

VNU-HCM
UNIVERSITY OF SCIENCE
FACULTY OF INFORMATION TECHNOLOGY

FINAL PROJECT REPORT

Project: Mario Game

Course: CS202 - Programming Systems

Students :

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1 Abstract:

This report will outline our group's work on the Mario game, including high-level architecture, implementation details, and all features of the game we made; it will show how the project adheres to SOLID principles and puts in use certain Gang-of-Four (GoF) design patterns to make development more robust. This report will also delineate technical difficulties we encountered and improvements we think can be made in the absence of time constraints. We also attach in this report a link to the live demonstration of the game.

2 Introduction:

As part of our CS202 - Programming Systems coursework, we are to create a Mario game clone that utilizes object-oriented (OO) concepts and design patterns we have learned. For this project, we have developed a simple 3-level game with basic blocks, power-ups, and enemy system, with a level editor and collision handler designed from scratch. We make sure that the game's architecture follows SOLID principles and implements around 5 GoF design patterns which we will explore further in this report.

3 Program Features:

3.1 Available features:

The game supports three main features: Play, Load, and Editor. Additionally, the Setting menu provides controls over certain aspect of the game. Below are the detailed explanation to each of these features:

1. **Play:** The "story mode" gameplay option, where users play the three levels in order. Before starting to play, players can select between two characters: Luigi or Mario. The game then load the selected characters into the first map.
2. **Load:** Players can choose one in the three levels in the "story mode" to play.
3. **Editor:** In the editor, players can make a map of their own to play. Players can save the map in two ways: to an in-built folder or to a specified path using a file dialog; they can load the same map from the file dialog as well.

4. **Settings:** Players can adjust the volume of sound effects and music. While playing, they also have the option to pause the game or return to the main menu (with or without saving their progress).

3.2 User Interface (UI):

- Using Raylib, a GUI library aimed towards game development, and royalty-free resource packs online, we design a user-friendly interface consisting of consistent and straightforward UI elements like buttons of similar graphic style or color for users to easily navigate the game.
- One notable aspect of the UI system is the map editor scene, which, despite remaining basic, communicates its functionality effectively. The controls are geared towards simplicity: players can place blocks with the left mouse, delete them with the right mouse, and traverse the map using the middle mouse; switching between the map layers and sprite sheets can be done via hotkeys. This design makes the drawing process more convenient and intuitive.

4 Architecture:

4.1 UML:

Below is the UML showing the high-level architecture of the game:

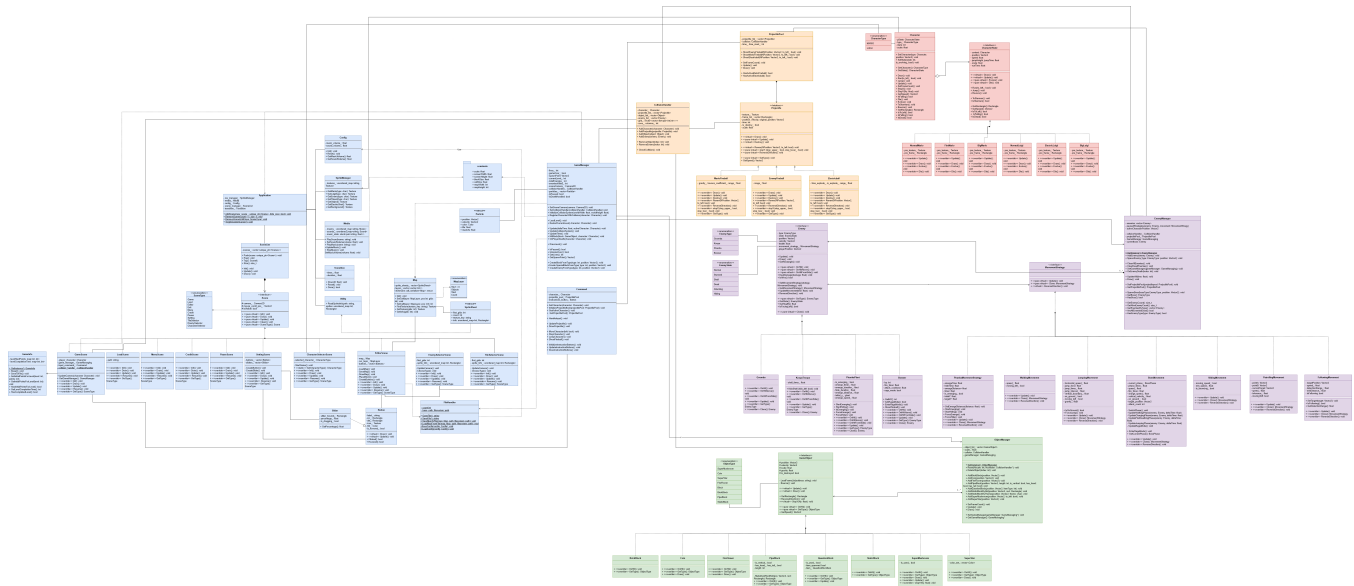


Figure 1: UML Diagram

4.2 High-level organization:

4.2.1 Codebase:

We choose a scene-based approach to the game by making all unique screens inherit from a Scene class with a four-stage lifecycle of Initialize - Draw - Update - Clear and managing their appearance via a scene stack. These scenes form the bulk of our Core system, along with managers for the game state, resources, and I/O. As per requirement of the game, we also design four other systems for major components of the game:

- Collision/Projectile (C/P): define projectile behaviors and how game objects (characters, enemies, objects) interact with each other.
- Character: define behaviors for playable characters (movement, power-ups, .etc.).
- Enemies: define behaviors for enemies (including boss and minions).
- Objects: define behaviors for objects (including blocks and power-ups).

4.2.2 Resources:

We organize all resources according to their type: image and audio. Image resources are mainly sprites, which are a mix between Super Mario 3, Super Mario World, and homegrown sprites; there are also packs of UI elements and backgrounds for certain screen. Sound effects and soundtracks are taken from various Mario games as we see fit. We make sure to only include royalty-free resources and pay attribution where necessary (in the credit section of the game's main menu).

4.2.3 Dependencies:

Apart from raylib, we also use Niels Lohmann's C++ json API for map loading and saving, and tinyfiles-dialogs for specifying save/load paths with a file dialog.

4.3 SOLID and Design Patterns Adherence:

4.3.1 SOLID principles:

Overall, the game adheres quite well to SOLID principles, with detailed examples outlined below:

1. **Single responsibility principle (SRP):** Most classes have a clear focus on what they do. For example, class `SpriteManager` only loads the textures for the sprites, which other classes can retrieve via its getter methods. However, certain classes, such as `GameManaging`, are still too clunky as a result of being overloaded with methods that deal with irrelevant functions such as updating the camera and particle effects and thus requires refactoring to better reflect their intended purposes.
2. **Open-closed principle (OCP):** The scene-based architecture allows the effortless inclusion of new scenes to extend capabilities without modifying existing code. Other components also express this principle, such as the serializers/deserializers functions in the `Map` class, which can readily be extended to handle other data types.
3. **Liskov Substitution principle (LSP):** Subclasses of `Scene`, the key components of the game, can be exchanged for their base class without breaking behavior. This adherence is also observed in other systems like `Character` or `Object`, where subclasses honor base classes' contracts.
4. **Interface Segregation principle (ISP):** Almost all systems, especially `Enemy` and `Object`, have a clear segregation between their interface and concrete implementation. Nonetheless, as stated

above, GameManaging class can benefit from further dividing its interface into smaller sub-services to decrease the level of tight coupling.

5. **Dependency Inversion principle (DIP):** Aside from the Scene class, Enemy class also exhibits this principle in practice by holding a reference to MovementStrategy and delegate all movement logic to it; this way, both the high-level modules (Enemy) and low-level ones (Goomba, Koopa) depend on the movement abstraction. This design can be mirrored in GameManaging, where the class is still dependent on a concrete CollisionHandler.

4.3.2 Design patterns:

We integrate numerous designs patterns into the game's architecture to enhance code performance and readability. Below is a table listing the design patterns used and their places in the codebase. We will explore these in-depth in the next section:

Pattern	Where/How
Singleton	ObjectManager::GetInstance(), EnemyManager::GetInstance()
Strategy	MovementStrategy injected into Enemy for AI behaviours
Template Method	CollisionHandler orchestrates collision checking process
State	Character delegates to CharacterState sub-classes
Prototype	Enemy::Clone() to duplicate enemy instances
Factory	GameManaging::CreateEnemyFromType(), CreateBlockFromType() methods
Façade	SpriteManager hides texture-loading complexity
Adapter (JSON)	nlohmann::adl_serializer adapting Map and Rectangle to JSON

Table 1: An outline of design patterns in program Architecture

We will divide this section into five parts, with each part exploring the detailed workings of each subsystem in the project that we outlined in the previous section.

[illegible]

1. **Organization:** The Core subsystem handles program state switching and key game logic. Its operation revolves a scene-based approach where a scene stack manages which screen is being shown to the players based on their input. Several other modules supports these "scenes" by supplying them with the required resources or functionalities. Below is a delineation of notable source files in this system and their responsibilities:

- Trang 6

- (b) `SceneList.cpp`: Manages all scene as a stack. Includes basic stack operations like Push - Pop - Top (get top element) - Size (check size).
- (c) `Application.cpp`: A singleton managing the entire game, with access to both the scene list and resources. Can add and remove scenes as well as providing resources via getters.
- (d) `GameScene.cpp`: A notable scene which handles running the actual game. This scene coordinates operations of the character, collision handler, and game manager, to ensure everything runs smoothly. This scene also handles level progression, with information saved in another class named `GameInfo.cpp`.
- (e) `EditorScene.cpp`: Another notable scene which handles drawing and saving the map. Contains an instance of the `Map` class for I/O purpose, and to other selector scenes for choosing the right block to place in the map. The map is layered, similar to graphical editors like Photoshop, to accommodate for objects with consistent sizes like blocks and inconsistent sizes like enemies.
- (f) `Map.cpp`, `FileHandler.cpp`: Responsible for I/O operations of the game. `Map` deals with serializing/deserializing the map to/from JSON and retrieving textures via blocks' Global ID (GID), while `FileHandler` deals with opening dialog boxes and saving/loading player-made maps/game configurations.
- (g) `SpriteManager.cpp`, `Media.cpp`: Facades managing visual and audio resources of the game, allowing easy retrieval via straightforward getters.
- (h) `GameManaging.cpp`, `Command.cpp`: Handles every aspects of gameplay, including loading, drawing, and updating the level, making calls to the collision handlers and managers of objects and enemies where necessary, and store relevant gameplay data like points, health, and game time. `Command` class maps players input to character and projectile movement and handles also the toggling of the instruction panel.

2. Adherence to SOLID principles and design patterns implementation:

- (a) **SOLID principles**: The Core subsystem follows most SOLID principles, though there is still room for improvement:

- **SRP:** Classes such as `SpriteManager` (resource loading), `Config` (settings), and individual `Scene` subclasses each focus on a single responsibility. However, `GameManaging` is overloaded with unrelated tasks (state, particles, collisions) and would benefit from refactoring.
 - **OCP:** The scene-based design allows new `Scene` types to be added without altering existing code. Serialization in `Map` can also be extended easily.
 - **LSP:** All `Scene` subclasses and `Command` types respect their base class contracts and are interchangeable.
 - **ISP:** Interfaces are concise (e.g., `Scene` only defines `Init`, `Update`, `Draw`, `Resume`, `Type`). Again, `GameManaging` is an exception due to its broad API.
 - **DIP:** High-level modules depend on abstractions (`Scene`, `Command`), but `GameManaging` still relies on concrete `CollisionHandler` instead of an interface.
- (b) **Design patterns:** The subsystem implements three design patterns: `Singleton`, `Façade`, and `Factory`:
- **Singleton:** `Application::Instance()` follows the singleton pattern to ensure a single global instance. We choose this pattern because at any given point in the game, having more than one `Application` process will surely lead to conflicting calls and duplicate program states, which will seriously compromise the game's performance.
 - **Façade:** `SpriteManager` and `Media` classes encapsulate and simplify access to texture resources, hiding the complexity of loading and managing them. We feel the need to simplify the interface of these managers due to their frequency of use; having to make too many complicated calls to these managers will slow down the development process and make the code look more messy. The `Façade` pattern is naturally the best choice we could think of to address this issue.
 - **Factory Method:** Methods like `GameManaging::CreateEnemyFromType()` and `CreateBlockFromType()` instantiate objects based on type parameters. We choose this pattern to instantiate new block and enemies because of several benefits: better encapsulation, higher extensibility, and the ease of integrating into bigger systems (including a factory function inside the `GameManaging` class).

5.2 Collision/Projectile (C/P):

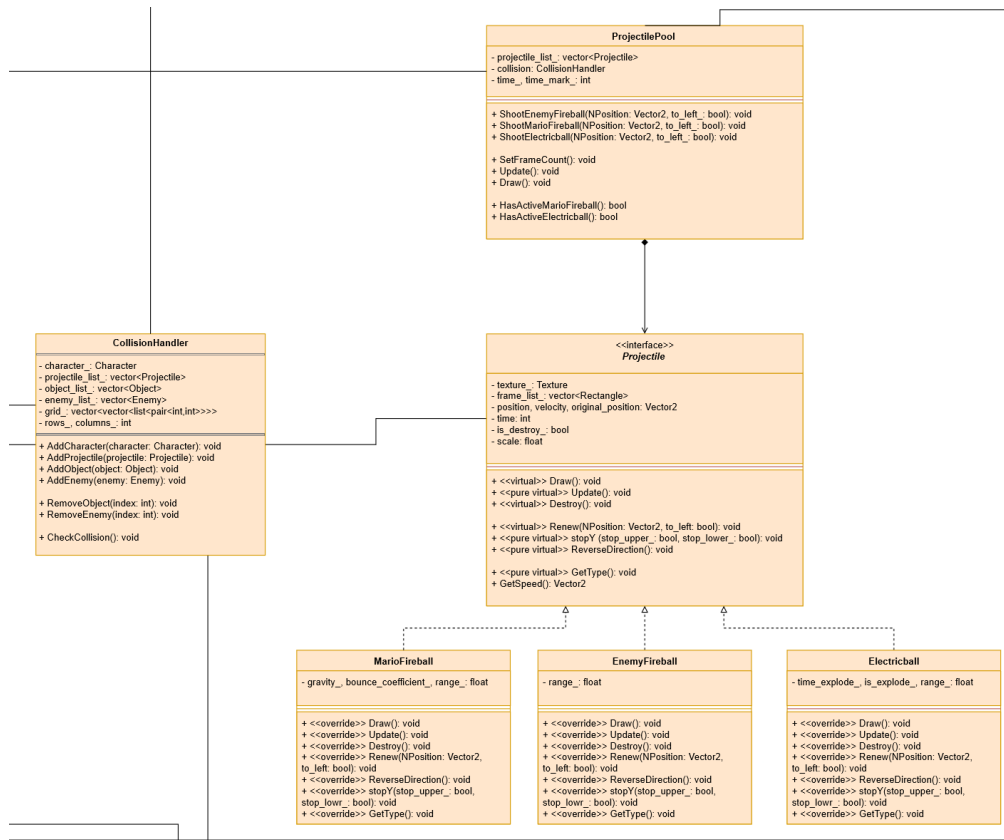


Figure 3: The C/P system of the project

1. **Organization:** This subsystem contains two modules: CollisionHandler and Projectile. Below is a brief overview of their responsibilities, as well as our design choice for keeping them separate from the Core subsystem:

- **Responsibilities:**

The Collision module manages collision detection between the player, projectiles, objects, and enemies via a spatial grid with buckets, i.e. a 2D vector whose entries are lists of pairs. Each pair contains a identifier for the type of object currently in that space and its index within the grid. Entities register themselves, and with each frame the handler updates their grid positions, then performs targeted checks. This design minimizes unnecessary collision checks and integrates tightly with other managers while keeping the collision logic centralized.

The Projectile module consists of an interface for the projectiles, implemented by three subclasses for Mario's fireball, Luigi's electric ball (our invention), and Bowser's fireball. These projectiles are managed in an array by the ProjectilePool class. Projectiles have three lifecycle methods: Draw - Update - Destroy, along with two utility methods to reverse direction and check y-axis position to let the projectiles bounce when they hit the ground.

- **Design choice:** We model Collision/Projectile (C/P) as its own subsystem rather than part of Core. This separation is to follow SRP: Core focuses on scenes/state/resources; C/P, on the other hand, works with collision and projectiles, aspects that mainly concern the character/object side of the game but do not belong to any of them. This separation also allows independent testing and easier extension of the C/P subsystem if needed.

2. Adherence to SOLID principles and design patterns implementation:

(a) **SOLID principles:** Overall, the subsystem adheres quite well to SOLID principles, with the exception of some aspects:

- **SRP:** Projectiles encapsulate their own motion/expiry/rendering; the pool manages lifecycle. However, CollisionHandler blends grid management, collision checking, and collision resolution into one class. As improvement, this class would benefit from being refactored into something like: *SpatialGrid* (management), *CollisionDetector* (collision checking), and *InteractionResolvers* (collision resolution).
- **OCP:** New projectile types can easily be plugged in via Projectile polymorphism, but ProjectilePool exposes type-specific Shoot* methods and CollisionHandler still uses large conditionals block which makes addition difficult. Replace with a factory/registry for the Shoot methods and collision strategy classes to add behaviors without editing core code.
- **LSP:** Projectile interface ensures all calls go through declared virtuals (avoid relying on subclass-only members).
- **ISP:** The API of both modules are sufficiently well-designed for a game this scale; however, as the game grows in size, more refactoring needs to be done to separate utility functions from rendering ones (in Projectile) and bookkeeping from resolution (as outlined above in SRP).

- **DIP:** The pool stores `Projectile*`, which is good, but it still depends on concrete `CollisionHandler`; `CollisionHandler` in turn depends on concrete `Character/Enemy/GameObject`. To better follow this principle, we would introduce more abstraction layers, e.g. (`ICollisionWorld`, `ICollider` to invert dependencies).
- (b) **Design patterns:** The subsystem implements two design patterns: Object Pool and Template Method.
- The `ProjectilePool` implements the Object Pool pattern, a performance-oriented creational pattern related to but not formally part of the original Gang of Four catalog. It can be viewed as a specialized factory that reuses instances instead of instantiating them afresh. We chose this pattern over Flyweight because the projectiles in our game has too little common attributes to be shared across all instances; instead, each projectile has a determined lifetime, and from what we have read, the Object Pool pattern, with clear acquire/release semantics (`Renew()`/`Destroy()` in our code), handles this aspect better.
 - The Template Method pattern lies inside the `CollisionChecking()` function, in which it allows the function to orchestrate the collision-checking process by calling relevant methods in a specific order (although in the original pattern, these methods would be subclasses that override the function calls). We feel this is a rather straightforward choice given the nature of the function call order and existing methods.
 - As possible improvement, after refactoring this class, we would like to use the Observer pattern to notify relevant classes in `Character` and `Enemy/Object` subsystems when a collision event happens, in order to let them process those events themselves, instead of letting the Collision subsystem implementing these side-effects.

5.3 Character:

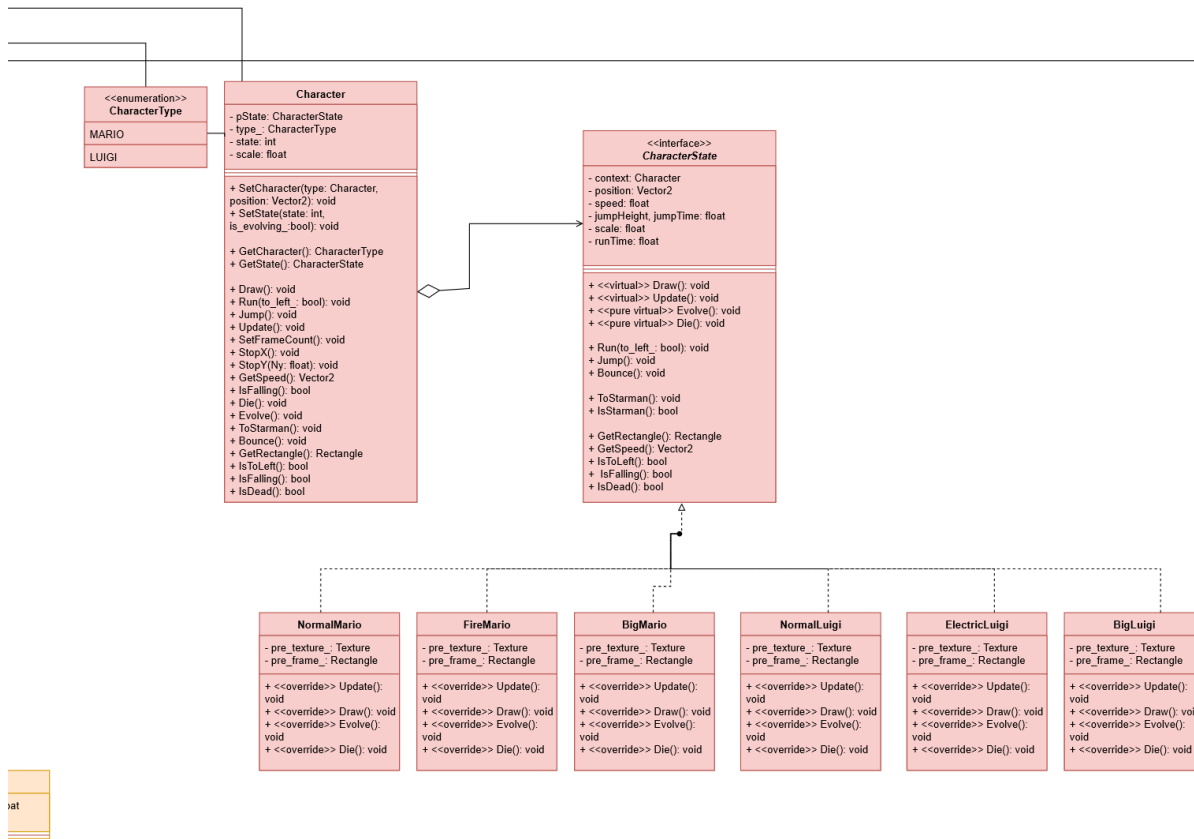


Figure 4: Character subsystem in the project

1. **Organization:** The Character subsystem consists of two modules. The first is a character class that creates and manages instances of playable characters Mario and Luigi. This module serves as the context and stores a reference to another interface named CharacterState for switching character states when a power-up is consumed (Normal, Fire/Electric, Starman). The six states (three for each character) are implemented by six subclasses.
2. **Adherence SOLID principles and design patterns implementation:**

(a) **SOLID principles:** Overall, this subsystem adheres quite well to SOLID principles:

- **SRP:** Character delegates gameplay logic to CharacterState subclasses, which encapsulate movement, physics, and state-specific rendering; this is desired behavior. However, CharacterState mixes physics, animation, and some game-rule logic, which could be refactored as program size grows.

- (b) Design patterns:**

The subsystem implements the State pattern, by letting the base `Character` class be the context and delegate state-switching logic and state-specific behavior to `CharacterState` and its subclasses instead. Given the number of states of both characters, we feel that this is a natural choice.

5.4 Enemy:

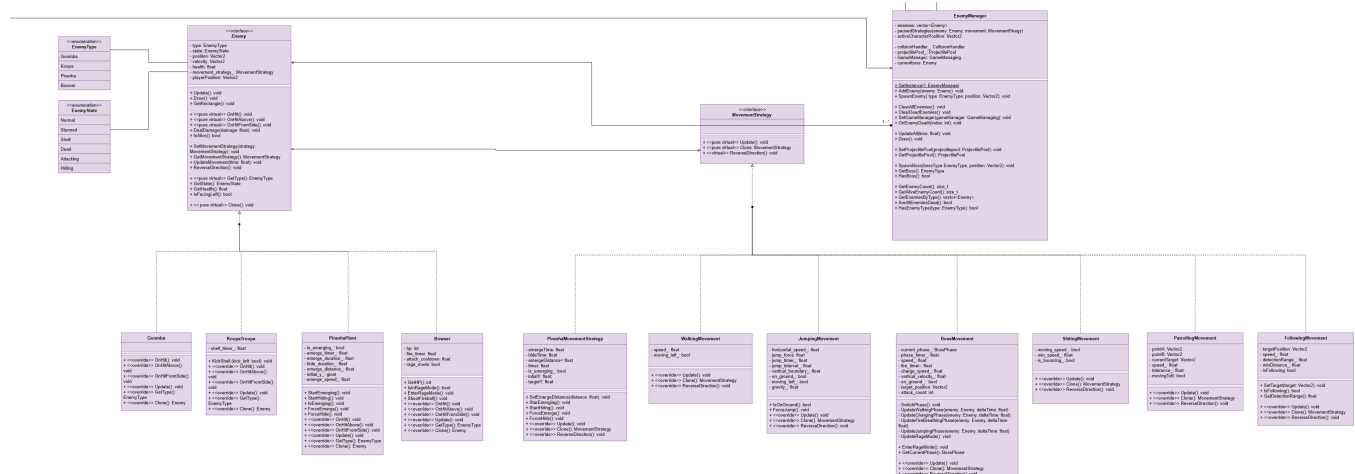


Figure 5: The Enemy subsystem in the project

1. **Organization:** This subsystem consists of one interface serving as the context, which relies on an enum class `EnemyState` that declares state names to handle state-switching and implement state-

specific behaviors in subclasses. Movement strategies are processed separately in another class through the Strategy pattern. All enemies are managed in an array by a `EnemyManager` class.

2. **SOLID principle adherence and design patterns implementation:**

(a) **SOLID principles:**

- **SRP:** separation of concerns (instantiation from management) is desired behavior. However, `EnemyManager` and `Enemy` have multiple responsibilities (e.g. `EnemyManager` has functions to specifically spawn the boss even though it is supposed to handle all enemy types); split into focused components.
- **OCF:** Addition and modification through the enum class remains unintuitive; it is better if the State pattern is followed, which involves turn the enum class into an interface and let the subclasses of `Enemy` depend on it for state logic.
- **LSP:** Inheritance chains (`Enemy` subclasses) respects this principle.
- **ISP:** `Enemy` interface is fairly broad, including physics, combat, and rendering at the same time. This class can benefit from being refactored into smaller interfaces.

DIP Classes in the subsystem should depend more on abstractions, instead of being locked in concrete dependencies or holding raw pointers.

(b) **Design pattern:**

- Class `EnemyManager` implements the Singleton patterns and acts as a process-wide singleton to centralize enemy. The uniqueness of managers is necessary in making the program run smoothly.
- Through the Façade pattern, `EnemyManager` provides a simplified façade over many object classes (add/update/draw); keep the façade thin after splitting responsibilities. Given the frequency of use of manager classes, we feel using the Façade pattern would help make function calls more intuitive, thus speeding up development.
- The `Enemy` class follows a weak version of the State pattern, where the state interface is instead an enum class, and the context's subclasses directly handles the state logic. We chose this approach at first since we think delegating all state logic, which is not much,

for the context's subclasses to implement would simplify the code. This class, however, does implement quite well the Prototype pattern through its pure virtual Clone() method, which we feel is suitable as it nicely supports duplication and pooling of enemies without costing performance.

- The Movement Strategy class implements the Strategy pattern, by delegating strategies through an interface and its set of subclasses. Since there are many strategies that only concern one aspect of the enemy - movement (hence rendering State pattern unsuitable), and is subject to multiple changes during runtime, we feel the choice of the Strategy pattern is logical.

5.5 Object:

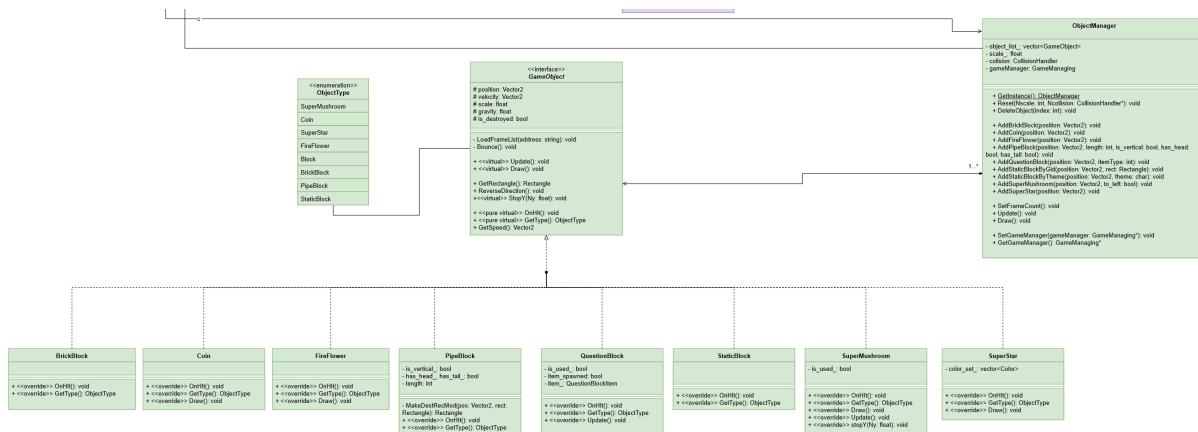


Figure 6: The Object subsystem in the project

1. **Organization:** The Object subsystem consists of an interface declaring general properties of game objects, including items and blocks, whose specific implementation are done by 8 subclasses (4 items and 4 types of block); all objects are managed in an array by another class ObjectManager.
2. **SOLID principle adherence and design patterns implementation:**

(a) SOLID principles:

- **SRP:** Again, ObjectManager class mixes creation, ownership, update/draw, collision wiring, and game callbacks logic. It would benefit from being split into smaller classes: ObjectFactory (instantiation using Factory pattern), ObjectSystem (update/draw).

- **OCP:** Add methods are hardcoded, while Factory logic is deferred upstream to GameManaging class. Although the presence of a Factory is good, it would be better to move its place to live inside the Object subsystem instead.
- **LSP:** Subclasses (BrickBlock, Coin, FireFlower, ...) override base GameObject operations consistently (e.g., OnHit, Draw/Update when needed), so substitutability holds.
- **ISP:** GameObject interface is broad (GetSpeed, ReverseDirection, StopY), just like that in the Enemy subsystem, and forces static objects (e.g., StaticBlock, QuestionBlock) to depend on irrelevant members (blocks cannot move or change direction).
- **DIP:** ObjectManager depends on concretes (CollisionHandler, GameManaging); invert dependency via interfaces so high-level logic depends on abstractions.

(b) **Design pattern:**

- Class ObjectManager implements the Singleton patterns and acts as a process-wide singleton to centralize objects. Again, the uniqueness of managers is necessary in making the program run smoothly.
- Through the Façade pattern, ObjectManager provides a simplified façade over many object classes (add/update/draw); keep the façade thin after splitting responsibilities. Given the frequency of use of manager classes, we feel using the Façade pattern would help make function calls more intuitive, thus speeding up development.
- As improvement, we would like to implement the Observer pattern to emit events (e.g., “object collected”, “block hit”) to IGameEvents instead of calling game systems directly; this decouples objects from scoring/timers.

6 Technical difficulties:

6.1 Uncertainty in library selection

- **Description:** Choosing a suitable graphics library posed difficulties due to limited knowledge about options. Raylib, selected for its simplicity and compatibility with C++, supports basic graphics but lacks advanced features like pre-made UI components, scene management, or animation tools, critical for a dynamic visualizer.
- **Impact:** This uncertainty risked inefficient effort, requiring extra work to overcome missing capabilities.
- **Evaluation:** Raylib proved adequate for basic rendering needs, though additional effort was needed to address its limitations.

6.2 Complexity in implementing multiple scenes

- **Description:** Creating an application with multiple scenes—like a menu, visualization, and input area—was challenging. Raylib’s single-loop structure offered no built-in way to manage transitions or states.
- **Impact:** This made organizing code and switching between scenes difficult, risking confusion and data inconsistencies.
- **Approach:** A custom system tracked scenes and handled rendering and transitions, requiring careful planning for clarity and consistency.

6.3 Handling I/O of sprites and maps

- **Description:** Choosing the suitable format for saving and loading resources is a critical part of the game’s design. Additionally, bridging the processes of reading and drawing the image resources poses serious challenges regarding correctness and efficiency, requiring multiple substantial revision before an desirable solution can be found. Storing and managing the resources in one centralized system is similarly an onerous task and requires numerous iterations.

- Approach: Spritesheets and icons are accessed using a separate text file which contains the positions of each sprite/icon. Maps are stored as json files, read and written using custom serializers and deserializers. Textures are pre-loaded into a manager then retrieved using getters.

6.4 Design unique aspects of the game

- Description: Map editor and collision handler are central components to a 2D platform whose implementation details are also novel to us novice programmers, therefore requiring great care and effort towards developing a functional prototype.
- Impact: Not being able to develop these system means the game is unplayable, in the case of collision handler, and boring due to lack of customization, in the case of map editor.
- Approach: Collision handler partitions entities into grid cells each frame, updating positions and detecting overlaps for characters, enemies, and projectiles against blocks and hazards, while the map editor provides interactive map editing with camera control, tile/enemy selection, map load/save, block placement, and layered grid rendering.

6.5 Lack of proficiency in using Git and managing GitHub

- Description: Limited experience with Git and GitHub made version control and project hosting challenging. Basic tasks like saving changes, tracking progress, and sharing code were unfamiliar.
- Impact: This risked losing work or struggling to manage updates, potentially limiting collaboration or visibility.
- Approach: Learning essential version control steps and repository management was necessary, starting with simple progress tracking and planning for more advanced use later.

7 Limitations and future improvements:

7.1 Limitations:

- Gameplay is still basic with few variation in playable characters, environments, power-ups, and enemies.
- Map editor can benefit from a redesign in UI and controls.
- Overall codebase is clunky and requires refactoring for more robustness.

7.2 Future improvements:

- Extend gameplay by adding more characters, environments, powerup, and enemies. Support for two players and other game modes is also desired.
- Redesign the UI for key components in the game to be intuitive and responsive to user input. Customizing a unique set of fonts, icons, and buttons for the game is also desired.
- Refactor the code, especially GameManaging class, and reorganize or modify resources to improve organization and consistency in quality.

8 Demonstration:

Below are some screenshots of the game:

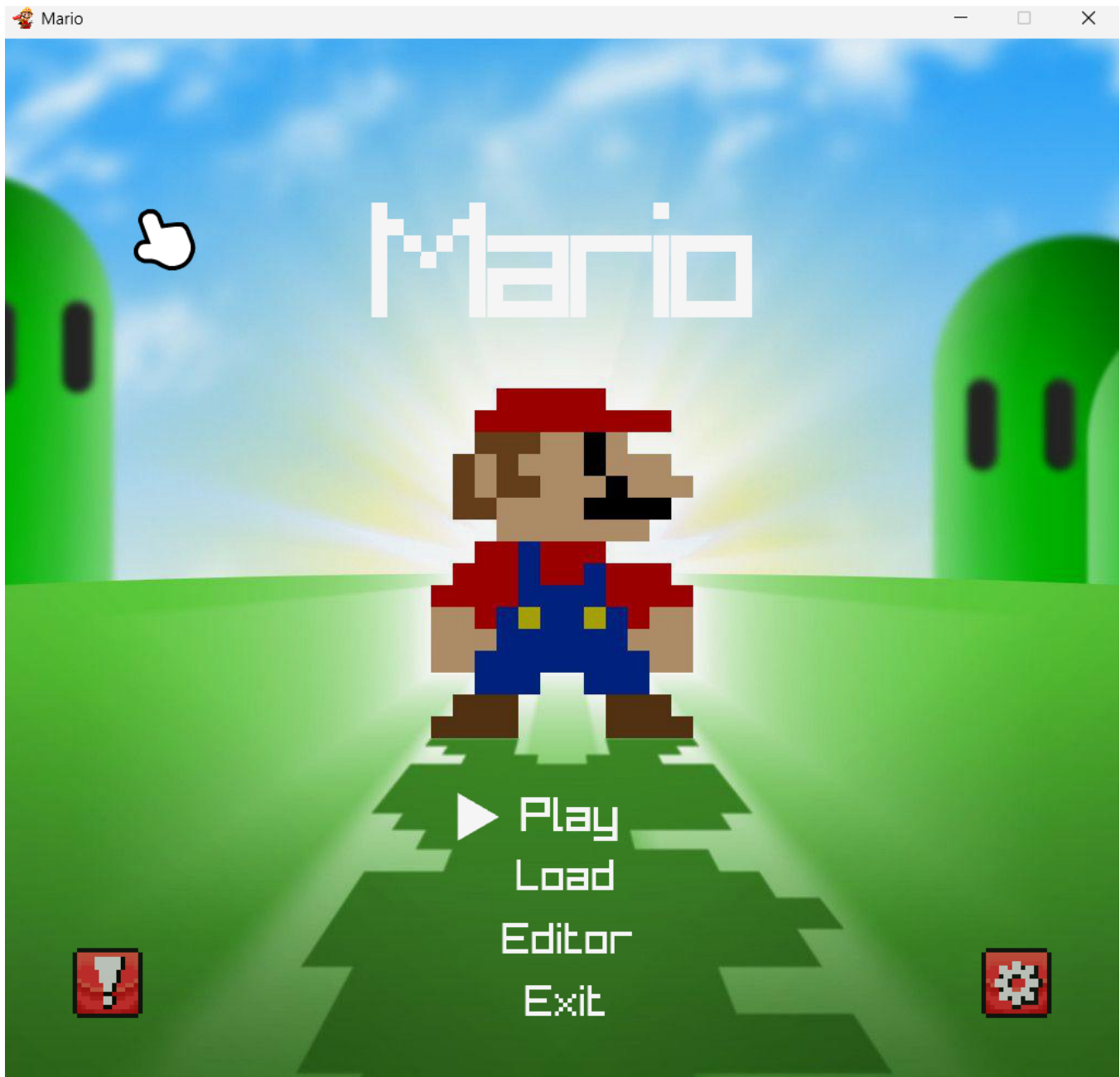


Figure 7: The game's main menu

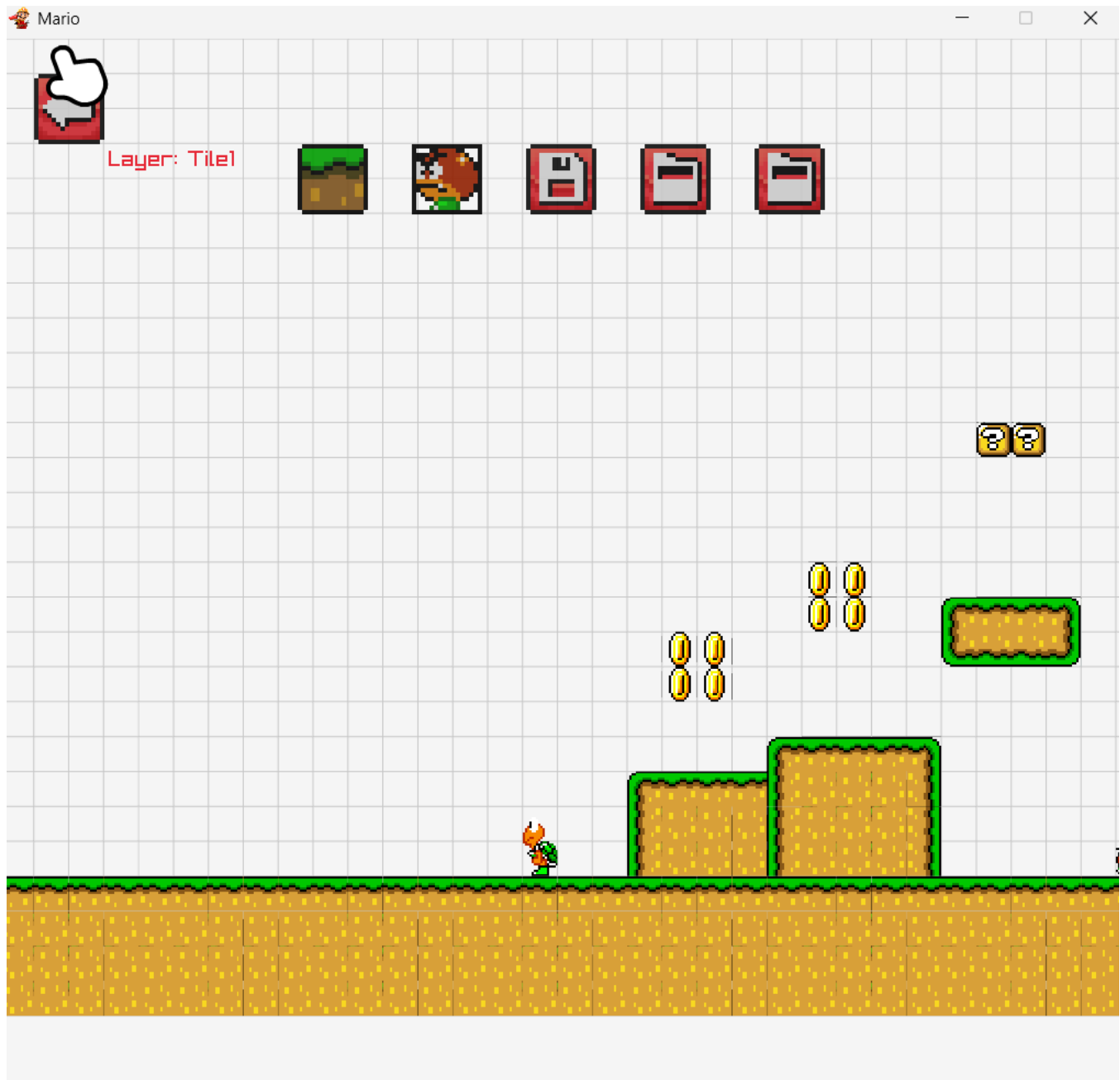


Figure 8: The game's editor scene, with a premade map



Figure 9: The game's character selection screen, before the level starts



Figure 10: The game's first level, with Bowser for demonstration purpose



Figure 11: Electric ball fired by Luigi. Both Electric Luigi and the electric ball are our invention.

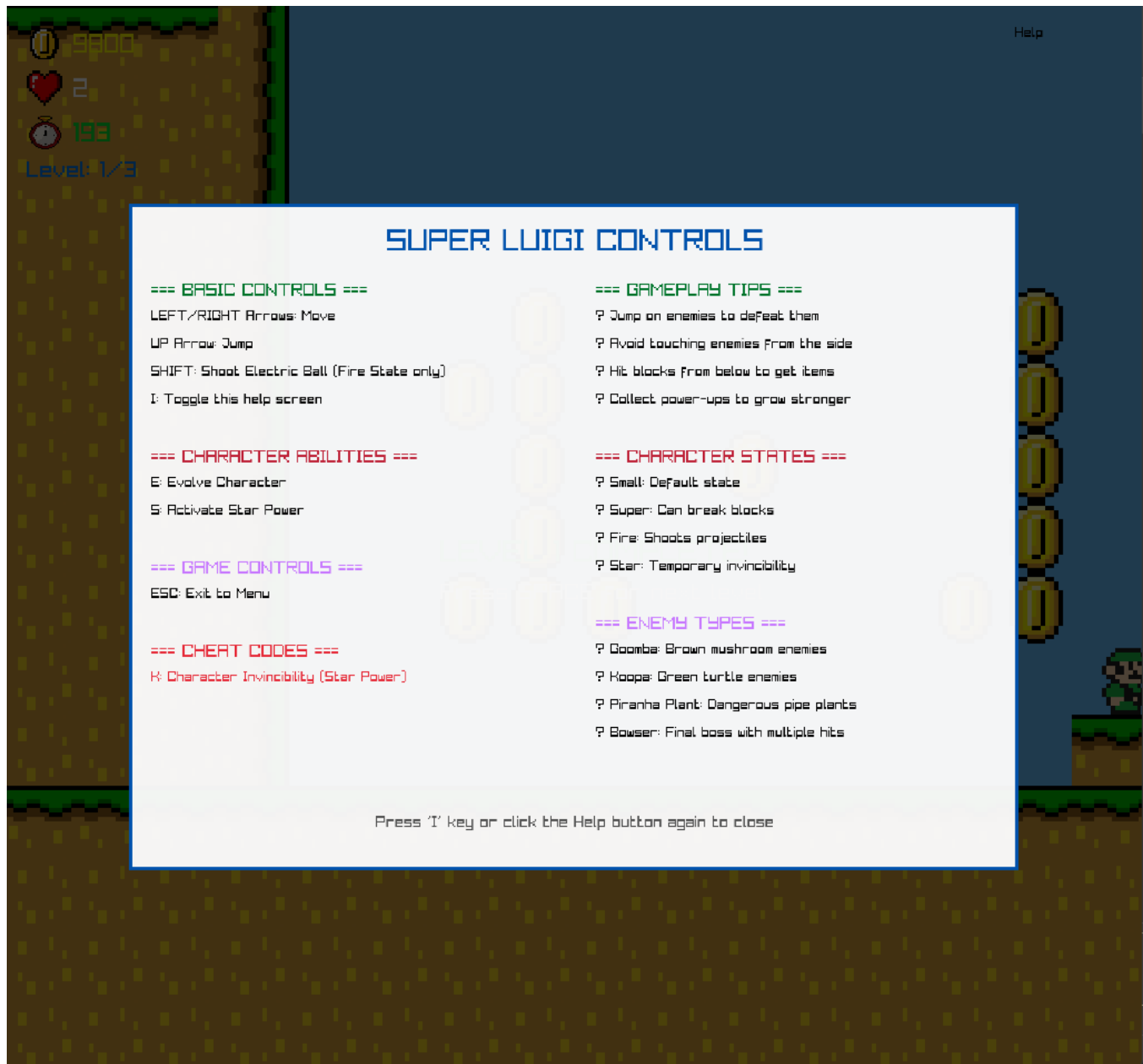


Figure 12: A table containing instructions for the game, toggle during gameplay by pressing "I"

9 Work division:

9.1 Team members:

1. Bao, Nguyen Chi - 24125025
2. Quan, Pham Nguyen Minh - 24125041
3. Khoa, Phan Anh - 24125092
4. Lac, Quach Thien - 24125092
5. Duy, Nguyen Quang - 18125048

9.2 Responsibilities

1. Bao: Implement the following parts: Character, Enemy (Bowser), Items, Projectiles, Collision Handler.
2. Quan: Implement the following parts: Menu/Editor/Character-Enemy-Tile Selector Scenes, Map Saving/Loading. Also prepare audio resources and manage the Github repository.
3. Khoa: Implement the following parts: Game Manager, Commands, Enemy (Minions).
4. Lac: Implement the following parts: File Handler, Load Scene, Level Design. Also prepare image resources and write this report.
5. Duy: Implement the following parts: Enemy, Objects.

9.3 Collaboration tools:

Messenger, Github.

10 Demo Video

Youtube video

11 References:

- [LaTeX by Quan, Tran Hoang](#)
- [Refactoring Guru](#)
- [SOLID Principle article on Wikipedia](#)