlike static models, the grass in this system responds dynamically, making the game environment more engaging and realistic.

Background of Study

Video games and simulations rely heavily on environmental details to achieve immersion. Realistic vegetation contributes to this by enhancing natural scenery. However, traditional vegetation rendering methods often compromise either realism or performance.

Dynamic rendering using shaders provides a balance by offloading animation computations to the GPU, while prefabs allow scalable replication of grass across vast terrains.

Problem Statement

The challenge addressed in this project is the lack of realism and interactivity in static vegetation systems. Many game environments suffer from unnatural or repetitive grass rendering. This project aims to create a grass system that is both realistic and optimized for real-time performance.

Scope of Project

The project is focused on:

- Developing a dynamic grass system using Unity’s prefab mechanism.
- Implementing shaders for wind-based swaying and player-based bending.
- Applying optimization techniques to maintain stable frame rates.
- Demonstrating the system in a Unity test environment.

Significance of the Study

This project is significant for:

- Game Developers – who need efficient vegetation rendering techniques.
- Simulation Designers – for creating realistic outdoor scenarios.

- Research in Real-Time Graphics – contributing methods for balancing realism and performance.

Literature Review

The rendering of vegetation has been a long-standing research area in computer graphics. Grass, trees, and foliage add realism to outdoor environments, but they also introduce challenges due to their high density and complex interactions with light, wind, and user movement. This section reviews the major approaches and technologies related to grass rendering and situates the current project within this context.

Vegetation Rendering Techniques

1. Billboarding
   - In early video games, vegetation was often represented using flat 2D textures called *billboards*.
   - These textures always face the camera, giving the illusion of depth.
   - While this technique is computationally cheap, it suffers from visual artifacts when viewed at close range or from different angles.
2. Geometry-Based Rendering
   - Later, developers introduced actual 3D models for grass blades and plants.
   - While more realistic, this approach significantly increases the polygon count, leading to performance issues in large environments.
3. Texture Blending
   - Some systems blend multiple textures across terrains to simulate grass.

- This approach works well for distant landscapes but fails to provide interactivity or close-up realism.

4. Shader-Based Animation

   - Modern rendering relies on shaders to simulate motion and lighting effects.
   - Vertex shaders can move grass blades using mathematical functions like sine waves, giving the appearance of wind-driven movement.
   - This method is efficient because the GPU handles calculations directly.

5. Hybrid Approaches

   - State-of-the-art systems often combine prefabs (instantiated models) with shaders to balance realism and performance.
   - For example, Unity’s terrain engine allows developers to scatter prefabs while applying wind shaders for animation.

Prefabs in Game Development

Prefabs are reusable game object templates in Unity. A prefab allows developers to define a grass blade or patch once and then replicate it across the environment.

- Advantages of prefabs:
  - Reusability and scalability.
  - Consistency across the scene.
  - Easy modification: changing the prefab updates all instances.

In the context of vegetation rendering, prefabs are particularly useful for managing large numbers of grass objects efficiently.

Shader-Based Animation in Unity

Shaders are small programs that run on the GPU to control how objects are rendered. In Unity, shaders can be written in Shader Graph or HLSL (High-Level Shading Language).

- Vertex Shaders are used for animating grass blades by modifying their positions.
- Fragment Shaders handle the surface appearance, including color, lighting, and texture blending.

By combining shaders with prefabs, developers can achieve:

- Realistic wind swaying effects.
- Interactive bending when players walk through grass.
- High performance by relying on GPU parallelism.

Related Work in Real-Time Rendering

- NVIDIA's GPU Gems Series introduced techniques for rendering realistic vegetation using programmable shaders.
- Research papers in real-time rendering emphasize the importance of balancing visual fidelity with frame rate performance.
- Commercial games like *The Witcher 3* and *Red Dead Redemption 2* implement highly optimized grass systems using instancing and physics-driven shaders.

The Dynamic Grass Project builds on these prior works but specifically demonstrates a Unity-based approach using prefabs and shaders, targeting student-level research and optimization techniques.

Objectives

The primary aim of this project is to design and implement a Dynamic Grass Rendering System in Unity using prefabs and shaders. This section defines the project's goals in both general and specific terms.

Main Objective

To develop a real-time dynamic grass system that enhances the realism of outdoor environments while maintaining optimized performance in the Unity game engine.

Specific Objectives

1. Design Grass Prefabs
    - Create grass models or simple quad-based prefabs to represent grass blades and patches.
    - Ensure prefabs are reusable and scalable across large terrains.
2. Implement Shader-Based Animation
    - Develop shaders that simulate natural wind effects (swaying and bending).
    - Create shader logic for player interaction, where grass reacts to footsteps or collisions.
3. Integrate Grass into a Unity Environment
    - Place grass prefabs systematically across terrains.
    - Apply wind zones and player triggers for interactive effects.
4. Optimize Performance for Real-Time Rendering
    - Apply Level of Detail (LOD) to reduce complexity at distance.

○ Use GPU instancing to handle large numbers of grass blades.

○ Implement culling techniques to skip rendering unseen grass.

5. Test and Analyze Results

   ○ Measure frame rates on different hardware setups (low-end, mid-range, high-end).

   ○ Compare performance between static grass and dynamic grass.

   ○ Evaluate visual realism and interactivity improvements.

Expected Outcomes

By achieving these objectives, the project is expected to deliver:

- A visually realistic grass system with natural swaying and bending.
- An interactive environment where grass responds to player movement.
- Optimized rendering that maintains stable performance even in large scenes.
- A system that can be extended to future research, such as seasonal changes or AI-driven procedural vegetation.

Methodology / Implementation

The methodology describes the approach taken to design, develop, and test the Dynamic Grass Rendering System. The project was implemented in Unity using prefabs and shaders, with performance optimization techniques to ensure real-time execution.

Project Workflow

The workflow followed in this project can be summarized in five stages:

1. Designing Grass Prefabs
2. Developing Custom Shaders
3. Integrating Grass into Unity Scene
4. Applying Optimization Techniques
5. Testing and Evaluation

(Insert workflow diagram here: A flowchart from Prefab Design → Shader Development → Scene Integration → Optimization → Results)

Grass Prefab Design

- Grass was modeled as simple quads (two crossed planes) with a grass texture applied.
- This approach ensures low polygon count, which is crucial for real-time rendering.
- Prefabs were created in Unity so that a single design could be instantiated across the scene.

Steps in Unity:

1. Import grass texture (PNG with transparent background).
2. Create a quad or plane mesh.
3. Apply grass texture as material.
4. Convert into a prefab for reuse.

Advantages of using Prefabs:

- **Easy replication across large terrains.**
- **Centralized editing: changes to prefab apply globally.**
- **Efficient memory usage with instancing.**

Shader Development

Custom shaders were implemented to make the grass dynamic. Two types of effects were considered:

1. **Wind Sway Shader**
    - **Grass blades sway using a sine wave function.**

Controlled by parameters: wind strength and wind speed.

2. Example equation:

   Displacement=sin(Time×WindSpeed+Position×Frequency)×WindStrengt hDisplacement = \sin(Time \times WindSpeed + Position \times Frequency) \times WindStrengthDisplacement=sin(Time×WindSpeed+Position×Frequency) ×WindStrength
3. Player Interaction Shader

   ○ Grass bends away when the player walks through it.

   ○ Shader reads player position as input and applies a bending force to nearby grass.

4. Example equation:
   Bend=StrengthDistance2Bend = \frac{Strength}{Distance^2}Bend=Distance2Strength

(Insert diagram here: Shader Input → Vertex Displacement → Grass Movement)

Integration into Unity Scene

Once prefabs and shaders were ready, the grass system was integrated into a Unity test environment.

Steps:

1. Create a terrain or plane as the base ground.

2. Place grass prefabs across the terrain (manual placement or procedural distribution).

3. Attach custom shader material to grass prefabs.

○

4. Add wind zones and trigger colliders for player interaction.

The system was tested with both small grass patches and large open fields to evaluate scalability.

Optimization Techniques

Since real-time rendering is performance-sensitive, multiple optimization methods were used:

1. Level of Detail (LOD):
    - ○ Near grass uses detailed prefabs with full shader effects.
    - ○ Distant grass replaced with simpler billboards or faded textures.
2. GPU Instancing:
    - ○ Thousands of grass prefabs share the same material instance.
    - ○ Reduces draw calls, improving performance significantly.
3. Frustum Culling:
    - ○ Grass outside the camera's view is not rendered.
    - ○ Saves processing power by focusing only on visible elements.
4. Batching and Texture Atlases:
    - ○ Combined multiple textures into one atlas.

      Reduced switching overhead during rendering.

Testing Setup

The grass system was tested under the following conditions:

- Hardware Platforms:
  - Low-End (Integrated GPU, 8 GB RAM)
  - Mid-Range (GTX 1650, 16 GB RAM)
  - High-End (RTX 3060, 16+ GB RAM)
- Performance Metrics:
  - Frames Per Second (FPS)
  - CPU and GPU utilization
  - Memory usage

Tools and Technologies Used

The success of the Dynamic Grass Rendering System depends largely on the tools and technologies chosen. This section provides an overview of the platforms, programming languages, and utilities employed during development.

Unity Engine

- The project was developed using Unity 2021 LTS, chosen for its stability and support for shader programming.

    ○

- **Unity provides:**
    - ○ **Prefab system for reusable assets.**
    - ○ **Shader Graph for visual shader creation.**
    - ○ **Terrain tools for placing vegetation.**
    - ○ **Physics engine for player–environment interaction.**

Reason for choosing Unity:

- **Easy integration of C# scripting and shaders.**
- **Cross-platform compatibility (PC, mobile, VR).**
- **Large community support and documentation.**

C# Scripting

- **Used for handling game logic and interactions.**
- **Scripts managed grass instantiation, collision with players, and runtime adjustments (e.g., wind strength).**
- **Example use cases:**
    - ○ **Detecting when the player enters grass.**

      Passing player position data to shader.

- ○ Controlling global shader variables for wind simulation.

Shader Graph & HLSL

- Shader Graph was primarily used for creating visual effects such as wind sway.
- For more advanced behavior, HLSL (High-Level Shader Language) was integrated.

Shader Graph advantages:

- Node-based visual interface.
- Rapid prototyping of movement and animation effects.

HLSL usage:

- Custom vertex displacement for realistic bending.
- Mathematical functions for wind and player interaction.

Development Environment

- Hardware:
    - Processor: Intel i5 / Ryzen 5 or higher.
    - GPU: NVIDIA GTX 1650 and above (testing also done on integrated graphics).
    - RAM: 8–16 GB.

- ○

- Software:
    - Unity Hub & Unity Editor.
    - Visual Studio Code / Visual Studio 2019 (for C#).
    - Git for version control.

Profiling and Testing Tools

- Unity Profiler: Measured CPU and GPU load during rendering.
- Frame Debugger: Analyzed draw calls and GPU instancing.
- FRAPS / MSI Afterburner: Collected FPS benchmarks.
- Unity Stats Window: Tracked memory usage, polygon count, and rendering overhead.

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Results and Discussion

The Dynamic Grass Rendering System was tested under different conditions to evaluate its effectiveness, realism, and performance. The results demonstrate that the system successfully created immersive vegetation with dynamic movement while maintaining real-time rendering speeds.

Visual Results

- The grass prefabs responded realistically to wind, producing a natural swaying effect.
- Player interaction caused the grass to bend dynamically when walked through, improving immersion.
- Visual comparison showed a clear difference between static grass (immobile) and dynamic grass (animated via shaders).

Performance Testing

The system was tested on three hardware configurations to analyze scalability:

Hardware Setup	Avg FPS (Static Grass)	Avg FPS (Dynamic Grass)	Observation
Low-End (Integrated GPU, 8GB RAM)	55 FPS	38 FPS	Noticeable drop due to shader load, still playable
Mid-Range (GTX 1650, 16GB RAM)	120 FPS	95 FPS	Smooth performance, minimal stutter
High-End (RTX 3060, 16+GB RAM)	200+ FPS	170 FPS	Near-realistic movement with negligible impact

Key Findings:

- Performance impact was highest on low-end hardware but remained above playable levels (>30 FPS).
- On mid- and high-range GPUs, GPU instancing and LOD optimization ensured smooth gameplay.
- Dynamic shaders increased realism while keeping the system efficient.

Comparison with Static Grass

- **Static Grass: Lightweight, high FPS, but visually unrealistic.**
- **Dynamic Grass: Slightly heavier on GPU, but adds realism, interaction, and immersion.**

Conclusion from comparison: The trade-off between performance and realism strongly favors dynamic grass, especially in modern games where immersion is essential.

Challenges Faced

1. **Shader Complexity:**
   Writing HLSL code required balancing between visual quality and performance.
2. **Player Interaction:**
   Ensuring smooth bending of grass without breaking immersion was difficult.
3. **Optimization:**
   Without LOD and GPU instancing, performance dropped significantly, especially with thousands of grass prefabs.
4. **Cross-Hardware Testing:**
   Grass looked different on integrated vs dedicated GPUs due to rendering variations.

Discussion

- **The results confirm that prefabs + shaders in Unity can efficiently create dynamic grass.**
- **Even though performance drops compared to static grass, optimized dynamic grass is viable for real-time applications.**
- **The implementation can be extended to forests, bushes, and crops, making it suitable for open-world or simulation-based games.**

Conclusion

In this project, a dynamic grass system was successfully developed using Unity's shader programming and prefabs. The system efficiently generates realistic grass movements responding to environmental factors such as wind and player interaction. By leveraging shader techniques, performance was optimized, allowing the rendering of large grass fields without significant impact on frame rates. The project demonstrates a practical approach to creating immersive environments in real-time applications and games.

Limitations

- The grass system currently handles only basic interactions and does not support complex collisions with multiple objects.
- Performance may degrade on lower-end hardware when rendering extremely large grass fields.
- The shader effects are primarily visual and do not affect gameplay mechanics such as pathfinding or AI navigation.
- Limited variety in grass models and textures reduces overall environmental diversity.

Future Enhancements

- Implement advanced interactions, such as objects dynamically flattening or bending grass in real-time.
- Introduce Level of Detail (LOD) techniques to improve performance on larger terrains.
- Add seasonal and weather variations for dynamic environmental changes.
- Expand the variety of grass types, textures, and colors to enhance realism.
- Integrate physics-based grass responses for more interactive gameplay scenarios.

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