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Tworzenie aplikacji wieloplatformowych na przykładzie silnika gier z
gatunku "match 3"

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Streszczenie pracy

Tworzenie aplikacji wieloplatformowych na przykładzie silnika gier z gatunku "match 3"

Rynek systemów operacyjnych na PC jest podzielony na trzech głównych graczy, tworzy to zapotrzebowanie na silniki do gier, które są wszechstronne i działają tak samo, niezależnie od platformy. Niniejsza praca inżynierska przedstawia projekt i implementację nowego silnika do gier opracowanego z myślą o grach typu "dopasuj 3", gatunku który jest zarówno popularny, jak i stosunkowo łatwy do wdrożenia, mimo to nadal nie ma wyspecjalizowanego silnika open-source pod gry "dopasuj 3". Silnik został zbudowany w oparciu o bibliotekę graficzną OpenGL i system zarządzania oknami glfw, zapewniając zaawansowane możliwości graficzne przy jednoczesnym zachowaniu kompatybilności między platformami. Silnikowi przyświecają dwa cele: prostota obsługi dla deweloperów i solidna wydajność. Architektura skupia się na wykorzystaniu dobrych praktyk, nowoczesnego kodu C++ i sprawieniu że czytanie kodu silnika będzie łatwe i zrozumiałe dla developerów. W rezultacie twórcy gier mogą skupić się na tworzeniu gier typu "dopasuj 3" bez konieczności nauki programowania, umożliwiając artystom bez zaplecza technicznego, którzy chcą stworzyć wyjątkowe doświadczenie. Niniejsza praca opisuje motywację, tło, dokumentację i przypadki użycia na trzech głównych platformach: Linux, Windows i MacOS. Silnik demonstruje użyteczność, możliwość dostosowania do różnych platform i zapewnia narzędzia niezbędne do tworzenia prostych gier typu "dopasuj 3". Niniejsza praca stara się wypełnić lukę w wyspecjalizowanych silnikach gier wideo open-source. {Multiplatformowość, Gry, Silniki do gier, Gry "dopasuj 3" OpenGL, GLFW, Grafika, Design, Prostota, Linux, Windows, MacOS, C++, Dobre praktyki kodowania}

Thesis abstract

Creating multiplatform applications with creation of match three game engine as an example
With three major operating systems on PC, there exists a need for game engines that are versatile and platform-agnostic. This thesis introduces the design and implementation of a new game engine developed with match-three games in mind, which is a game genre that is both popular and relatively easy to implement, despite this there is still no specialized open-source match three game engine. The engine is built upon the foundations of the OpenGL graphics library and the glfw windowing system, ensuring advanced graphics capabilities while retaining platform compatibility. There are two goals for the engine: simplicity of use for developers, and robustness in performance. The architecture focuses on using good practices, modern C++ code and making the code developer friendly. As a result, game developers can focus on crafting match-three games without need to learn programming, empowering artists without technical background who want to create an unique experience. This work provides motivation, background, documentation and use-case across three major platforms: Linux, Windows, and MacOS. The engine demonstrates usability, adaptability to different platforms, and provides the tools necessary for creation of simple match-three games. This thesis is trying to fill the gap of specialized open-source video game engines. {Multiplatform, Gaming, Game engines, Match-three games, OpenGL, GLFW, Graphics, Platform-agnostic, Design, Robustness, Simplicity, Linux, Windows, MacOS, C++, Good coding practices}

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Chapter 1

Introduction

1.1 Background and Motivation

Among us, computer science students, video games were—and still are—one of the driving forces pushing us into the field of IT. Video games allow people with technical background to express their artistic side and create visually stunning projects. In particular "Match Three" games, characterized by their intuitive mechanics and satisfying gameplay, have attracted millions of players around the globe. They offer satisfying experience of aligning three or more similar game pieces, often resulting in gratifying chain reactions. This led to success of titles like "Candy Crush Saga" and "Bejeweled", staple titles for both mobile and desktop market.

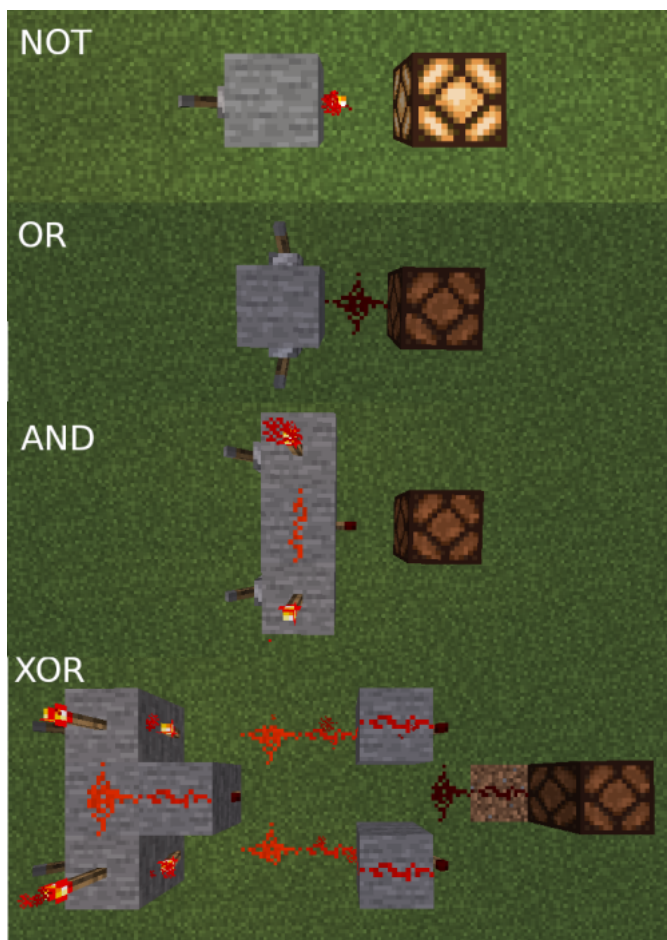


Figure 1: Minecraft redstone offers introduction to logical gates ?

Match three games are from technological point of view relatively easy to make, despite that there is no dedicated open-source game engine designed just for them. This engineering thesis aims to fill this void, to give back to the world of game developers and open-source projects.

Another motivation is a chance to learn one of the most popular graphical API - OpenGL, It is a graphical API which proved useful again and again with video game engines, rendering engines or for desktop applications.

1.2 Scope of the Thesis

Game development is a broad spectrum, This section aims to define to what extent the game engine will be developed

1.2.1 Game Engine Focus: Match Three Genre

While game engines can be created for multiple game genres, this thesis focuses on Match Three genre. This decision comes from its ease of implementation, combined with relatively high popularity and applicability on all platforms. We will focus on core logic, rendering techniques, and controls focused on Match Three games.

1.2.2 Multiplatform Development

Another important part of the thesis is multiplatform game development. We will focus on three major desktop operating systems: Windows, Mac, and GNU/Linux. The challenges associated with creating an uniform gaming experience across these platforms, taking into consideration differences in architecture, functionality and graphics.

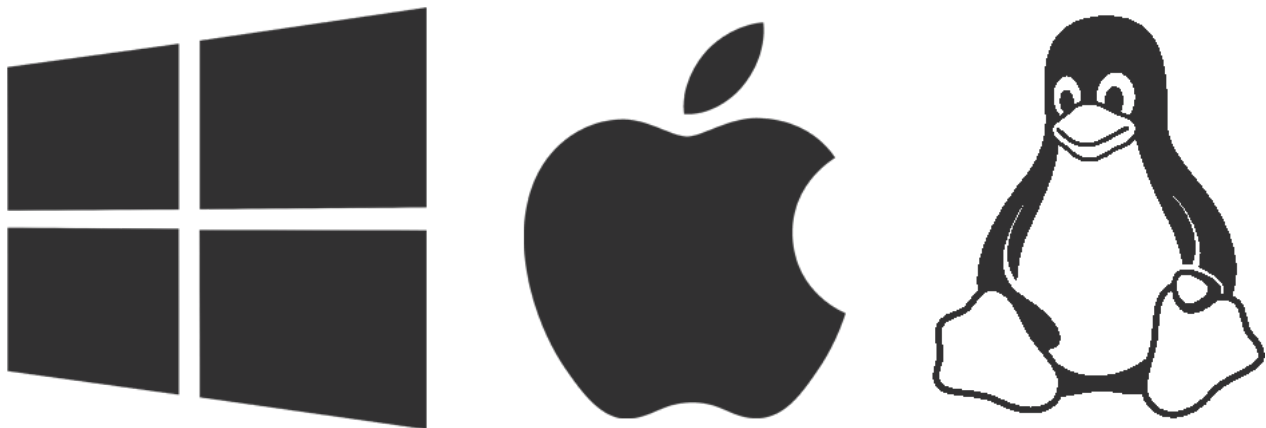


Figure 2: Logos of platforms we will be focusing on, from left: Windows, Mac and Linux [Windows Mac Linux Logo \(2009\)](#)

1.2.3 Tool and Library Integration

This thesis will make biggest use of OpenGL API together with libraries: GLFW, GLAD, FreeType, stb_image, and ft2build. In order used for platform-independed creation of windows, context and handling inputs, loader for OpenGL, library for rendering text, library for loading images and library for building free type sources. Later in the thesis we will dvelve deeper into those libraries

1.2.4 Theoretical and Practical Exploration

Main portion of this thesis is practical implementation, still we are going to explore theoretical concepts crucial for game engine development.



Figure 3: GLFW project logo [GLFW Logo](#) (2013)

1.2.5 Limitations

Since the engine aims to be simple and robust, it will not contain every possible feature or optimization like in commercial-grade game engines. The primary intent is to create a solid structure for which further advancements can be made.

In conclusion, this thesis goal is to provide an understanding of multiplatform Match Three game engine development. By setting manageable boundaries, it aims to dive deep into specific challenges, tools, and solutions, providing valuable insights for aspiring engine developers. Next sections will further describe the objectives, methodologies, and findings of this exploration into the world of game development.

1.3 Objectives of the Thesis

Clear objectives allow for accomplishments that can be measured. Therefore it is important to define goals that underpin this thesis. In this section, we describe the primary goals of this thesis.

1.3.1 Design of a Cross-Platform Core Architecture

The foremost objective is to design a core multiplatform engine architecture. This demands a good understanding of the operating systems differences, from their system calls to their graphics pipelines. The engine should be modular and scalable, in order to make sure that the core mechanics and logic can be implemented across Windows, Mac, and GNU/Linux platforms.

1.3.2 Effective Integration of Libraries

With numerous libraries at our disposal, an important goal is to combine them into the engine in a cohesive manner. We will make use of GLFW for window management, GLAD for OpenGL function pointers, FreeType and ft2build for text rendering, and stb_image for image handling. In addition to integrating them into an engine, these libraries must operate in such a way that they complement each other to improve the engine's overall performance and capability.

1.3.3 Development of Core Match Three Mechanics

Architecture and libraries used form the skeleton, the Match Three mechanics are the most important part of the engine. The aim is to create algorithms and techniques to take care of typical Match Three functionalities – from matching detection to gravity-induced piece drops and chain reactions.

1.3.4 Providing a Blueprint for Future Development

While the first objective is the engine's development, a broader goal is to expand upon created engine. By addressing challenges and sharing solutions, this thesis hopes to offer an example for engine developers. Whether they wish to enhance this engine or create new game engines. This thesis tries to improve their understanding of the topic

1.4 Match Three Games and Engines

The world of video games is vast and varied, Offering anything from massive multiplayer role playing games to small mobile puzzles. Match Three games offer players a blend of strategy, pattern recognition, and instant gratification. To better understand the significance of our task in creating a multiplatform Match Three game engine, it's important to trace how the genre evolved, understanding its roots, its development, and its appeal.

1.4.1 Origins and Early Forerunners

Match Three games owe their existence to the broader genre of tile-matching video games. The earliest entrants in this category were games like "Tetris" in the 1980s, where players manipulated falling blocks to create complete lines. "Tetris" kickstarted games focused on spatial reasoning and pattern recognition.

Expanding on this formula, 1980s and 1990s saw games like "Columns" and "Dr. Mario". These games introduced the mechanic of matching three or more identical items, but they were still using the falling-block paradigm. The true prototype of modern Match Three mechanics can be credited to "Shariki," a 1994 game where players swapped adjacent pieces to form chains of three or more identical items.

1.4.2 Mainstream Adoption and Innovations

In 2001 game titled "Bejeweled" came out. Simplifying and refining the mechanics of "Shariki", "Bejeweled" was the first mainstream success of Match Three genre. It provided intuitive gameplay, visually appealing graphics and set the benchmark for games that followed.



Figure 4: Bejeweled gameplay [Bejeweled gameplay](#) (2001)

The success of "Bejeweled" led to several innovations. Developers experimented with various twists on the core mechanics. Games introduced power-ups, barriers, objectives, and narrative elements. "Candy Crush Saga", released in 2012, integrated a level-based progression system, increasing the genre's complexity and depth.

1.4.3 Technological Influences and Platform Diversification

The evolution of Match Three games is interlocked with technological improvements in the gaming industry. Initially developed to PCs and consoles, the rise of mobile devices opened a new opportunities for the genre. The touch interface of smartphones and tablets proved to be an ideal medium for the drag-and-swap mechanics of Match Three games.

At the same time, browser-based games, using technologies like Flash, allowed players to engage with Match Three puzzles without heavy downloads or installations. As technology progressed, the need for engines that worked on multiple platforms – mobile, browser, consoles and desktop – became apparent.

1.4.4 Enduring Appeal and Contemporary Significance

Despite multiple competing genres, Match Three games remain popular. Their success can be attributed to their 'easy to learn, hard to master' trait. The games offer immediate rewards – the satisfaction of creating a match, beauty of pieces disappearing, and the strategic depth of planning several moves ahead. Additionally, the modular nature of their design allows for easy adaptation, whether it's incorporating a narrative, integrating with popular cultures, or tailoring to specific demographics.

In conclusion, the history of Match Three games is a proof to their adaptability and universal charm. They established themselves as one of the most recognizable genres in mobile and desktop gaming, they continue to gather players. This perspective marks significance of engines tailored to Match Three games specifically.

1.5 Overview of Multiplatform Game Development

Game developres try to reach wider audiences by ensuring that their creations are accessible across a variety of operating systems. Multiplatform game development aims to deliver the same experience to different user bases. This section describes challenges and methodologies connected with multiplatform game development.

1.5.1 The Need for Multiplatform Development

There are three main operating systems, Windows, Mac, and GNU/Linux which together are responsible for over 90% of desktop market share [Desktop Operating System Market Share Worldwide Chart \(2023\)](#), the potential to reach a bigger audience increases when a game is made available across all of these platforms.

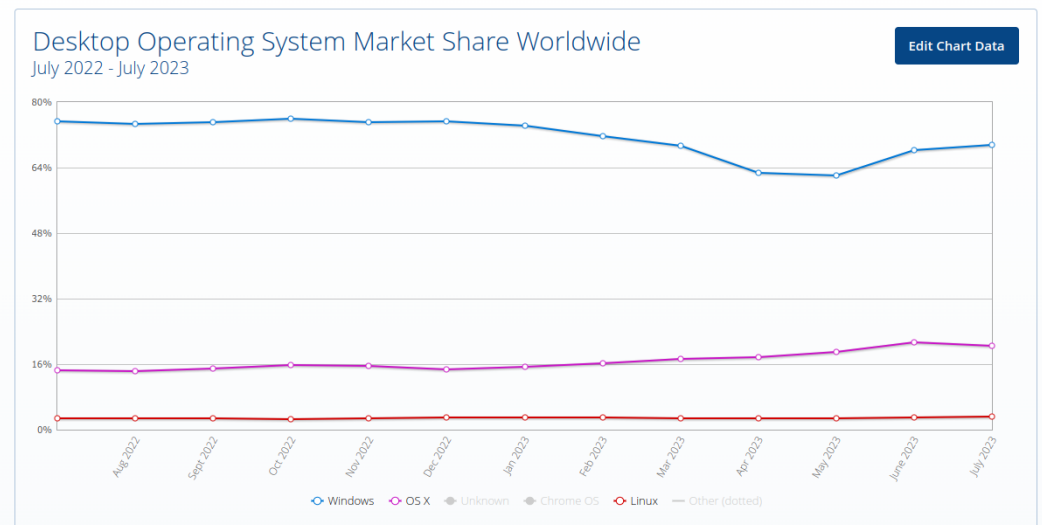
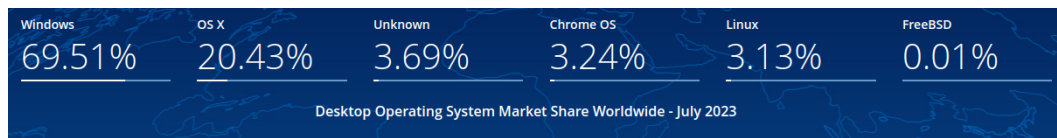


Figure 5: Desktop OS market share worldwide [Desktop Operating System Market Share Worldwide Chart \(2023\)](#)

1.5.2 Challenges in Multiplatform Development

Idea of developing once and deploying everywhere comes with its set of challenges:

- **Hardware Disparity:** Different platforms might have varying hardware specifications, which can influence the game's performance.
- **OS Specific Limitations:** Each operating system operates under its own rules, from system calls to user interface.
- **Toolchain Variability:** Development tools and libraries might have platform-specific versions or may not be available for all platforms.

1.5.3 Tools and Libraries for Cross-Platform Development

In order to face multiplatform development challenges, we use a set of tools and libraries. Libraries like OpenGL offer an unified graphics rendering solution, while GLFW enforces consistent window management and input handling. stb_image, and ft2build are other libraries that offer consistent behavior across platforms for handling images and font rendering.

1.5.4 Strategies for Effective Multiplatform Development

- **Modular Design:** By dividing the game engine into distinct modules, developers can isolate platform-specific code, ensuring that core logic remains unchanged by platform dependencies.
- **Continuous Integration and Testing:** Automated testing across platforms can identify inconsistencies, ensuring that the game offers an uniform experience.
- **Community Engagement:** Using the community that uses the game engine across multiple platforms offers developers insights into existing bugs and potential optimizations

1.5.5 Future Trajectory of Multiplatform Development

With the cloud gaming on the rise, resurrection of web-based games, and increasingly powerful mobile devices, multiplatform development's scope is constantly expanding. There will be newer platforms and more varied devices to handle. The goal will remain the same: ensuring that games offer a consistent, engaging, and seamless experience, independent of the platform.

Multiplatform game development requires technological knowledge and good design. By understanding its challenges and methodologies, developers are better equipped to face-on multiple platforms of modern gaming. This foundation will become crucial later into the development of our multiplatform Match Three game engine.

1.6 Existing Game Engines and Their Limitations

The gaming industry has seen rise of various game engines, each offering a unique set of tools and functionalities for different needs. While these engines have facilitated the creation of iconic games, they also come with certain limitations, especially concerning specific genres or platforms. This section will describe prominent game engines and analyze their shortcomings, providing a reference for our multiplatform Match Three game engine.

1.6.1 Unity Game Engine



Figure 6: Unity engine logo [Unity Game Engine Logo](#) (2005)

Unity is one of the most popular game engines available today. It's known for its versatility, supporting a wide range of platforms, from PCs to consoles to mobile devices.

- Strengths: Plenty of community resources, a vast asset store, and an intuitive interface make Unity a popular choice among both beginners and professional developers.
- Limitations: Unity's all-purpose nature might introduce unnecessary load for simpler games, like Match Three titles, potentially impacting performance.

1.6.2 Unreal Engine



Figure 7: Unreal engine logo [Unreal Game Engine Logo](#) (2014)

Epic Games' Unreal Engine stands out for its impressive graphical capabilities, often employed in AAA game titles.

Strengths:

- Blueprints: Blueprint visual scripting system allows for easier game development especially for non-technical users
- Graphics: Unreal Engine offers top-tier rendering capabilities, which makes it ideal for creating visually stunning games.

Limitations:

- Learning Curve: Its advanced features can be overwhelming for beginners.
- Simpler Genres: As with Unity, for a simple game like Match Three game, the engine might be too sophisticated, leading to longer load times and increased resource consumption compared to custom solution.

1.6.3 Godot

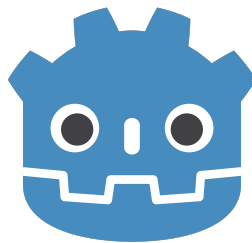


Figure 8: Godot game engine logo [Godot Game Engine Logo](#) (2014)

Godot is the biggest multipurpose game engine that is also free and open-source.

Strengths:

- No licensing: Godot is free to use
- Open: Godot source code can be accessed and modified by anyone
- Community: As with many open source projects community offers huge support for potential developers

Limitations:

- Limited professional presence: While unity and unreal dominate professional market, Godot is a less popular alternative
- Scalability: Godot game engine is not famous for building big game projects

1.6.4 RPG Maker and Ren'Py

RPG Maker and Ren'Py are examples of game engines focusing on one genre of games. RPG Maker focuses on top-down rpg games, while ren'py aims to ease the process of making visual novel games. Both of those engines were used with commercial and critical success, with creation of games like "To The Moon" and "Doki Doki Literature Club". Their limitations are both their strength and weaknesses, allowing to speedup development process but blocking the developer for leaving the area of interest for those engines.



Figure 9: Ren'Py engine logo [Ren'Py Game Engine Logo](#) (2004)



Figure 10: RPG Maker engine logo [RPG Maker Engine Logo](#) (2015)

1.6.5 Limitations

While each game engine has its unique strengths and weaknesses, some common limitations come apparent when considering the development of a specialized game like a Match Three title, those engines either do not allow for match three development (RPG Maker or Ren'Py) or deliver match three titles with too much technological bloat (Unity/Unreal/Godot)

While existing game engines offer a lot of tools and capabilities, there exists a space for specialized engines made for specific genres. Recognizing the limitations of mainstream engines explains development of our multiplatform Match Three game engine, which tries to fix these gaps while providing an easy development.

Chapter 2

Basics of Game Engine Design

2.1 Core Components of Game Engines

Game engines serve as the backbone for game development, providing a selection of tools and features that simplify the process of creating a game from scratch. At the heart of every game engine lie its core components, which define its capabilities, flexibility, and performance. This section explains those elements that we are going to implement in our engine.

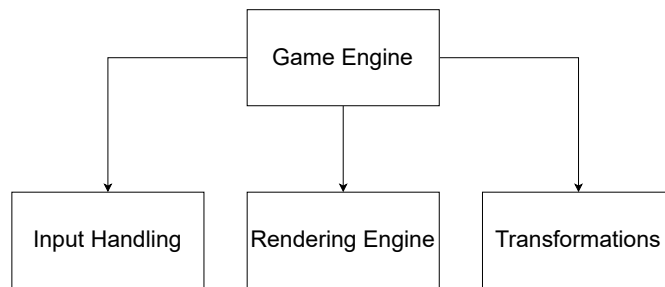


Figure 11: Components used in our game engine

2.1.1 Rendering Engine

The rendering engine is responsible for all visual aspects within a game. It takes the game's data – including textures and shaders – and converts them into pixels on the screen.

- **Role:** Ensures that all visual elements, from static backgrounds to animations, are displayed with clarity, smoothness, and consistency.
- **Key Features:** Supports various rendering techniques such as ray tracing, rasterization, and shadow mapping to enhance visual quality.

2.1.2 Input Handling

Games are interactive by nature, and this interaction is delivered by the engine's input handling system.

- **Role:** Processes user inputs from various sources, like a keyboard, mouse, gamepad, or touch screen. Translates these inputs into in-game actions or commands.
- **Key Features:** Detects multiple simultaneous key presses, supports touch gestures, and allows for input remapping.

2.1.3 Transformations

In order for object in game to move, game engine must handle its position on screen, this is a job of transformation system

- Role: Move objects based on user input, delete, add and modify existing coordinates
- Key Features: Matrices and vectors calculation

Each component of game engine plays a different role, in combination they ensure that the game runs smoothly, offers an enjoyable experience, and responds to user interactions. These core parts form the foundation upon which our multiplatform Match Three game engine will be built and updated.

2.2 The Role of OpenGL in Game Development

Game engines need graphics libraries, those libraries provide the necessary tools to bring visual elements to the screen. Among these libraries, OpenGL (Open Graphics Library) has established itself as one of the most popular choices for graphics rendering. This section explores the role of OpenGL in game development, focusing on library functionalities and how they can be used.

2.2.1 Introduction to OpenGL

OpenGL is a cross-language, cross-platform application programming interface (API) designed for rendering vector graphics. Initially developed by Silicon Graphics in the 1990s, it is now taken care by the non-profit technology organization, the Khronos Group. It is platform-agnostic which makes experience consistent across different platforms.

2.2.2 Rendering Mechanism

At its core, OpenGL is about rendering. It provides developers with the tools needed to draw complex 3D and 2D graphics.

- Role: OpenGL communicates directly with a system's GPU (Graphics Processing Unit) and translates the game's data into visual elements displayed on screen.
- Key Features: Supports techniques such as texture mapping, anti-aliasing, and shader programming.

2.2.3 Shader Programming

Shaders allow for creating stunning visuals programmatically, and OpenGL provides extensive support for shader programming.

- Role: Shaders allow developers to program the GPU directly, which gives massive control over how individual pixels or vertices are processed.
- Key Features: OpenGL's GLSL (OpenGL Shading Language) lets developers create custom shaders, enabling dynamic lighting, shadows, and other advanced visual effects.

2.2.4 Extensibility

One of OpenGL's strengths lies in its extensible design, allowing to include advancements in hardware and software.

- Role: As hardware evolves, new extensions can be added to OpenGL without changing the entire API. This makes OpenGL relevant, independent of technological improvements.
- Key Features: These extensions can be used to utilize latest graphics hardware capabilities, making games look and perform their best.

2.2.5 Cross-Platform Development

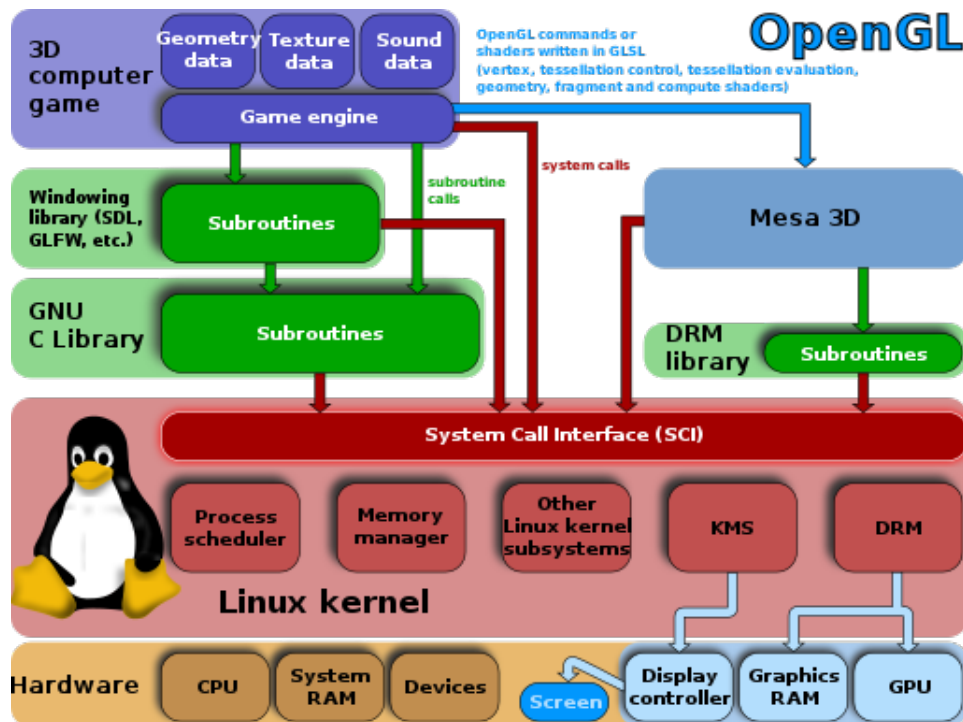


Figure 12: Connection between Linux and OpenGL-based games [Linux kernel and OpenGL video games \(2014\)](#)

Gamers are spread across Windows, Mac, GNU/Linux, and other platforms, OpenGL's platform-independent allows for creating games for all platforms.

- Role: OpenGL ensures that games look consistent across different platforms, easing the process of multiplatform game development.
- Key Features: It abstracts underlying platform-specific differences, allowing developers to focus on creating the game without need to adapt to platform-specific constraints.

2.2.6 Integration with Other Libraries and Tools

OpenGL is compatible with many libraries and development tools.

- Role: Enhances OpenGL capabilities by working with libraries like GLFW for window management, GLAD for handling extensions, and more.
- Key Features: Provides an unified development environment, where various tools and libraries work together under OpenGL, again simplifying the process of game development.

In summary, OpenGL combines software and hardware, enabling developers to create experiences with enough precision and speed. Understanding impact of OpenGL will make explaining our own game engine inner workings much easier.

2.3 Multiplatform Considerations

In order to reach as wide an audience as possible, developers try to develop a game for multiple platforms – mostly Windows, Mac, and GNU/Linux. Creating multiple platforms game engine is filled with challenges and considerations. This section explores difficulties of multiplatform game development, describing what developers must be conscious of when targeting multiple operating systems.

2.3.1 Platform-Specific Hardware and Software

Every platform has its unique hardware and software configurations, which influence a game's performance and appearance.

- Role: Ensuring the game runs smoothly across different hardware setups, from different GPU architectures to memory configurations.
- Key Features: Developers need tools to abstract these hardware-software differences, allowing the game engine to react dynamically based on the platform.

2.3.2 User Input Variations

Different platforms often have different input methods, from touchscreens to gamepads to keyboard-mouse setups.

- Role: Making sure that the game responds accurately to various input methods.
- Key Features: Input handling system that can detect and adapt to different input devices.

2.3.3 Graphical Rendering Nuances

There are platform-specific nuances in how graphics are presented.

- Role: Making engine work under different display resolutions, aspect ratios, and screen sizes.
- Key Features: Dynamic resolution scaling and responsive UI layouts to ensure the game looks similar across platforms.

2.3.4 File System and Data Management

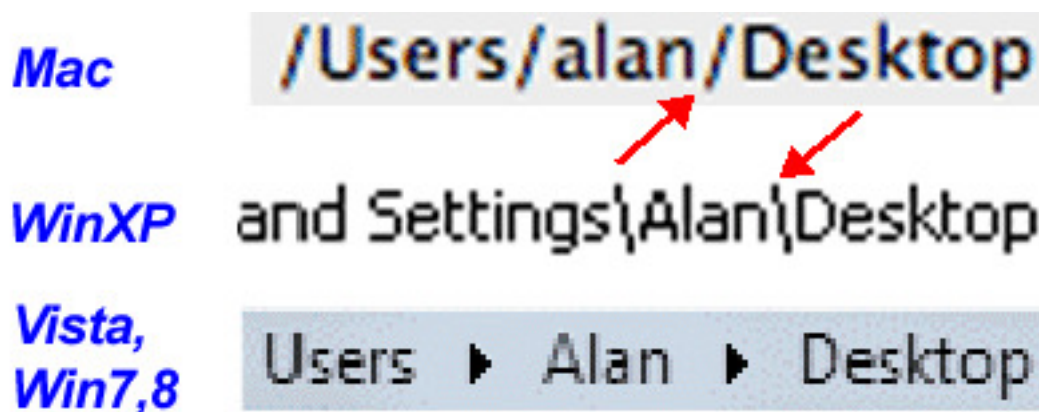


Figure 13: Separating folders with backslash and forward slash is one of many differences between Windows and Linux systems [PCMag encyclopedia backslash](#) (2013)

File systems vary between Windows, Mac, and GNU/Linux, influencing how game data is stored, retrieved, and updated.

- Role: Managing game saves, configurations, and other data across platforms.
- Key Features: Data management system that behaves the same for platform-specific directory structures and access permissions.

Chapter 3

Toolchain and Libraries Overview

3.1 Introduction to GLFW

In the arena of game development, libraries related to window management and input handling play crucial role. GLFW offers an interface for developers to create interactive applications. This section offers an introduction to GLFW, explaining into its origins, functionalities, and relevance in game development.

3.1.1 Historical Context

GLFW, which stands for Graphics Library Framework, was a response to the need for an open-source library that simplifies the challenges of window management and input handling, especially for OpenGL applications. Initially developed to provide a more straightforward alternative to existing solutions, GLFW has grown in popularity due to its simplicity, efficiency, and cross-platform capabilities.

3.1.2 GLFW's Core Competencies

GLFW serves as a bridge between the game's logic and the operating system, handling tasks that are crucial for interactive applications.

- **Window Management:** GLFW's manages window creation, querying, and manipulation. It allows developers to focus on their game logic rather than handling platform-specific windowing.
- **Input Handling:** GLFW provides a system to capture and process user inputs. It forms for keyboard strokes, mouse movements, or even joystick inputs, GLFW makes sure that user interactions are detected and communicated to the application efficiently.
- **Context Management:** Especially relevant for OpenGL applications, GLFW helps create contexts, manage profiles, and handle extensions, for easier development experience.

3.1.3 Integration with OpenGL

While GLFW is platform-agnostic and can support multiple rendering systems, its mostly used with OpenGL.

- **Role:** It functions as the companion to OpenGL, offering an environment where OpenGL can work more efficiently by addressing system-specific challenges that are outside OpenGL's specification.
- **Key Features:** Context creation for OpenGL.

3.1.4 Cross-Platform Capabilities

GLFW's is able to work across Windows, Mac, and GNU/Linux.

- Role: GLFW is a consistent interface for developers, regardless of the target platform. This ensures uniformity in window creation, input handling, and other functionalities across different operating systems.
- Key Features: An architecture that ensures platform-specific norms while offering a consistent API for developers.

3.1.5 Community and Support

Being open-source, GLFW benefits from a huge community that continually refines, optimizes, and extends the library.

- Role: Ensures GLFW remains up-to-date, addresses challenges and evolves with the needs of developers.
- Key Features: Tutorials and forums, assisting both new and trained developers in using GLFW

GLFW proves useful to many game developers, especially those using OpenGL. Its ability to handle window management, input processing, and other tasks ensures that developers can focus on crafting game mechanics and narratives.

3.2 Role of GLAD in OpenGL Loading

GLAD is a robust and flexible loader-generator designed for OpenGL. It ensures the dynamic loading of OpenGL functions based on the specific version and extensions a developer chooses. GLAD was developed to automate handling OpenGL extensions.

3.2.1 The Need for Loading OpenGL Extensions

OpenGL's is an extensible API. With changes in hardware, new functionalities are introduced through extensions without changing the core API. This creates new challenges on their own.

- Role: Extensions allow developers to use the latest graphics capabilities, which are not always part of the core OpenGL library.
- Key Features: Handling these extensions requires dynamic loading at runtime, so that the game can access and utilize these advanced functionalities.

3.2.2 GLAD's Functionality in Extension Loading

GLAD simplifies working with OpenGL extensions through its automated approach.

- Role: Provided with the OpenGL version and extensions, GLAD generates C/C++ code to load these extensions dynamically at runtime. This removes the need to manually address each extension, reducing errors and inefficiencies.
- Key Features: GLAD supports multiple languages and specifications. It is also up-to-date with the latest OpenGL specifications, making it compatible with newest graphics capabilities.

3.2.3 Integration with GLFW and OpenGL

GLAD interacts with both OpenGL and GLFW, creating an unified development environment. Once GLFW creates the OpenGL context, GLAD is utilized to load the necessary functions. This collaboration ensures that GLFW handles the platform-specific instructions, while GLAD focuses on OpenGL's extensibility.

3.3 Handling text and images with FreeType, ft2build and stb_image

3.3.1 Introduction to FreeType

FreeType is an open-source software font engine, It offers ability to render text onto bitmaps and other font-related functionalities.

3.3.2 Key Capabilities of FreeType

- **Font Parsing and Loading:** Before rendering, fonts need to be parsed and loaded. FreeType supports many font formats, ensuring broad compatibility.
- **Glyph Rendering:** FreeType is good at converting individual glyphs into bitmaps, handling anti-aliasing and hinting to create clear, sharp text rendering.
- **Font Metrics and Kerning:** Rendering text isn't just about individual glyphs. The spacing between them (kerning) and their metrics are crucial for readability and aesthetics, and FreeType is able to deliver this functionality.

3.3.3 Understanding ft2build

ft2build serves as an essential interface, allowing for the inclusion and deployment of FreeType headers in development projects. ft2build was created to ease the integration process of FreeType 2.

3.3.4 Introduction to stb_image

While FreeType takes charge of fonts, stb_image is a solution for image loading and decoding, popular for its simplicity and compactness. It is part of the stb collection of single-file libraries.

3.3.5 Key Capabilities of stb_image

- **Image Loading:** It is capable of handling popular formats like JPEG, PNG, BMP, and more, this way developers can incorporate multiple types of graphical assets into their game
- **Image Decoding:** stb_image decodes images into a format that can be directly used with OpenGL or other rendering systems.
- **Simplicity and Efficiency:** stb_image has minimalistic design. With just a single header file, developers can use its capabilities without employing complex dependencies or configurations.

Specialized tools like FreeType and stb_image elecate the visual experience of games with text rendering and images inclusion into game engine

Chapter 4

Design and Architecture of the Match Three Engine

4.1 Game Loop and State Management

In the heart of every video game lies the game loop. This cycle dictates the game's pacing, ensuring that events, updates, and rendering processes all appear in a correct order. Game loop functions together with state management, which ensures the game behaves consistently in response to player actions and internal events. This section will focus on both the game loop and state management and how they influence our multiplatform Match Three game engine.

4.1.1 The Anatomy of a Game Loop

The game loop is a repetitive process that continues for the lifespan of the game session. It tries to:

- Poll Input: Gather and process player inputs.
- Update Game State: Based on the inputs and game rules, modify game entities and overall state.
- Render: Draw the current state of the game onto the screen.
- Sleep (Optional): Introduce a short delay, if necessary, to control the loop's frequency and match the target framerate.

4.1.2 Importance of State Management

As games grow complex, they may contain numerous states, including:

- Menu Screens: Where players can start, configure settings, or view credits.
- Gameplay Modes: Different modes or levels of gameplay, each with its unique rules and environments.
- Pause/Resume States: Allowing players to stop the game and later resume it.
- Endgame Scenarios: Winning, losing, or drawing conditions.

State management ensures the game recognizes and responds appropriately to these states.

4.1.3 Interlinking Game Loop and State Management

Game Loop and State Management must work together:

- State-Driven Rendering: What the game displays during each loop iteration depends on its current state. For instance, the game may render a main menu, gameplay screen, or a 'game over' message based on its active state.
- State Transitions: Player inputs or internal events can trigger state changes. The game loop continually checks for such triggers and initiates the necessary transitions.

4.1.4 Challenges and Considerations

Managing a game loop and states is filled with challenges:

- **Performance:** The game loop must run efficiently to maintain smooth gameplay, especially crucial for real-time games where fast decisions matter.
- **State Persistence:** Some states may require data persistence, like saving a game, which requires storing and retrieving game data.
- **Synchronization:** Ensuring that state transitions and game loop iterations are in sync is essential to avoid unexpected behaviors.

4.1.5 Role in the Multiplatform Match Three Game Engine

For our game engine, the game loop and state management fulfill following functions:

- **Cross-Platform Consistency:** The game's behavior, pacing, and responses should be consistent across Windows, Mac, and GNU/Linux platforms.
- **Match-Three Logic:** The game engine will manage states specific to match-three mechanics, like checking for matches, handling cascades, and introducing new game pieces.

In summary, game loop maintains the rhythm of the game, while state management ensures logic in the game's behavior.

4.2 Asset Management and Rendering

Game development consists of art and logic, where visual assets behave based on game code. Ensuring these assets are well-organized, efficiently loaded, and rendered is vital for any gaming experience. This section explores asset management and rendering.

4.2.1 What are Game Assets?

In the context of game development, assets refer to:

- **Graphics:** These include textures, sprites, animations, and UI elements.
- **Data:** Configurations, level designs, scripts, and other data structures that define gameplay mechanics.

4.2.2 Rendering: Bringing Assets to Life

Once assets are organized and loaded, rendering puts them onto the screen:

- **Displaying Graphics:** Textures and sprites are mapped onto game entities.
- **Shaders & Effects:** Advanced graphical effects, such as lighting, shadows, and particle effects, are layered on to assets to elevate visuals.

4.2.3 Cross-Platform Considerations in Asset Management

Given our engine's multiplatform nature, certain challenges arise:

- **Format Compatibility:** Not all asset formats are supported uniformly across platforms. Ensuring assets are in universally compatible formats and using libraries like `stb_image` that unify asset formats among different operating systems is crucial.
- **Optimization:** Different platforms may have varying memory capacities and processing power. Assets might need to be optimized, resized, or compressed to respond to those limitations.

4.2.4 Role in the Multiplatform Match Three Game Engine

Our game engine's being multiplatform complicates assets rendering:

- **Uniformity Across Platforms:** Visual experience should remain consistent across Windows, Mac, and GNU/Linux.
- **Match-Three Specifics:** Given the genre, the engine must effectively manage assets like gems, power-ups, grid structures, and cascade animations and then render them in a visually pleasing way.

4.3 Event Handling and User Input

Main trait of video game is interactivity. Game must have the ability to capture, interpret, and respond to user input, whether it is the click of a mouse, the press of a keyboard key, or the swipe on a touchscreen. Managing those interactions is called event handling. In this section we will describe event handling and user input, and their role in our game engine.

4.3.1 Understanding User Input and Events

Every action by the user generates an event. This event contains specific data, such as:

- **Type of Input:** Whether it's a key press, mouse movement, click, or touch.
- **Coordinates:** In case of mouse or touch, the precise location of the interaction.
- **Duration:** The length of time an input is maintained, like a long press.

4.3.2 Event Polling vs. Event Callbacks

There are two primary ways to handle these events:

- **Event Polling:** The game loop consistently checks (or "polls") for user inputs at fixed intervals, processing any detected events.
- **Event Callbacks:** The system is set up to notify (or "call back") the game engine immediately when an event occurs.

4.3.3 Role in the Multiplatform Match Three Game Engine

Our game engine should provide following features connected with user input:

- **Intuitive Matching:** Selecting and swaping game pieces should be easy and convenient, with the engine accurately capturing and responding to these interactions.
- **Feedback Loop:** Upon receiving an input, the game engine must also provide immediate feedback, such as highlighting a selected piece, initiating a combo move or playing animation.

Event handling and user input are ways for players to communicate with the game. It is crucial to make them intuitive and smooth.

Chapter 5

Cross-Platform Development Challenges and Solutions

5.1 Operating System Variabilities

Operating systems (OS) are a middle ground between human interaction and hardware functionality. With Windows, Mac, and GNU/Linux operating systems as the most popular desktop environments, a multiplatform game engine must work under each of them. This section describes differences between these operating systems and how our engine can handle them.

5.1.1 Core Architectural Differences

Some of the distinctive features of OS architecture are:

- **Kernel Design:** Windows uses a hybrid kernel, while Linux is a monolithic kernel, MacOS is based around Unix XNU kernel.
- **File Systems:** Windows primarily offers NTFS, MacOS stores files using APFS, and GNU/Linux has multiple options like ext4, Btrfs, and many, many more.
- **APIs & System Calls:** Each OS provides developers with its own set of APIs and system calls, changing how software communicates with the system.

5.1.2 Graphical User Interface (GUI) Divergence

Differences in GUI of each OS:

- **Window Management:** Windows uses a floating window system, MacOS has its unique mission control, and Linux distributions can use anything from floating, fixed to no graphical interface at all.
- **Input Methodologies:** Multi-touch gestures work different under MacOS than under Windows. Linux, depending on its distribution and desktop environment, may have a the same or different approach altogether.

5.1.3 Driver Support

Certain hardware, sometimes crucial to game engine like graphics card or keyboard, might be optimized for one OS over the others, or might not be supported entirely.

5.1.4 Middleware & Third-party Libraries

The accessibility, performance, and support of middleware and third-party libraries can differ, while some libraries are universally compatible, others might be OS-specific, another problem might be with the update cycle, the frequency of libraries updates can vary, impacting game engine compatibility and performance.

5.1.5 Implications for the Multiplatform Match Three Game Engine

Operating system variances impact directly on our game engine:

- **Performance Optimizations:** Depending on the OS, certain code paths might be more efficient. The engine must be adaptable.
- **Consistent Gameplay Experience:** Players on all platforms should have a similar gameplay experience.
- **Updates & Maintenance:** As OSs change, the game engine must be ready for regular updates to ensure compatibility.

Multitude of operating systems poses challenges for game engine developers. By understanding these differences, developers can make sure that the game functions across different platforms.

5.2 Addressing Hardware and Driver Differences

Hardware and its associated drivers act as the final execution devices for any game engine. When creating a game engine, developer must keep in mind a variety of hardware configurations and their driver implementations. This section focuses on understanding these differences and how we can challenge them.

5.2.1 A Landscape of Diverse Hardware

Across all platforms, multiple hardware components exist:

- **Processors:** Mostly Intel and AMD's x86 architecture (32 and 64 bits), together with ever more popular ARM processors
- **Graphics Cards:** NVIDIA, AMD, and Intel dominate the market, each with their architectures and feature sets.
- **Memory Configurations:** RAM specifications, speeds, and type of storage devices (SSDs and HDDs) can influence performance.
- **Input Devices:** Various keyboards, mice, touchpads, touchscreens, and game controllers, each have unique specs and capabilities.

5.2.2 Drivers: The Link to Hardware

Drivers allow an operating system to interact with hardware:

- **Proprietary vs. Open-Source:** While NVIDIA provides proprietary drivers, AMD and Intel often offer open-source alternatives for Linux. There are also community driven, universal, open-source drivers.
- **Update Frequencies:** Hardware vendors release driver updates at different intervals, each update possibly affects game performance and compatibility.
- **Feature Support:** New hardware features may be enabled in driver updates.

5.2.3 Challenges Posed to Game Engines

- **Optimization Issues:** What's optimized for one graphics card might not be for another.
- **Feature Inconsistencies:** Some hardware may support specific graphical features, while others might not.
- **Input Latency Variations:** Different input devices and their drivers can lead to varied response times and inconsistent responses.

5.2.4 Abstraction Layers in Match Three Game Engine

To address these challenges, our engine adopts abstraction layers: by utilizing existing libraries and solutions (OpenGL, GLAD and GLFW), our game engine is ready for easier adjustments for specific hardware.

Chapter 6

Implementation Details

6.1 Core Engine Implementation

For our Match Three game engine, we aimed to create a simple core, capable of ensuring basic gameplay and small codebase allowing developers to extend or modify the engine's capabilities as needed. This section describes the implementation of the Match Three game engine.

6.1.1 Foundational Principles

- Platform Independence: Core engine functionalities independent of any specific platform, allowing for easy porting across Windows, MacOS, and GNU/Linux.
- Simplicity: There are no more than 2500 lines of code in the entire engine
- Good coding style: When writing code, popular coding styles of cpplint and clang-tidy were used
- Good coding principles: when writing code, clang-tidy was extensively used to highlight potential errors and eliminate bad practices

6.1.2 Core Modules

The engine's architecture is segmented into modules:

- Game object: (`game_object.cpp`) Defines base class for game objects used by the engine, this class is later used to define tiles
- Main Game class: (`game.cpp`) This class combines all of the other modules and runs the game loop
- Game Level: (`game_level.cpp`) Loads and saves game levels.
- Particle Generator: (`particle_generator.cpp`) Generates particle effects for tiles
- Post Processor: (`post_processor.cpp`) Combines particle and shader effects
- Resource Manager: (`resource_manager.cpp`) Handles assets and shaders files
- Shader: (`shader.cpp`) calculates shaders and applies their effects
- Sprite Renderer: (`sprite_renderer.cpp`) Renders sprites from images
- Text Renderer: (`text_renderer.cpp`) Renders text
- Texture Renderer: (`texture.cpp`) Renders textures

6.1.3 Dependency Management

There are several libraries: OpenGL, GLFW, stb_image and freetype being integrated into engine, they are simply included at the top of any files that need them.

6.1.4 Constants file

Game parameters, from graphics settings to gameplay variables, are stored in constants.cpp file, which can be modified, to apply the changes the engine must be compiled again.

6.2 Match Three Logic and Mechanics

Match Three game challenges players to align identical items in rows or columns of three or more. This section describes how the Match Three logic and mechanics were implemented within our game engine.

6.2.1 The Fundamental Game Grid

A Match Three game takes place on a grid, where each cell holds an item (tile):

- **Dynamic Grid Generation:** The engine supports grids of various sizes, ensuring adaptability for different game designs or levels.
- **Item Diversity:** While classic Match Three games primarily used jewels or candies, our engine supports any kind of 2d image assets user wants to use, these assets can later be processed by user created shaders

6.2.2 Matching Logic

- **Pattern Recognition:** The engine monitors the grid, identifies patterns where three or more items align vertically or horizontally.
- **Combo Chains:** Beyond the basic three-item match, the engine recognizes and rewards larger matches and cascading chain reactions.

6.2.3 Player Interactions and Moves

- **Drag and Swap:** The primary interaction method, where players drag items to swap positions and create matches.
- **Move Validation:** Not every swap leads to a match. The engine predicts potential matches before finalizing a move, ensuring players don't make invalid swaps.

Our engine offers basic match three experience with couple of additional features added on the top.

6.3 Integration of Libraries and Tools

In this section we will explain rationality for choosing libraries and tools for our engine and how they were implemented

6.3.1 Choice of graphic rendering API

There are 3 main APIs for graphical rendering

- DirectX
- OpenGL
- Vulkan

DirectX developed by Microsoft focuses on Windows operating systems and Microsoft line of consoles Xbox, it is deemed as being harder with more low level programming and requiring better understanding of how underlying mechanisms work but in turn offers functionalities and better performance. It does not have free license.

OpenGL is developed by Khronos Group and offers good compatibility, especially if using OpenGL ES subset which works on Windows, Linux, Mac OS, Android, iOS and all major consoles. It is widely recognized as easiest of APIs and most popular choice for writing first game engine. On the other hand it lacks some of more advanced features which have to be written manually. It uses open source license similar to BSD

Vulkan is also developed by Khronos Group and as such is deemed as a spiritual successor of OpenGL with focus on using modern C++ features and fixing issues created by OpenGL 30 years old development time. Out of these three it is recognized as the hardest one as it is both complicated and newest. Similarly as OpenGL it uses open source license, namely Apache License 2.0.

Considering all of those characteristics I decided to go with OpenGL API, specifically OpenGL ES subset with its focus on compatibility as making a multiplatform application is one of the focuses of this thesis. I decided that since this will be my first attempt at game engine development I need something that is relatively easy and has a lot of resources online. I would most likely not use advanced features of Vulkan and DirectX and therefore finish my thesis before approaching problems where OpenGL does not deliver more complicated architecture. From my own private preferences I also prefer software with open source license.

6.3.2 Choice of OpenGL Library

There are 4 basic OpenGL libraries that I considered:

- freeGLUT
- SDL
- SFML
- GLFW

freeGLUT was created as opensource alternative to GLUT, is considered to be the worst out of all 4, written in archaic way, using C or very old C++, which in turn results in unexpected "buggy" behaviour, it is also not really popular with lack of online guides

SDL - Simple DirectMedia Layer has big userbase, it is not designed to be used as a standalone library and requires additional libraries to do networking or to create more complex applications.

SFML is the library with most features out of all 4, it supports networking, audio and has system features by default. It uses modern object oriented C++. Main problem with SFML is that it is not very popular API, therefore troubleshooting problems with SFML is quite hard and it has only few use guides online

GLFW is an library that is both the most popular and with fewest features by default. It forces users to use additional libraries for networking, sound, physic calculations and so on but in turn is also quite small and flexible. It has biggest community and a lot of guides, like one hosted at learnopengl.com or one created by programming youtuber Chernov

I decided to use GLFW library. I wanted something that is relatively easy to troubleshoot and has abundance of learning materials online.

6.3.3 GLAD and OpenGL Extension Handling

GLAD enabled the dynamic loading of OpenGL functions, this way engine can use the latest OpenGL features.

6.3.4 Text and Image Rendering with FreeType, stb_image, and ft2build

FreeType and stb_image were chosen for their simplicity and popularity

- Font Rendering: With FreeType and ft2build, the engine can render text, crucial for messages, scores, and menus.
- Image Loading: stb_image simplifies the task of loading and processing various image formats, from PNGs and JPGs to more complex formats, making asset integration much easier.

Chapter 7

Case Study: Development of a Prototype Match Three Game

7.1 Game Concept and Design

In order to gauge the usability of our game engine, we decided to create a sample match three game using royalty free assets. First part of this process was game design

7.1.1 Game Theme and Narrative

We decided to create a classic gem filled match three game, comparable to old bejeweled games.

7.1.2 Core Mechanics and Gameplay

Game utilizes full functionality of our engine, player needs to match three or more gems, chaining matches or achieving higher combos grants the player higher score

7.1.3 User Interface and User Experience

- Game HUD: The Heads-Up Display is minimalistic, showcasing only essential elements like score and moves left.
- , Feedback Mechanics: Animations, particles and shaders provide feedback for successful matches and combos.

7.2 Application of the Engine in Real-world Development

After designing the game, we started creating it using our game engine.

7.2.1 Seamless Integration with Game Design

Since the engine was created exactly with this type of game in mind, brining design decisions to life was very easy

7.2.2 Challenges in Implementation

Biggest challenge was our toolset, we had to either modify the existing engine solutions or create new one from scratch.

7.2.3 Advantages of a Custom-built Engine

- Optimized Performance: Tailored specifically for a Match Three game, the engine could be highly optimized for this genre, reducing unnecessary overheads. Using OpenGL and plain C++ also added to engine speed
- Direct Control: Having complete control over engine we could introduce, modify, or remove features as needed.

We were able to create a game using our engine, which means that the goal of this entire thesis was reached.

Chapter 8

Future Work and Enhancements

8.1 Potential Extensions to the Engine

While we were able to produce a game using our engine, it still has a potential to grow more and introduce many new features.

8.1.1 Enhanced Graphics and Physics

Enhancing the visual and interactive experience:

- Ray Tracing: Using ray tracing can provide more realistic lighting, shadows, and reflections, increasing visual depth with little cost to an engine user.
- Advanced Particle Systems: Enhancing particle effects can create more immersive environments, from weather effects to more dynamic game elements.
- Physics Enhancements: More advanced physics simulations can improve feel to game interactions, from simple collisions to complex motion dynamics.

8.1.2 Adaptive Difficulty

Machine learning can analyze player performance and adjust game difficulty in real-time, ensuring a balanced challenge.

8.1.3 Real-time Multiplayer

Adding capabilities for online multiplayer modes can increase engagement, replayability and competitiveness.

8.1.4 More platforms

Engine could be adapted to work under mobile systems (Android and IOs) and consoles (Xbox, PlayStation and Switch)

As can be seen there are still a lot of features that can be added to our engine to make it even more useful

Chapter 9

Conclusion

9.1 Summary of Achievements

In this section we will look back at our project and describe our achievements.

9.1.1 Multiplatform Support

- OS Versality: We successfully developed a game engine that operates across Windows, Mac, and GNU/Linux platforms, addressing the title of this thesis.
- Addressed Platform-specific Challenges: Overcame technical challenges associated with different operating systems, ensuring a consistent user experience.

9.1.2 Library Integrations

We managed to integrate libraries such as GLFW, glad, freetype, stb_image, and ft2build, all within one game engine

- GLFW/glad: easing the process of using OpenGL
- freetype/ft2build: allowing for rendering text within game
- stb_image: for ease of importing image assets into game engine

9.1.3 Robust Game Mechanics

- Match Three Logic: Core match three logic was implemented, matching 3 or more tiles, chain reactions and limited moves
- Event Management: The game responds successfully to user interactions

9.1.4 Practical usage

We managed to create a fully functional match-three game, using only our game engine and royalty free assets.

9.1.5 Contributions to the Field of Game Development

Our engine allows aspiring game developers to create their own match three games, and engine developers to learn from it and expand it.

In conclusion, we managed to accomplish all of the goals we set for this thesis, our engine successfully produces a game for all three operating systems we were aiming for.

9.2 Reflection on the Development Process

Creating this game engine was a long process, it took almost a year to bring it to the state it is now in, during this time several reflections came about.

9.2.1 Embracing the Multiplatform Challenge

In order to overcome differences for different operating system, a lot of time was put into choosing correct graphical api and libraries that could work on Windows, GNU/Linux and MacOS. This proved crucial when later developing the engine as this issue did not come back and I could focus on creating the engine itself.

9.2.2 Library Integrations

Using multiple different libraries and integrating them with our game engine was a challenge, thanks to existing solutions like learnopengl repository which already overcame those difficulties and KDevelop easy approach to external libraries it was possible to implement all of libraries within our game engine.

9.2.3 Time management

Lastly, probably the biggest challenge was managing time for this thesis. Finishing it required a lot of determination, setting barriers and working every day to ensure that the thesis is finished on time. Thankfully past experiences helped in guiding through this task that could be compared to colossus.

Chapter 10

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Chapter 11

Appendices

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