

NEA

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Chapter 1

Analysis

1.1 Background

Mr Myslov is a teacher at Tonbridge School, and currently runs the school chess club. Seldomly, a field day event will be held, in which the club convenes together, playing a chess, or another variant, tournament. This year, Mr Myslov has decided to instead, hold a tournament around another board game, namely laser chess, providing a deviation yet retaining the same familiarity of chess. However, multiple physical sets of laser chess have to be purchased for the entire club to play simultaneously, which is difficult due to it no longer being manufactured. Thus, I have proposed a solution by creating a digital version of the game.

1.1.1 Game Description

Laser Chess is an abstract strategy game played between two opponents. The game differs from regular chess, involving a 10x8 playing board arranged in a predefined condition. The aim of the game is to position your pieces such that your laser beam strikes the opponents Pharoah (the equivalent of a king). Pieces include:

1. Pharoah
 - Equivalent to the king in chess
2. Scarab
 - 2 for each colour
 - Contains dual-sided mirrors, capable of reflecting a laser from any direction
 - Can move into an occupied adjacent square, by swapping positions with the piece on it (even with an opponent's piece)
3. Pyramid
 - 7 for each colour
 - Contains a diagonal mirror used to direct the laser
 - The other 3 out of 4 sides are vulnerable from being hit
4. Anubis

- 2 for each colour
- Large pillar with one mirrored side, vulnerable from the other sides

5. Sphinx

- 1 for each colour
- Piece from which the laser is shot from
- Cannot be moved

On each turn, a player may move a piece one square in any direction (similar to the king in regular chess), or rotate a piece clockwise or anticlockwise by 90 degrees. After their move, the laser will automatically be fired. It should be noted that a player's own pieces can also be hit by their own laser. As in chess, a three-fold repetition results in a draw. Players may also choose to forfeit or offer a draw.

1.1.2 Current Solutions

Current free implementations of laser chess that are playable online are limited, seemingly only available on <https://laser-chess.com/>.

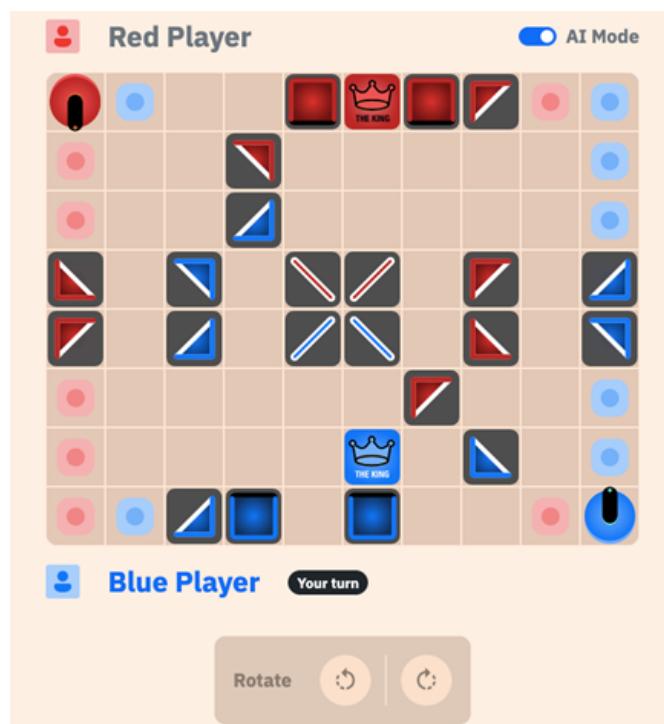


Figure 1.1: Online implementation on laser-chess.com

The game is hosted online and is responsive and visually appealing, with pieces easy to differentiate and displaying their functionality clearly. It also contains a two-player mode for playing between friends, or an option to play against a functional CPU bot. However, the game lacks the following basic functionalities that makes it unsuitable for my client's requests:

- No replay options (going through past moves)
 - A feature to look through previous moves is common in digital board game implementations
 - My client requires this feature as it is an essential tool for learning from past games and to aid in analysing past games
- No option to save and load previous games
 - This QOL feature allows games to be continued on if they cannot be finished in one sitting, and to keep an archive of past games
- Internet connection required
 - My client has specifically requested an offline version as the game will predominantly be played in settings where a connection might not be available (i.e. on a plane or the maths dungeons)
- Unable to change board configuration
 - Most versions of laser chess (i.e. Khet) contain different starting board configurations, each offering a different style of play

Our design will aim to append the missing feature from this website while learning from their commendable UI design.

1.1.3 Client Interview

Q: Why have you chosen Laser Chess as your request?

A: Everyone is familiar with chess, so choosing a game that feels similar, and requires the same thinking process and calculations was important to me. Laser chess fit the requirements, but also provides a different experience in that the new way pieces behave have to be learnt and adapted to. It hopefully will be more fun and a better fit for the boys than other variants such as Othello, as the laser aspects and visuals will keep it stimulating.

Objectives 1 & 7

Implementing laser chess in a style similar to normal chess will be important. The client also requests for it to be stimulating, requiring both proper gameplay and custom visuals.

Q: Have you explored any alternatives?

A: I remember Laser Chess was pretty popular years ago, but now it's harder to find a good implementation I can use, since I don't plan on buying multiple physical copies or paid online copies for every student. I have seen a few free websites offering a decent option, but I'm worried that with the terrible connection in the basement will prove unreliable if everybody tries to connect at once. However, I did find the ease-of-use and simple visuals of some websites pleasing, and something that I wish for in the final product as well.

Objective 6

The client's limitations call for a digital implementation that plays offline. Taking inspiration from alternatives, a user-friendly GUI is also expected.

Q: What features are you looking for in the final product?

A: I'm looking for most features chess websites like Chess.com or Lichess offer, a smooth playing experience with no noticeable bugs. I'm also expecting other features such as having a functional timer, being able to draw and resign, as these are important considerations in our everyday chess games too. Since this will be a digital game, I think having handy features such as indicators for moves and audio cues will also make it more user-friendly and enjoyable. If not for myself, having the option to play against a computer bot will be appreciated as well, since I'll be able to play during lesson time, or in the case of odd numbers in the tournament. All in all, I'd be happy with a final product that plays Laser Chess, but emulates the playing experience of any chess website well.

Objectives 1 & 3 & 5

Gameplay similar to that of popular chess websites is important to our client, introducing the requirement of subtle features such as move highlighting. A CPU bot is also important to our client, who enjoys thinking deeply and analysing chess games, and so will prove important both as a learning tool and as an opponent.

Q: Are there any additional features that might be helpful for your tournament use-cases?

A: Being able to configure the gameplay will be useful for setting custom time-controls for everybody. I also would like to archive games and share everybody's matches with the team, so having the functionality to save games, and to go through previous ones, will be highly requested too. Being able to quickly setup board starting positions or share them will also be useful, as this will allow more variety into the tournament and give the stronger players some more interesting options.

Objectives 2 & 4

Saving games and customising them is a big logistical priority for a tournament, as this will provide the means to record games and for opponents to all agree on the starting conditions, depending on the circumstances of the tournament.

1.2 Objectives

1.2.1 Client Objectives

The following objectives should be met to satisfy my clients' requirements:

1. All laser chess game logic should be properly implemented
 - All pieces should be display correct behaviour (i.e reflect the laser correctly)
 - Option to rotate laser chess pieces should be implemented
 - Option to move laser chess pieces should be implemented
 - Game should allocate alternating player's turns
 - Travel path of laser should be correctly implemented
 - Pieces should be automatically detected and eliminated when hit by the laser
 - Game should automatically detect when a player has lost or won
 - Three-fold repetition should be automatically detected
2. Save or load game options should be implemented

- Games should be encoded into FEN string format
- Games can be saved locally into external files
- User should be able to scroll through previous games
- User should be able to scroll through previous moves
- Game should display information relevant to each game, and display moves correctly

3. Other board game requirements should be implemented

- Draws should be made an option
- Resigning should be made an option
- Timer displaying time left for each player should be displayed
- Time logic should be implemented, pausing when it is the opponent's turn, forfeiting players who run out of time

4. Game settings and config should be customisable

- User should be able to select board colours
- User should be able to play against another player or CPU
- User should be able to customise timer and duration
- User should be able to customise starting board layout and colour

5. Game UI should improve player experience

- Drag and drop should be implemented
- Selected pieces should be clearly marked with an indicator
- Indicator showing available squares to move to when clicking on a piece
- Destroying a piece should display a visual and audio cue
- Captured pieces should be displayed for each player
- Status message should display current status of the game (whose turn it is, move a piece, game won etc.)

6. GUI design should be functional and display concise information

- GUI should always remain responsive throughout the running of the program
- Application should be divided into separate sections with their own menus and functionality (e.g. title page, settings)
- Navigation buttons (e.g. return to menu) should concisely display their functionality
- UI should contain exit and help buttons
- UI should be designed for clarity in mind and visually pleasing
- Application should be responsive, draggable and resizable

1.2.2 Other User Considerations

Although my current primary client is Mr Myslov, I aim to make my program shareable and accessible, so other parties who would like to try laser chess can access a comprehensive implementation of the game, which currently is not readily available online. Additionally, the code should be concise and well commented, complemented by proper documentation, so other parties can edit and implement additional features such as multiplayer to their own liking.

1.3 Research

Before proceeding with the actual implementation of the game, I will have to conduct research to plan out the fundamental architecture of the game. Reading on available information online, prior research will prevent me from committing unnecessary time to potentially inadequate ideas or code. I will consider the following areas: board representation, CPU techniques and GUI framework.

1.3.1 Board Representation

Board representation is the use of a data structure to represent the state of all pieces on the chessboard, and the state of the game itself, at any moment. It is the foundation on which other aspects such as move generation and the evaluation function are built upon, with different methods of implementation having their own advantages and disadvantages on simplicity, execution efficiency and memory footprint. Every board representation can be classified into two categories: piece-centric or square-centric. Piece-centric representations involve keeping track of all pieces on the board and their associated position. Conversely, square-centric representations track every available square, and if it is empty or occupied by a piece. The following are descriptions of various board representations with their respective pros and cons.

Square list

Square list, a square-centric representation, involves the encoding of each square residing in a separately addressable memory element, usually in the form of an 8x8 two-dimensional array. Each array element would identify which piece, if any, occupies the given square. A common piece encoding could involve using the integers 1 for a pawn, 2 for knight, 3 for bishop, and + and - for white and black respectively (e.g. a white knight would be +2). This representation is easy to understand and implement, and has easy support for multiple chess variants with different board sizes. However, it is computationally inefficient as nested loop commands must be used in frequently called functions, such as finding a piece location. Move generation is also problematic, as each move must be checked to ensure that it does not wrap around the edge of the board.

0x88

0x88, another square-centric representation, is an 128-byte one-dimensional array, equal to the size of two adjacent chessboards. Each square is represented by an integer, with two nibbles used to represent the rank and file of the respective square. For example, the 8-integer 0x42 (0100 0010) would represent the square (4, 2) in zero-based numbering. The advantage of 0x88 is that faster bitwise operations are used for computing piece transformations. For example, add 16 to the current square number to move to the square on the row above, or add 1 to move to the next column. Moreover, 0x88 allows for efficient off-the-board detection. Every valid square number is under 0x88 in hex (0111 0111), and by performing a bitwise AND operation between the square number and 0x88 (1000 1000), the destination square can be shown to be invalid if the result is non-zero (i.e. contains 1 on 4th or 8th bit).

Bitboards

Bitboards, a piece-centric representation, are finite sets of 64 elements, one bit per square. To represent the game, one bitboard is needed for each piece-type and colour, stored as an array of bitboards as part of a position object. For example, a player could have a bitboard

for white pawns, where a positive bit indicates the presence of the pawn. Bitboards are fast to incrementally update, such as flipping bits at the source and destination positions for a moved piece. Moreover, bitmaps representing static information, such as spaces attacked by each piece type, can be pre-calculated, and retrieved with a single memory fetch at a later time. Additionally, bitboards can operate on all squares in parallel using bitwise operations, notably, a 64-bit CPU can perform all operations on a 64-bit bitboard in one cycle. Bitboards are therefore far more execution efficient than other board representations. However, bitboards are memory-intensive and may be sparse, sometimes only containing a single bit in 64. They require more source code, and are problematic for devices with a limited number of process registers or processor instruction cache.

1.3.2 CPU techniques

Minimax

Minimax is a backtracking algorithm that evaluates the best move given a certain depth, assuming optimal play by both players. A game tree of possible moves is formulated, until the leaf node reaches a specified depth. Using a heuristic evaluation function, minimax recursively assigns each node an evaluation based on the following rules:

- If the node represents a white move, the node's evaluation is the *maximum* of the evaluation of its children
- If the node represents a black move, the node's evaluation is the *minimum* of the evaluation of its children

Thus, the algorithm *minimizes* the loss involved when the opponent chooses the move that gives *maximum* loss.

Several additional techniques can be implemented to improve upon minimax. For example, transposition tables are large hash tables storing information about previously reached positions and their evaluation. If the same position is reached via a different sequence of moves, the cached evaluation can be retrieved from the table instead of evaluating each child node, greatly reducing the search space of the game tree. Another, such as alpha-beta pruning can be stacked and applied, which eliminates the need to search large portions of the game tree, thereby significantly reducing the computational time.

Monte-Carlo Tree Search

Monte-Carlo Tree Search (MCTS) involves playouts, where games are played to its end by selecting random moves. The result of each playout is then backpropagated up the game tree, updating the weight of nodes visited during the playout, meaning the algorithm successively improves at accurately estimating the values of the most promising moves. MCTS periodically evaluates alternatives to the currently perceived optimal move, and could thereby discover a better, otherwise overlooked, path. Another benefit is that it does not require an explicit evaluation function, as it relies on statistical sampling as opposed to developed theory on the game state. Additionally, MCTS is scalable and may be parallelized, making it suitable for distributed computing or multi-core architectures. However, the rate of tree growth is exponential, requiring huge amounts of memory. In addition, MCTS requires many iterations to be able to reliably decide the most efficient path.

1.3.3 GUI framework

Pygame

Pygame is an open-source Python module geared for game development. It offers abundant yet simple APIs for drawing sprites and game objects on a screen-canvas, managing user input, audio et cetera. It also has good documentation, an extensive community, and receives regular updates through its community edition. Although it has greater customizability in drawing custom bitmap graphics and control over the mainloop, it lacks built-in support for UI elements such as buttons and sliders, requiring custom implementation. Moreover, it is less efficient, using 2D pixel arrays and the RAM instead of utilising the GPU for batch rendering, being single-threaded, and running on an interpreted language.

PyQt

PyQt is the Python binding for Qt, a cross-platform C++ GUI framework. PyQt contains an extensive set of documentation online, complemented by the documentation and forums for its C++ counterpart. Unlike Pygame, PyQt contains many widgets for common UI elements, and support for concurrency within the framework. Another advantage in using PyQt is its development ecosystem, with peripheral applications such as Qt Designer for layouts, QML for user interfaces, and QSS for styling. Although it is not open-source, containing a commercial licensing plan, I have no plans to commercialize the program, and can therefore utilise the open-source license.

OpenGL

Python contains multiple bindings for OpenGL, such as PyOpenGL and ModernGL. Being a widely used standard, OpenGL has the best documentation and support. It also boasts the highest efficiency, designed to be implemented using hardware acceleration through the GPU. However, its main disadvantage is the required complexity compared to the previous frameworks, being primarily a graphical API and not for developing full programs.

1.4 Proposed Solution

1.4.1 Language

The two main options regarding programming language choice, and their pros and cons, are as listed:

		Python
Pros	Cons	

- Versatile and intuitive, uses simple syntax and dynamic typing
 - Supports both object-oriented and procedural programming
 - Rich ecosystem of third-party modules and libraries
 - Interpreted language, good for portability and easy debugging
 - Slow at runtime
 - High memory consumption
-

		Javascript
Pros	Cons	
<ul style="list-style-type: none"> • Generally faster runtime than Python • Simple, dynamically typed and automatic memory management • Versatile, easy integration with both server-side and front-end • Extensive third-party modules • Also supports object-oriented programming 	<ul style="list-style-type: none"> • Mainly focused for web development • Comprehensive knowledge of external frameworks (i.e. Electron) needed for developing desktop applications 	

I have chosen Python as the programming language for this project. This is mainly due to its extensive third-party modules and libraries available. Python also provides many different GUI frameworks for desktop applications, whereas options are limited for JavaScript due to its focus on web applications. Moreover, the amount of resources and documentation online will prove invaluable for the development process.

Although Python generally has worse performance than JavaScript, speed and memory efficiency are not primary objectives in my project, and should not affect the final program. Therefore, I have prioritised Python's simpler syntax over JavaScript's speed. Being familiar with Python will also allow me to divert more time for development instead of researching new concepts or fixing unfamiliar bugs.

1.4.2 Development Environment

A good development environment improves developer experiences, with features such as auto-indentation and auto-bracket completion for quicker coding. The main development environments under consideration are: Visual Studio Code (VS Code), PyCharm and Sublime Text. I have decided to use VS Code due to its greater library of extensions over Sublime, and its more

user-friendly implementation of features such as version control and GitHub integration. Moreover, VS Code contains many handy features that will speed up the development process, such as its built-in debugging features. Although PyCharm is an extensive IDE, its default features can be supplemented by VS Code extensions. Additionally, VS Code is more lightweight and customizable, and contains vast documentation online.

1.4.3 Source Control

A Source Control Tool automates the process of tracking and managing changes in source code. A good source control tool will be essential for my project. It provides the benefits of: protecting the code from human errors (i.e. accidental deletion), enabling easy code experimentation on a clone created through branching from the main project, and by tracking changes through the code history, enabling easier debugging and rollbacks. For my project, I have chosen Git as my version control tool, as it is open-source and provides a more user-friendly interface and documentation over alternatives such as Azure DevOps, and contains sufficient functionality for a small project like mine.

1.4.4 Techniques

I have decided on employing the following techniques, based on the pros and cons outlined in the research section above.

Board representation

I have chosen to use a bitboard representation for my game. The main consideration was computational efficiency, as a smooth playing experience should be ensured regardless of device used. Bitboards allow for parallel bitwise operations, especially as most modern devices nowadays run on 64-bit architecture CPUs. With bitboards being the mainstream implementation, documentation should also be plentiful.

CPU techniques

I have chosen minimax as my searching algorithm. This is due to its relatively simplistic implementation and evaluation accuracy. Additionally, Monte-Carlo Tree Search is computationally intensive, with a high memory requirement and time needed to run with a sufficient number of simulations, which I do not have.

GUI framework

I have chosen Pygame as my main GUI framework. This is due to its increased flexibility, in creating custom art and widgets compared to PyQt's defined toolset, which is tailored towards building commercial office applications. Although Pygame contains more overhead and boilerplate code to create standard functionality, I believe that the increased control is worth it for a custom game such as laser chess, which requires dynamic rendering of elements such as the laser beam.

I will also integrate Pygame together with ModernGL, using the convenient APIs in for handling user input and sprite drawing, together with the speed of OpenGL to draw shaders and any other effect overlays.

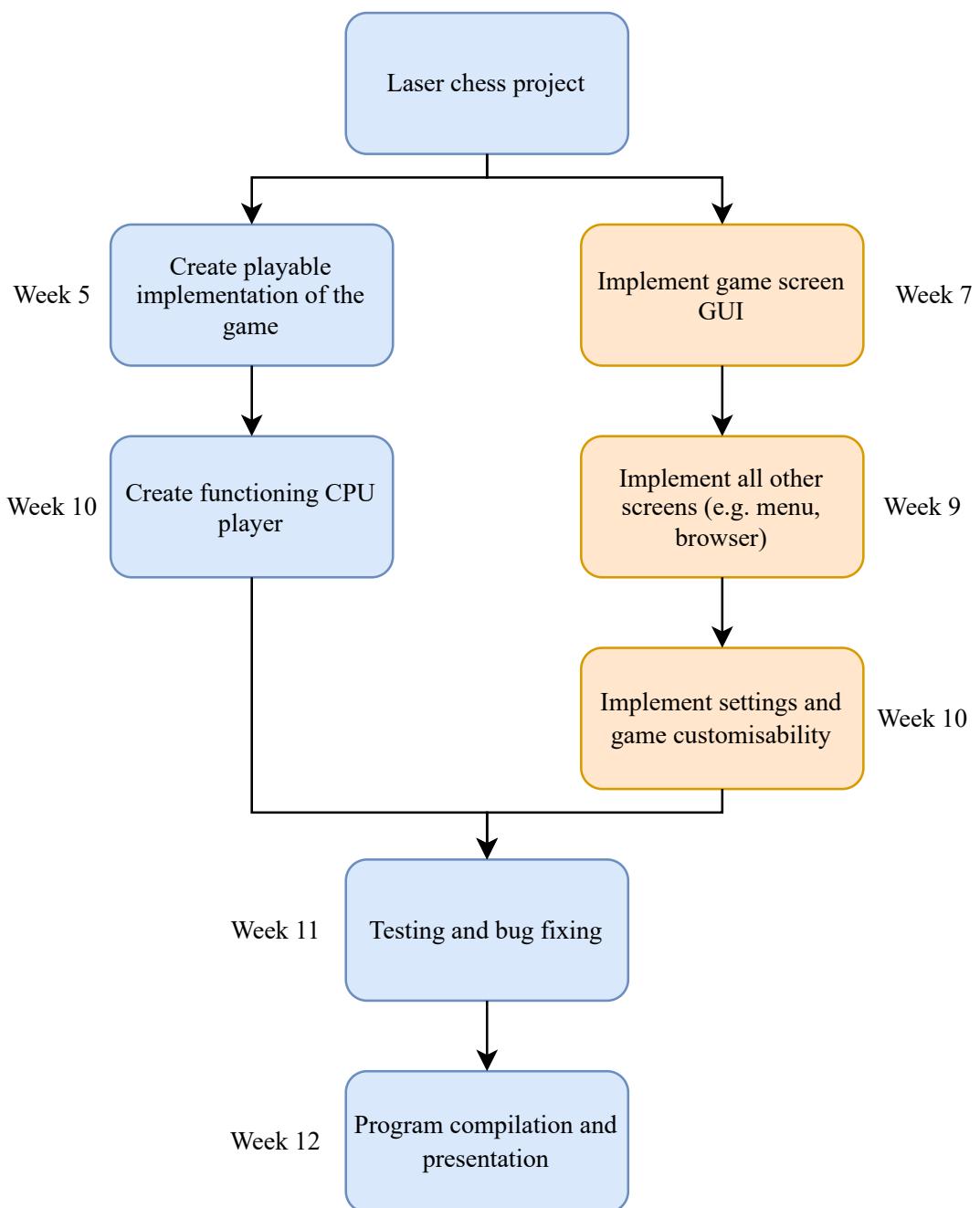
1.5 Limitations

I have agreed with my client that due to the multiple versions of Laser Chess that exist online, together with a lack of regulation, an implementation that adheres to the general rules of Laser Chess, and not strictly to a specific version, is acceptable.

Moreover, due to the time constraints on both my schedules for exams and for the date of the tournament, the game only has to be presented in a functional state, and not polished for release, with extra work such as porting to a wide range of OS systems.

1.6 Critical Path Design

In order to meet my client's requirement of releasing the game before the next field day, I have given myself a time limit of 12 weeks to develop my game, and have created the following critical path diagram to help me adhere to completing every milestone within the time limit.



Chapter 2

Design

2.1 System Architecture

In this section, I will lay out the overall logic, and an overview of the steps involved in running my program. By decomposing the program into individual abstracted stages, I can focus on the workings and functionality of each section individually, which makes documenting and coding each section easier. I have also included a flowchart to illustrate the logic of each screen of the program.

I will also create an abstracted GUI prototype in order to showcase the general functionality of the user experience, while acting as a reference for further stages of graphical development. It will consist of individually drawn screens for each stage of the program, as shown in the top-level overview. The elements and layout of each screen are also documented below.

The following is a top-level overview of the logic of the program:

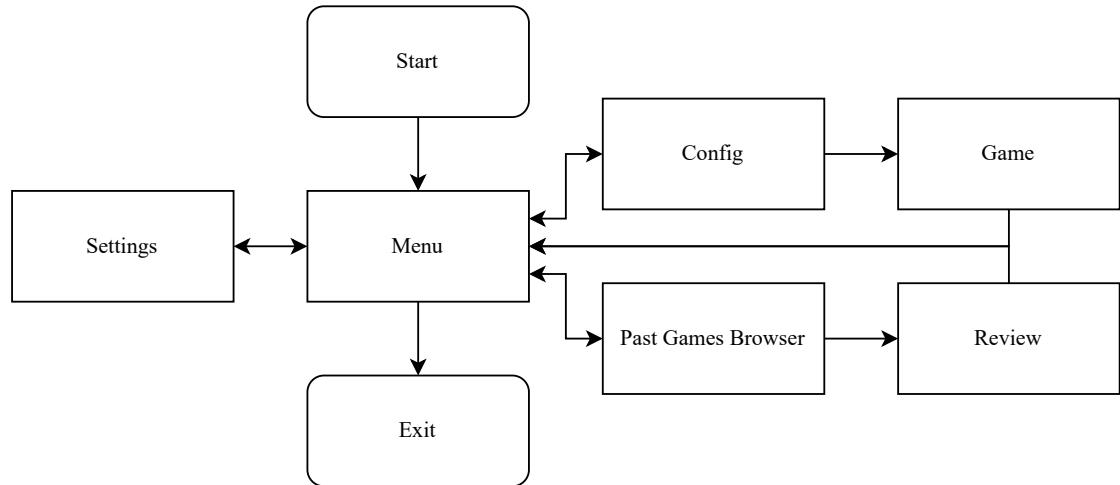


Figure 2.1: Flowchart for Program Overview

2.1.1 Main Menu



Figure 2.2: Main Menu screen prototype

The main menu will be the first screen to be displayed, providing access to different stages of the game. The GUI should be simple yet effective, containing clearly-labelled buttons for the user to navigate to different parts of the game.

2.1.2 Settings

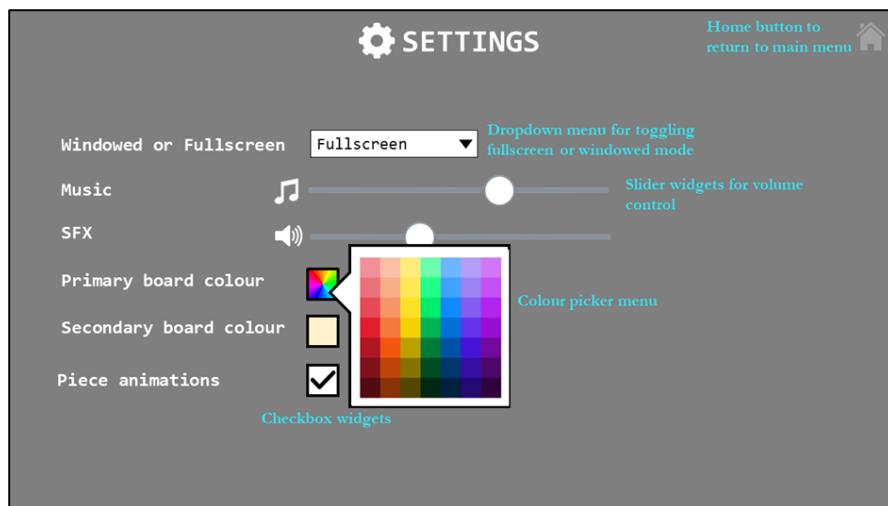


Figure 2.3: Settings screen prototype

The settings menu allows for the user to customise settings related to the program as a whole. The settings will be changed via GUI elements such as buttons and sliders, offering the ability

to customize display mode, volume, board colour etc. Changes to settings will be stored in an intermediate code class, then stored externally into a JSON file. Game settings will instead be changed in the Config screen.

The setting screen should provide a user-friendly interface for changing the program settings intuitively; I have therefore selected appropriate GUI widgets for each setting:

- Windowed or Fullscreen - Drop-down list for selecting between pre-defined options
- Music and SFX - Slider for selecting audio volume, a continuous value
- Board colour - Colour grid for the provision of multiple pre-selected colours
- Piece animation - Checkbox for toggling between on or off

Additionally, each screen is provided with a home button icon on the top right (except the main menu), as a shortcut to return to the main menu.

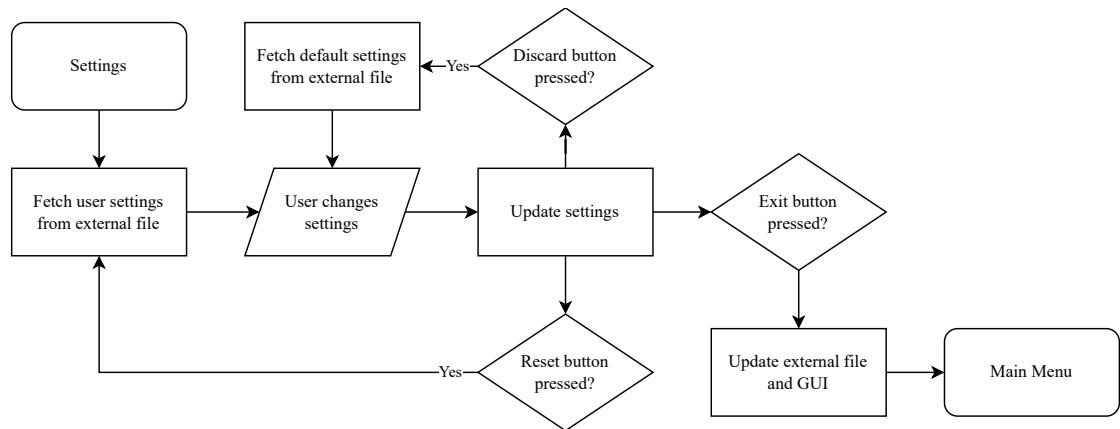


Figure 2.4: Flowchart for Settings

2.1.3 Past Games Browser



Figure 2.5: Browser screen prototype

The Past Games Browser menu displays a list of previously played games to be replayed. When selecting a game, the replay will render out the saved FEN string into a board position identical to the one played previously, except the user is limited to replaying back and forth between recorded moves. The menu also offers the functionality of sorting games in terms of time, game length etc.

For the GUI, previous games will be displayed on a strip, scrolled through by a horizontal slider. Information about the game will be displayed for each instance, along with the option to copy the FEN string to be stored locally or to be entered into the Review screen. When choosing a past game, a green border will appear to show the current selection, and double clicking enters the user into the full replay mode. While replaying the game, the GUI will appear identical to an actual game. However, the user will be limited to scrolling throughout the moves via the left and right arrow keys.

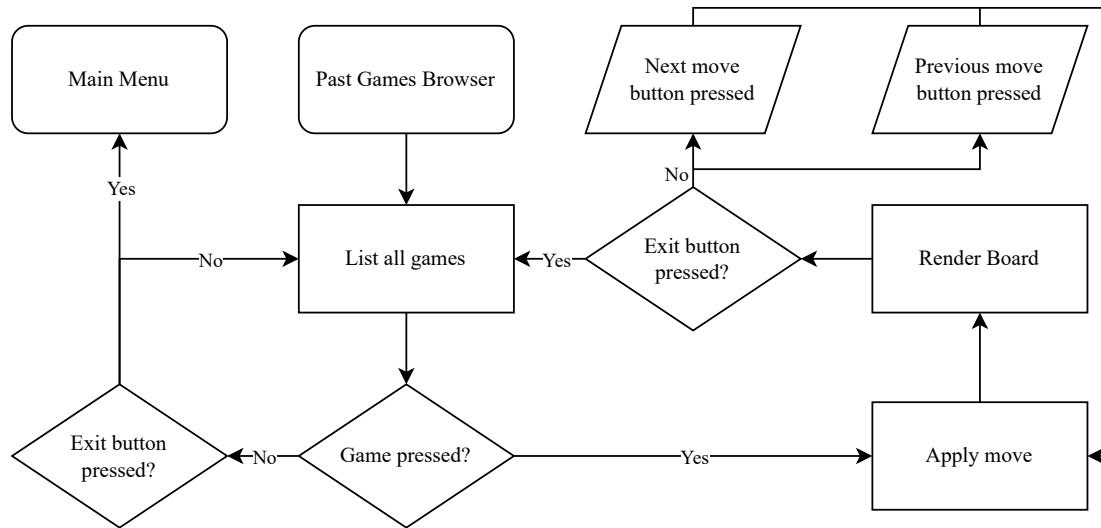


Figure 2.6: Flowchart for Browser

2.1.4 Config

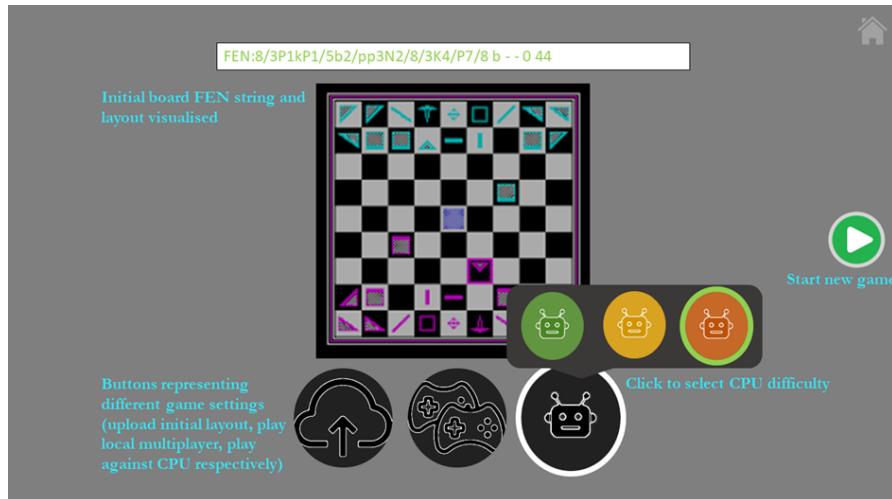


Figure 2.7: Config screen prototype

The config screen comes prior to the actual gameplay screen. Here, the player will be able to change game settings such as toggling the CPU player, time duration, playing as white or black etc.

The config menu is loaded with the default starting position. However, players may enter their own FEN string as an initial position, with the central board updating responsively to give a visual representation of the layout. Players are presented with the additional options to play against a friend, or against a CPU, which displays a drop-down list when pressed to select the CPU difficulty.

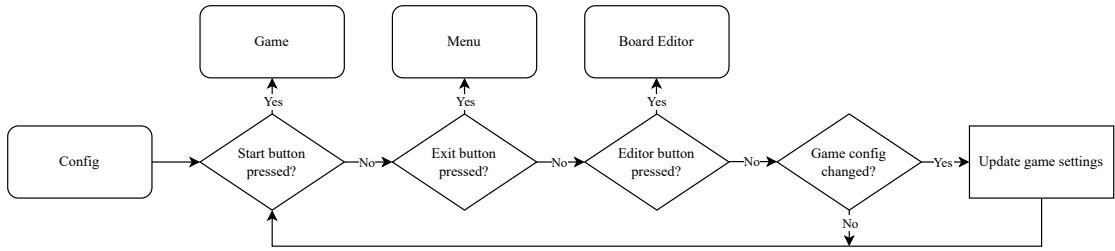


Figure 2.8: Flowchart for Config

2.1.5 Game



Figure 2.9: Game screen prototype

During the game, handling of the game logic, such as calculating player turn, calculating CPU moves or laser trajectory, will be computed by the program internally, rendering the updated GUI accordingly in a responsive manner to provide a seamless user experience.

In the game screen, the board is positioned centrally on the screen, surrounded by accompanying widgets displaying information on the current state of the game. The main elements include:

- Status text - displays information on the game state and prompts for each player move
- Rotation buttons - allows each player to rotate the selected piece by 90° for their move
- Timer - displays available time left for each player
- Draw and forfeit buttons - for the named functionalities, confirmed by pressing twice
- Piece display - displays material captured from the opponent for each player

Additionally, the current selected piece will be highlighted, and the available squares to move to will also contain a circular visual cue. Pieces will either be moved by clicking the

target square, or via a drag-and-drop mechanism, accompanied by responsive audio cues. These implementations aim to improve user-friendliness and intuitiveness of the program.

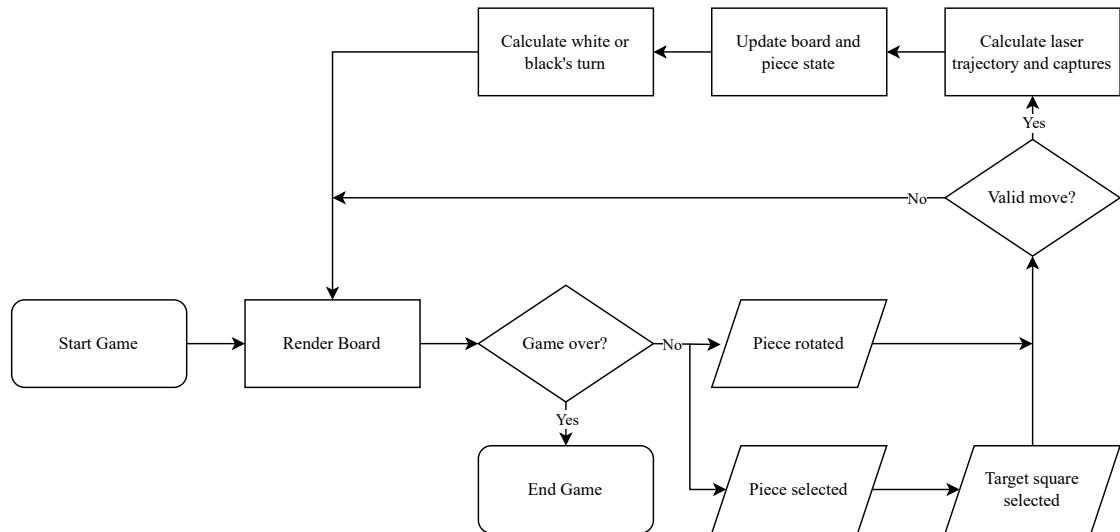


Figure 2.10: Flowchart for Game

2.1.6 Board Editor

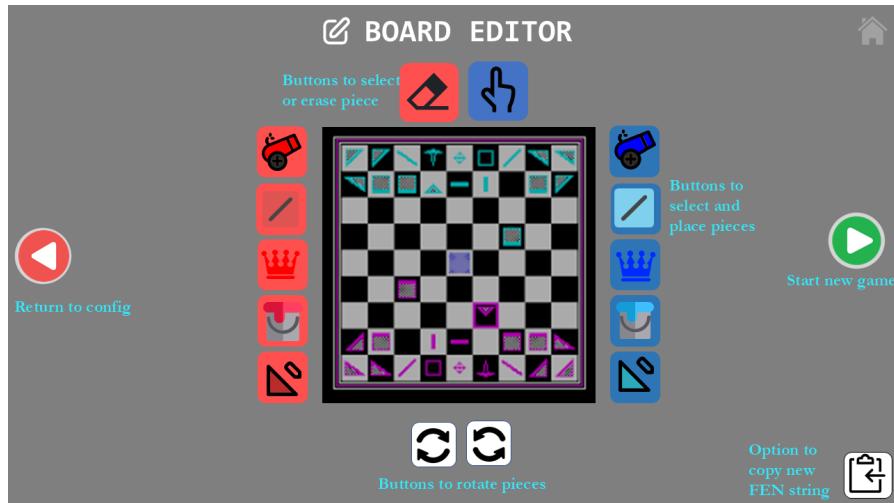


Figure 2.11: Editor screen prototype

The editor screen is used to configure the starting position of the board. Controls should include the ability to place all piece types of either colour, to erase pieces, and easy board manipulation shortcuts such as dragging pieces or emptying the board.

For the GUI, the buttons should clearly represent their functionality, through the use of icons and appropriate colouring (e.g. red for delete).

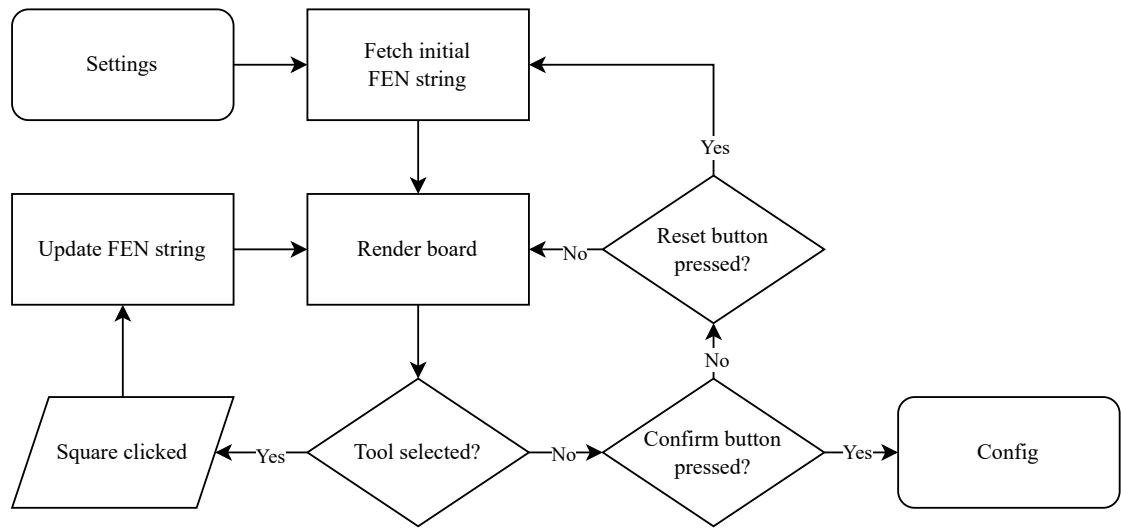


Figure 2.12: Flowchart for board editor

2.2 Algorithms and Techniques

2.2.1 Minimax

Minimax is a backtracking algorithm commonly used in zero-sum games used to determine the score according to an evaluation function, after a certain number of perfect moves. Minimax aims to minimize the maximum advantage possible for the opponent, thereby minimizing a player's possible loss in a worst-case scenario. It is implemented using a recursive depth-first search, alternating between minimizing and maximizing the player's advantage in each recursive call.

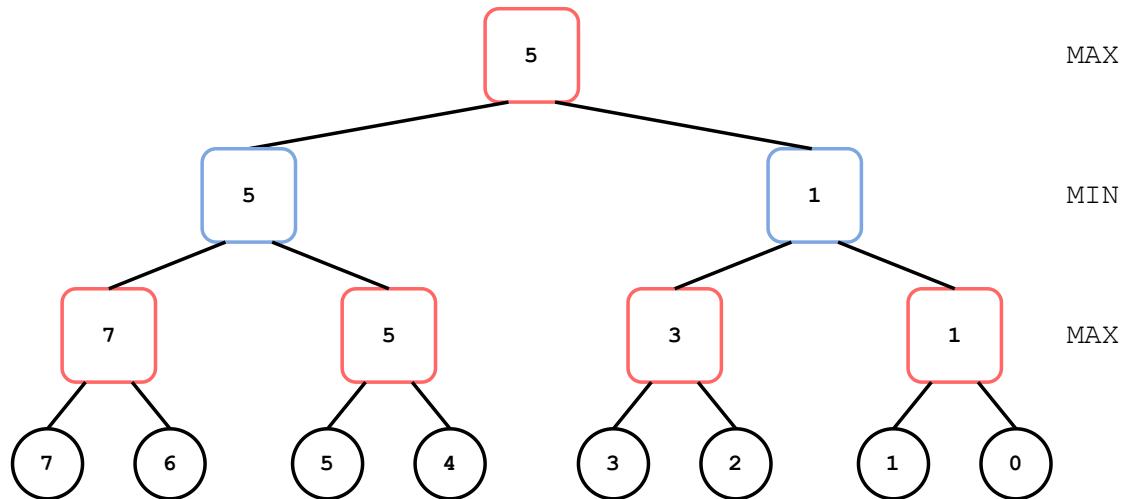


Figure 2.13: Example minimax tree

For the example minimax tree show in Figure 2.13, starting from the bottom leaf node

evaluations, the maximising player would choose the highest values (7, 5, 3, 1). From those values, the minimizing player would choose the lowest values (5, 1). The final value chosen by the maximum player would therefore be the highest of the two, 5.

Implementation in the form of pseudocode is shown below:

Algorithm 1 Minimax pseudocode

```

function MINIMAX(node, depth, maximisingPlayer)
  if depth = 0 OR node equals game over then
    return EVALUATE
  end if

  if maximisingPlayer then
    value ← −∞
    for child of node do
      value ← MAX(value, MINIMAX(child, depth − 1, false))
    end for
    return value
  else
    value ← +∞
    for child of node do
      value ← MIN(value, MINIMAX(child, depth − 1, true))
    end for
    return value
  end if
end function
```

2.2.2 Minimax improvements

Alpha-beta pruning

Alpha-beta pruning is a search algorithm that aims to decrease the number of nodes evaluated by the minimax algorithm. Alpha-beta pruning stops evaluating a move in the game tree when one refutation is found in its child nodes, proving the node to be worse than previously-examined alternatives. It does this without any potential of pruning away a better move. The algorithm maintains two values: alpha and beta. Alpha (α), the upper bound, is the highest value that the maximising player is guaranteed of; Beta (β), the lower bound, is the lowest value that the minimizing player is guaranteed of. If the condition $\alpha \geq \beta$ for a node being evaluated, the evaluation process halts and its remaining children nodes are ‘pruned’.

This is shown in the following maximising example:

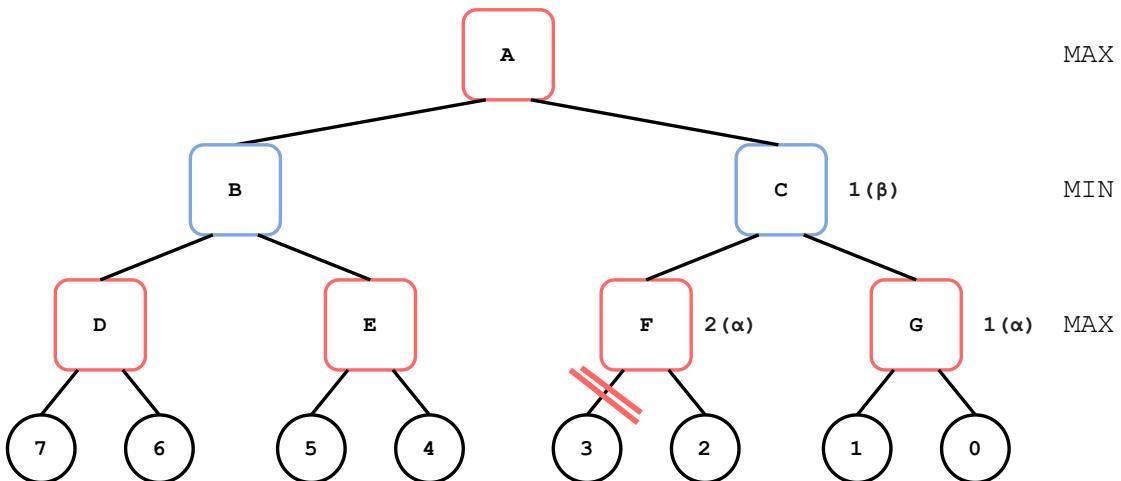


Figure 2.14: Example minimax tree with alpha-beta pruning

Since minimax is a depth-first search algorithm, nodes C and G and their α and β have already been searched. Next, at node F , the current α and β are $-\infty$ and 1 respectively, since the β is passed down from node C . Searching the first leaf node, the α subsequently becomes $\alpha = \max(-\infty, 2)$. This means that the maximising player at this depth is already guaranteed an evaluation of 2 or greater. Since we know that the minimising player at the depth above is guaranteed a value of 1, there is no point in continuing to search node F , a node that returns a value of 2 or greater. Hence at node F , where $\alpha \geq \beta$, the branches are pruned.

Alpha-beta pruning therefore prunes insignificant nodes by maintain an upper bound α and lower bound β . This is an essential optimization as a simple minimax tree increases exponentially in size with each depth ($O(b^d)$, with branching factor b and d ply depth), and alpha-beta reduces this and the associated computational time considerably.

The pseudocode implementation is shown below:

Algorithm 2 Minimax with alpha-beta pruning pseudocode

```

function MINIMAX(node, depth,  $\alpha$ ,  $\beta$ , maximisingPlayer)
    if depth = 0 OR node equals game over then
        return EVALUATE
    end if

    if maximisingPlayer then
        value  $\leftarrow -\infty$ 
        for child of node do
            value  $\leftarrow \text{MAX}(\text{value}, \text{MINIMAX}(\text{child}, \text{depth} - 1, \alpha, \beta, \text{false}))$ 
            if value >  $\beta$  then break
            end if
             $\alpha \leftarrow \text{MAX}(\alpha, \text{value})$ 
        end for
        return value
    else
        value  $\leftarrow +\infty$ 
        for child of node do
            value  $\leftarrow \text{MIN}(\text{value}, \text{MINIMAX}(\text{child}, \text{depth} - 1, \alpha, \beta, \text{true}))$ 
            if value <  $\alpha$  then break
            end if
             $\beta \leftarrow \text{MIN}(\beta, \text{value})$ 
        end for
        return value
    end if
end function

```

Transposition Tables & Zobrist Hashing

Transition tables, a memoisation technique, again greatly reduces the number of moves searched. During a brute-force minimax search with a depth greater than 1, the same positions may be searched multiple times, as the same position can be reached from different sequences of moves. A transposition table caches these same positions (transpositions), along with its associated evaluations, meaning commonly reached positions are not unnecessarily re-searched.

Flags and depth are also stored alongside the evaluation. Depth is required as if the current search comes across a cached position with an evaluation calculated at a lower depth than the current search, the evaluation may be inaccurate. Flags are required for dealing with the uncertainty involved with alpha-beta pruning, and can be any of the following three.

Exact flag is used when a node is fully searched without pruning, and the stored and fetched evaluation is accurate.

Lower flag is stored when a node receives an evaluation greater than the β , and is subsequently pruned, meaning that the true evaluation could be higher than the value stored. We are thus storing the α and not an exact value. Thus, when we fetch the cached value, we have to recheck if this value is greater than β . If so, we return the value and this branch is pruned (fail high); If not, nothing is returned, and the exact evaluation is calculated.

Upper flag is stored when a node receives an evaluation smaller than the α , and is subsequently pruned, meaning that the true evaluation could be lower than the value stored. Similarly, when we fetch the cached value, we have to recheck if this value is lower than α . Again, the current branch is pruned if so (fail low), and an exact evaluation is calculated if not.

The pseudocode implementation for transposition tables is shown below:

Algorithm 3 Minimax with transposition table pseudocode

```

function MINIMAX(node, depth,  $\alpha$ ,  $\beta$ , maximisingPlayer)
    hash_key  $\leftarrow$  HASH(node)
    entry  $\leftarrow$  GETENTRY(hash_key)

    if entry.hash_key = hash_key AND entry.hash_key  $\geq$  depth then
        if entry.hash_key = EXACT then
            return entry.value
        else if entry.hash_key = LOWER then
             $\alpha \leftarrow \text{MAX}(\alpha, \text{entry.value})$ 
        else if entry.hash_key = UPPER then
             $\beta \leftarrow \text{MIN}(\beta, \text{entry.value})$ 
        end if
        if  $\alpha \geq \beta$  then
            return entry.value
        end if
    end if

    ...normal minimax...

    entry.value  $\leftarrow$  value
    entry.depth  $\leftarrow$  depth
    if value  $\leq \alpha$  then
        entry.flag  $\leftarrow$  UPPER
    else if value  $\geq \beta$  then
        entry.flag  $\leftarrow$  LOWER
    else
        entry.flag  $\leftarrow$  EXACT
    end if

    return value
end function

```

The current board position will be used as the index for a transposition table entry. To convert our board state and bitboards into a valid index, Zobrist hashing may be used. For every square on the chessboard, a random integer is assigned to every piece type (12 in our case, 6 piece type, times 2 for both colours). To initialise a hash, the random integer associated with the piece on a specific square undergoes a XOR operation with the existing hash. The hash is incrementally update with XOR operations every move, instead of being recalculated from scratch improving computational efficiency. Using XOR operations also allows moves to be reversed, proving useful for the functionality to scroll through previous moves. A Zobrist hash is also a better candidate than FEN strings in checking for threefold-repetition, as they are less

intensive to calculate for every move.

The pseudocode implementation for Zobrist hashing is shown below:

Algorithm 4 Zobrist hashing pseudocode

RANDOMINTS represents a pre-initialised array of random integers for each piece type for each square

```

function HASH _ BOARD(board)
    hash  $\leftarrow$  0
    for each square on board do
        if square is not empty then
            hash  $\oplus$  RANDOMINTS[square][piece on square]
        end if
    end for
    return hash
end function

function UPDATEHASH(hash, move)
    hash  $\oplus$  RANDOMINTS[source square][piece]
    hash  $\oplus$  RANDOMINTS[destination square][piece]
    if red to move then
        hash  $\oplus$  hash for red to move  $\triangleright$  Hash needed for move colour, as two identical positions
        are different if the colour to move is different
    end if
    return hash
end function

```

2.2.3 Board Representation

FEN string

Forsyth-Edwards Notation (FEN) notation provides all information on a particular position in a chess game. I intend to implement methods parsing and generating FEN strings in my program, in order to load desired starting positions and save games for later play. Deviating from the classic 6-part format, a custom FEN string format will be required for our laser chess game, accommodating its different rules from normal chess.

Our custom format implementation is show by the example below:

sc3ncfancpb2/2pc7/3Pd7/pa1Pc1rbra1pb1Pd/pb1Pd1RaRb1pa1Pc/6pb3/7Pa2/2PdNaFaNa3Sa
r

Our FEN string format contains two parts, denoted by the space between them:

- Part 1: Describes the location of each piece. The construction of this part is defined by the following rules:
 - The board is read from top-left to bottom-right, row by row
 - A number represents the number of empty squares before the next piece
 - A capital letter represents a blue piece, and a lowercase letter represents a red piece

- The letters F , R , P , N , S stand for the pieces Pharaoh, Scarab, Pyramid, Anubis and Sphinx respectively
- Each piece letter is followed by the lowercase letters a , b , c or d , representing a 0° , 90° , 180° and 270° degree rotation respectively
- Part 2: States the active colour, b means blue to move, r means red to move

Having inputted the desired FEN string board configuration in the config menu, the bitboards for each piece will be initialised with the following functions:

Algorithm 5 FEN string pseudocode

```

function PARSE_FEN_STRING(fen_string, board)
  part_1, part_2 ← SPLIT(fen_string)
  rank ← 8
  file ← 0

  for character in part_1 do
    square ← rank × 8 + file
    if character is alphabetic then
      if character is lower then
        board.bitboards[red][character] | 1 << character
      else
        board.bitboards[blue][character] | 1 << character
      end if
    else if character is numeric then
      file ← file + character
    else if character is / then
      rank ← rank - 1
      file ← file + 1
    else
      file ← file + 1
    end if

    if part_2 is b then
      board.active_colour ← b
    else
      board.active_colour ← r
    end if
  end for
end function
```

The function first processes every piece and corresponding square in the FEN string, modifying each piece bitboard using a bitwise OR operator, with a 1 shifted over to the correctly occupied square using a Left-Shift operator. For the second part, the active colour property of the board class is initialised to the correct player.

Bitboards

Bitboards are an array of bits representing a position or state of a board game. Multiple bitboards are used with each representing a different property of the game (e.g. scarab position and

scarab rotation), and can be masked together or transformed to answer queries about positions. Bitboards offer an efficient board representation, its performance primarily arising from the speed of parallel bitwise operations used to transform bitboards. To map each board square to a bit in each number, we will assign each square from left to right, with the least significant bit (LSB) assigned to the bottom-left square (A1), and the most significant bit (MSB) to the top-right square (J8).

8	70	71	72	73	74	75	76	77	78	79
7	60	61	62	63	64	65	66	67	68	69
6	50	51	52	53	54	55	56	57	58	59
5	40	41	42	43	44	45	46	47	48	49
4	30	31	32	33	34	35	36	37	38	39
3	20	21	22	23	24	25	26	27	28	29
2	10	11	12	13	14	15	16	17	18	19
1	0	1	2	3	4	5	6	7	8	9

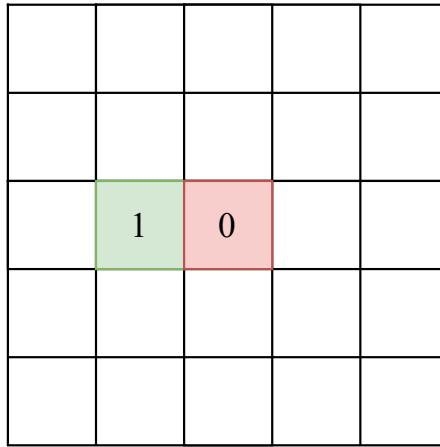
a b c d e f g h j k

Figure 2.15: Square to bit position mapping

Firstly, we need to initialise each bitboard and place 1s in the correct squares occupied by pieces. This is achieved whilst parsing the FEN-string, as shown in Algorithm 5. Secondly, we should implement an approach to calculate possible moves using our computed bitboards. We can begin by producing a bitboard containing the locations of all pieces, achieved through combining every piece bitboard with bitwise OR operations:

```
all_pieces_bitboard = white_pharaoh_bitboard | black_pharaoh_bitboard |
                     white_scarab_bitboard ...
```

Now, we can utilize this aggregated bitboard to calculate possible positional moves for each piece. For each piece, we can shift the entire bitboard to an adjacent target square (since every piece can only move one adjacent square per turn), and perform a bitwise AND operator with the bitboard containing all pieces, to determine if the target square is already occupied by an existing piece. For example, if we want to compute if the square to the left of our selected piece is available to move to, we will first shift every bit right (as the lowest square index is the LSB on the right, see diagram above), as demonstrated in the following 5x5 example:

Figure 2.16: `shifted_bitboard = piece_bitboard >> 1`

Where green represents the target square shifted into, and orange where the piece used to be. We can then perform a bitwise AND operation with the complement of the all pieces bitboard, where a square with a result of 1 represents an available target square to move to.

```
available_squares_right = (piece_bitboard >> 1) & ~all_pieces_bitboard
```

However, if the piece is on the leftmost A file, and is shifted to the right, it will be teleported onto the J file on the rank below, which is not a valid move. To prevent these erroneous moves for pieces on the edge of the board, we can utilise an A file mask to mask away any valid moves, as demonstrated below:

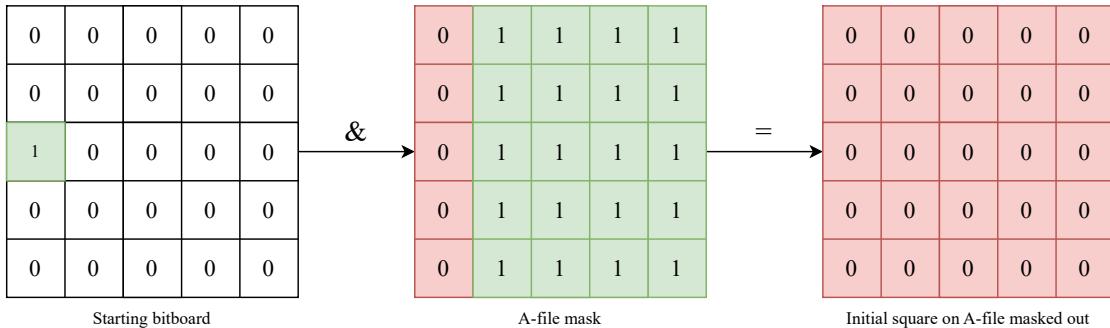


Figure 2.17: A-file mask example

This approach uses the logic that a piece on the A file can never move to a square on the left. Therefore, when calculating if a piece can move to a square on the left, we apply a bitwise AND operator with a mask where every square on the A file is 0; If a piece was on the A file, it will become 0, leaving no possible target squares to move to. The same approach can be mirrored for the far-right J file.

In theory, we do not need to implement the same solution for clipping in regards to ranks, as they are removed automatically by overflow or underflow when shifting bits too far. Our final function to calculate valid moves combines all the logic above: Shifting the selected piece in all

9 adjacent directions by their corresponding bits, masking away pieces trying to move into the edge of the board, combining them with a bitwise OR operator, and finally masking it with the all pieces bitboard to detect which squares are not currently occupied:

Algorithm 6 Finding valid moves pseudocode

```

function FIND_VALID_MOVES(selected_square)
  masked_a_square ← selected_square & A_FILE_MASK
  masked_j_square ← selected_square & J_FILE_MASK

  top_left ← masked_a_square << 9
  top_left ← masked_a_square << 9
  top_middle ← selected_square << 10
  top_right ← masked_ << 11
  middle_right ← masked_ << 1
  bottom_right ← masked_ >> 9
  bottom_middle ← selected_square >> 10
  bottom_left ← masked_a_square >> 11
  middle_left ← masked_a_square >> 1

  possible_moves = top_left | top_middle | top_right | middle_right | bottom_right |
  bottom_middle | bottom_left | middle_left
  valid_moves = possible_moves & ~ ALL_PIECES_BITBOARD

  return valid_moves
end function
  
```

2.2.4 Evaluation Function

The evaluation function is a heuristic algorithm to determine the relative value of a position. It outputs a real number corresponding to the advantage given to a player if reaching the analysed position, usually at a leaf node in the minimax tree. The evaluation function therefore provides the values on which minimax works on to compute an optimal move.

In the majority of evaluation functions, the most significant factor determining the evaluation is the material balance, or summation of values of the pieces. The hand-crafted evaluation function is then optimised by tuning various other positional weighted terms, such as board control and king safety.

Material Value

Since laser chess is not widely documented, I have assigned relative strength values to each piece according to my experience playing the game:

- Pharaoh - ∞
- Scarab - 200
- Anubis - 110
- Pyramid - 100

To find the number of pieces, we can iterate through the piece bitboard with the following popcount function:

Algorithm 7 Popcount pseudocode

```

function POPCOUNT(bitboard)
    count ← 0
    while bitboard do
        count ← count + 1
        bitboard ← bitboard&(bitboard − 1)
    end while
    return count
end function

```

Algorithm 7 continually resets the left-most 1 bit, incrementing a counter for each loop. Once the number of pieces has been established, we multiply this number by the piece value. Repeating this for every piece type, we can thus obtain a value for the total piece value on the board.

Piece-Square Tables

A piece in normal chess can differ in strength based on what square it is occupying. For example, a knight near the center of the board, controlling many squares, is stronger than a knight on the rim. Similarly, we can implement positional value for Laser Chess through Piece-Square Tables. PSQTs are one-dimensional arrays, with each item representing a value for a piece type on that specific square, encoding both material value and positional simultaneously. Each array will consist of 80 base values representing the piece's material value, with a bonus or penalty added on top for the location of the piece on each square. For example, the following PSQT is for the pharaoh piece type on an example 5x5 board:

0	0	0	0	0
0	0	1	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Piece index

-10	-10	-10	-10	-10
-10	-10	-10	-10	-10
-5	-5	-5	-5	-5
0	0	0	0	0
5	5	5	5	5

Used to reference positional value in PSQT

Figure 2.18: PSQT showing the bonus position value gained for the square occupied by a pharaoh

For asymmetrical PSQTs, we would ideally like to label the board identically from both player's point of views. Although the PSQTs are displayed from the blue player's perspective (blue pharaoh at the bottom of the board), it uses indexes from the red player's perspective, as arrays and lists are defined with index 0 being at the topleft of the board. We would like to flip

the PSQTs to be reused with blue indexes, so that a generic algorithm can be used to sum up and calculate the total positional values for both players.

To utilise a PSQT for blue pieces, a special ‘FLIP’ table can be implemented:

8	70	71	72	73	74	75	76	77	78	79
7	60	61	62	63	64	65	66	67	68	69
6	50	51	52	53	54	55	56	57	58	59
5	40	41	42	43	44	45	46	47	48	49
4	30	31	32	33	34	35	36	37	38	39
3	20	21	22	23	24	25	26	27	28	29
2	10	11	12	13	14	15	16	17	18	19
1	0	1	2	3	4	5	6	7	8	9
	a	b	c	d	e	f	g	h	j	k

Figure 2.19: FLIP table used to map a blue piece index to the red player’s perspective

The FLIP table is just an array of indexes, mapping every blue player’s index onto the corresponding red index. The following expression utilises the FLIP table to retrieve a blue player’s value from the red player’s PSQT:

$$\text{blue_psqt_value} = \text{PHAROAH_PSQT}[\text{FLIP}[\text{square}]]$$

The following function retrieves an array of bitboards representing piece positions from the board class, then sums up all the values of these pieces for both players, referencing the corresponding PSQT:

Algorithm 8 Calculating positional value pseudocode

```

function CALCULATE_POSITIONAL_VALUE(bitboards, colour)
    positional_score ← 0
    for all pieces do
        for square in bitboards[piece] do
            if square = 1 then
                if colour is blue then
                    positional_score ← positional_score + PSQT[piece][square]
                else
                    positional_score ← positional_score + PSQT[piece][FLIP[square]]
                end if
            end if
        end for
    end for
    return positional_score
end function

```

Using valid squares

Using Algorithm 6 for finding valid moves, we can implement two more improvements for our evaluation function: Mobility and King Safety.

Mobility is the number of legal moves a player has for a given position. This is advantageous in most cases, with a positive correlation between mobility and the strength of a position. To implement this, we simply loop over all pieces of the active colour, and sum up the number of valid moves obtained from the previous algorithm.

King safety (Pharaoh safety) describes the level of protection of the pharaoh, being the piece that determines a win or loss. In normal chess, this would be achieved usually by castling, or protection via position or with other pieces. Similarly, since the only way to lose in Laser Chess is via a laser, having pieces surrounding the pharaoh, either to reflect the laser or to be sacrificed, is a sensible tactic and improves king safety. Thus, a value for king safety can be achieved by finding the number of valid moves a pharaoh can make, and subtracting them from the maximum possible of moves (8) to find the number of surrounding pieces.

2.2.5 Shadow Mapping

Following the client's requirement for engaging visuals, I have decided to implement shadow mapping for my program, especially as lasers are the main focus of the game. Shadow mapping is a technique used to create graphical hard shadows, with the use of a depth buffer map. I have chosen to implement shadow mapping, instead of alternative lighting techniques such as ray casting and ray marching, as its efficiency is more suitable for real-time usage, and results are visually decent enough for my purposes.

For typical 3D shadow mapping, the standard approach is as follows:

1. Render the scene from the light's point of view
2. Extract a depth buffer texture from the render
3. Compare the distance of a pixel from the light to the value stored in the depth texture
4. If greater, there must be an obstacle in the way reducing the depth map value, therefore that pixel must be in shadow

To implement shadow casting for my 2D game, I have modified some steps and arrived on the final following workflow:

1. Render the scene with only occluding objects shown
2. Crop texture to align the center to the light position
3. To create a 1D depth map, transform Cartesian to polar coordinates, and increase the distance from the origin until a collision with an occluding object
4. Using polar coordinates for the real texture, compare the z-depth to the corresponding value from the depth map
5. Additively blend the light colour if z-depth is less than the depth map value

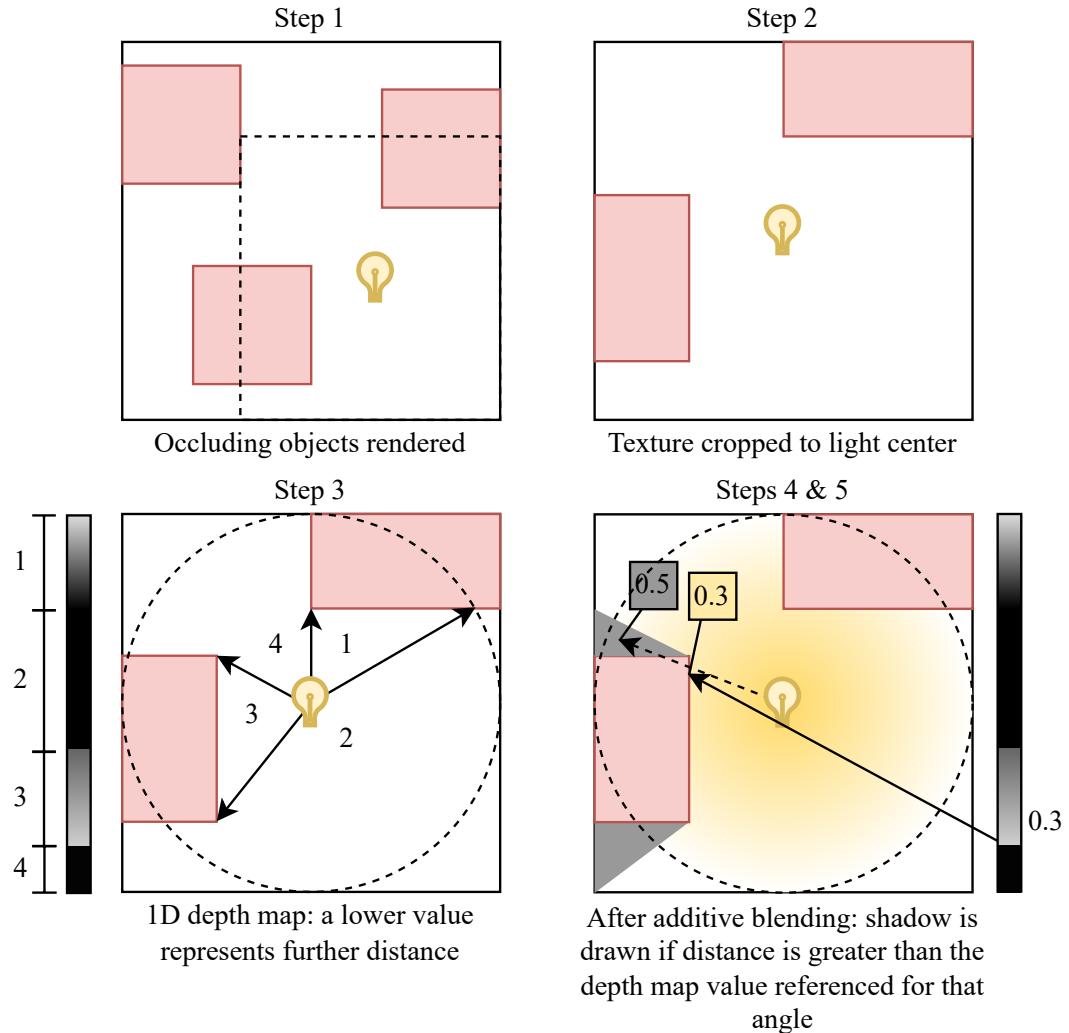


Figure 2.20: Workflow for 2D shadow mapping

Our method requires a coordinate transformation from Cartesian to polar, and vice versa. Polar to Cartesian transformation can be achieved with trigonometry, forming a right-angled triangle in the center and using the following two equations:

$$x = r \cos(\theta)$$

$$y = r \sin(\theta)$$

Cartesian to polar can also similarly be achieved with the right-angled triangle, finding the radius with the Pythagorean theorem, and the angle with arctan. However, since the range of the arctan function is only a half-circle ($\frac{\pi}{2} < \theta < \frac{3\pi}{2}$), we will have to use the atan2 function, which accounts for the negative quadrants, or the following:

$$\theta = 2 \arctan \left(\frac{r - x}{y} \right)$$

There are several disadvantages to shadow mapping. The relevant ones for us are Aliasing and Shadow Acne:

Aliasing occurs when the texture size for the depth map is smaller than the light map, causing shadows to be scaled up and rendered with jagged edges.

Shadow Acne occurs when the depth from the depth map is so close to the light map value, that precision errors cause unnecessary shadows to be rendered.

These problems can be mitigated by increasing the size of the shadow map size. However, due to memory and hardware constraints, I will have to find a compromised resolution to balance both artifacting and acuity.

Soft Shadows

The approach above is used only for calculating hard shadows. However, in real-life scenarios, lights are not modelled as a single particle, but instead emitted from a wide light source. This creates an umbra and penumbra, resulting in soft shadows.

To emulate this in our game, we could calculate penumbra values with various methods, however, due to hardware constraints and simplicity again, I have chosen to use the following simpler method:

1. Sample the depth map multiple times, from various differing angles
2. Sum the results using a normal distribution
3. Blur the final result proportional to the length from the center

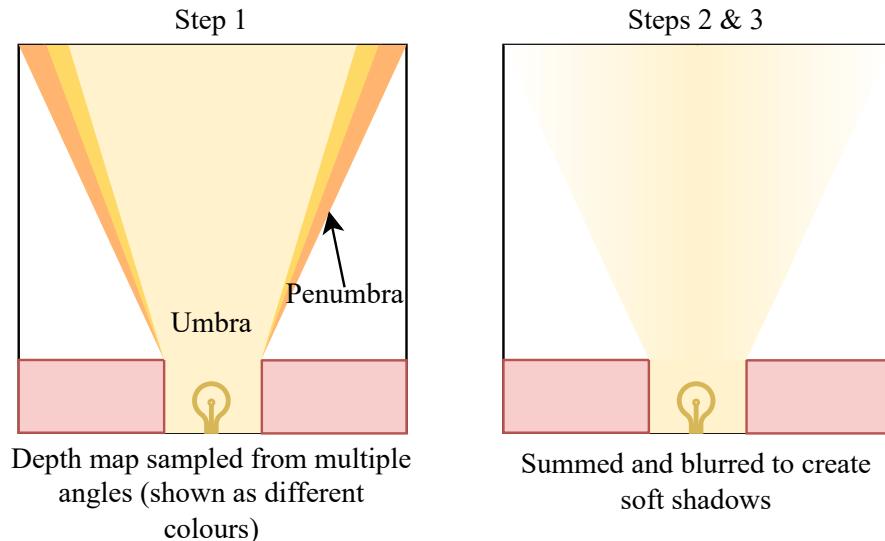


Figure 2.21: Workflow for 2D soft shadows

This method progressively blurs the shadow as the distance from the main shadow (umbra) increases, which results in a convincing estimation while being less computationally intensive.

2.2.6 Multithreading

In order to fulfill Objective 6 of a responsive GUI, I will have to employ multi-threading. Since python runs on a single thread natively, code is executed serially, meaning that a time consuming function such as minimax will prevent the running of another GUI-drawing function until it is finished, hence freezing the program. To overcome this, multi-threading can execute both functions in parallel on different threads, meaning the GUI-drawing thread can run while minimax is being computed, and stay responsive. To pass data between threads, since memory is shared between threads, arrays and queues can be used to store results from threads. The following flowchart shows my chosen approach to keep the GUI responsive while minimax is being computed:

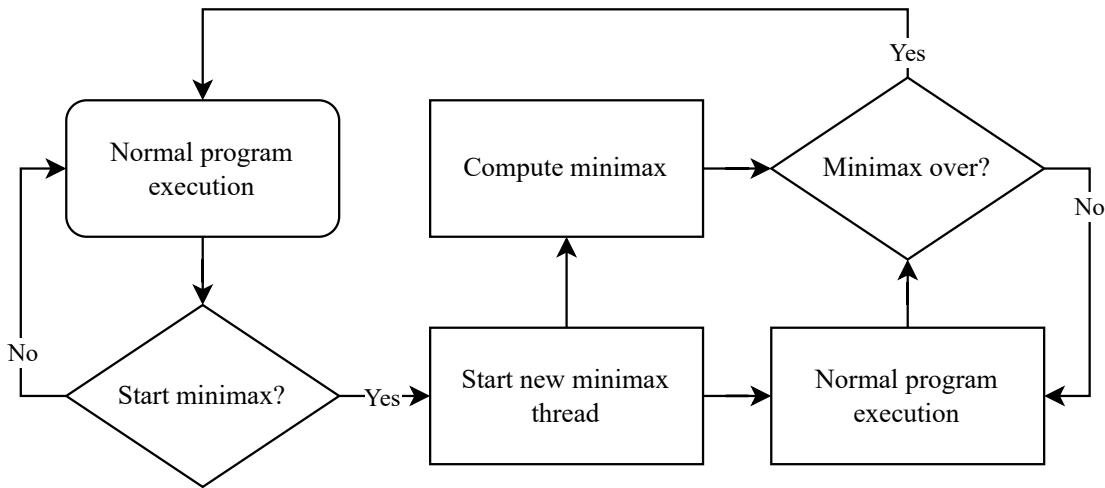


Figure 2.22: Multi-threading for minimax

2.3 Data Structures

2.3.1 Database

To achieve Objective 2 and stores previous games, I have opted to use a relational database. Choosing between different relational database, I have decided to use SQLite, since it does not require additional server softwares, has good performance with low memory requirements, and adequate for my use cases, with others such as Postgres being overkill.

DDL

Only a single entity will be required for my program, a table to store games. The table schema will be defined as follows:

Table: games			
Field	Key	Data Type	Validation
game_id	Primary	INT	NOT NULL
winner		INT	
cpu_depth		INT	

number_of_moves	INT	NOT NULL
cpu_enabled	BOOL	NOT NULL
moves	TEXT	NOT NULL
initial_board_configuration	TEXT	NOT NULL
time	FLOAT	
created_dt	TIMESTAMP	NOT NULL

Table 2.1: Data table scheme for *games* table

All fields are either generated or retrieved from the board class, with the exception of the moves attribute, which will need to be encoded into a suitable data type such as a string. All attributes are also independent of each other¹, and so the the table therefore adheres to the third normal form.

To create the entity, a `CREATE` statement like the following can be used:

```

1 CREATE TABLE games(
2     id INTEGER PRIMARY KEY,
3     winner INTEGER,
4     cpu_depth INTEGER,
5     time real NOT NULL,
6     moves TEXT NOT NULL,
7     cpu_enabled INTEGER NOT NULL,
8     created_dt TIMESTAMP NOT NULL,
9     number_of_moves INTEGER NOT NULL,
10    initial_fen_string TEXT NOT NULL,
11 )

```

Removing an entity can also be done in a similar fashion:

```

1 DROP TABLE games

```

Migrations are a version control system to track incremental changes to the schema of a database. Since there is no popular SQL Python-binding libraries that support migrations, I will just be using a manual solution of creating python files that represent a change in my schema, defining functions that make use of SQL `ALTER` statements. This allows me to keep track of any changes, and rollback to a previous schema.

DML

To insert a new game entry into the table, an `INSERT` statement can be used with the provided array, where the appropiate arguments are binded to the correct attribute via ? placeholders when run.

```

1 INSERT INTO games (
2     cpu_enabled,
3     cpu_depth,
4     winner,
5     time,
6     number_of_moves,
7     moves,
8     initial_fen_string,

```

¹There is a case to be made for *moves* and *number_of_moves*, however I have included *number_of_moves* to save the computational effort of parsing the moves for every game just to display it on the browser preview section.

```

9     created_dt
10    )
11   VALUES  (?, ?, ?, ?, ?, ?, ?, ?, ?)

```

Moreover, we will need to fetch the number of total game entries in the table to be displayed to the user. To do this, the aggregate function `COUNT` can be used, which is supported by all SQL databases.

```
1   SELECT COUNT(*) FROM games
```

Pagination

When there are a large number of entries in the table, it would be appropriate to display all the games to the user in a paginated form, where they can scroll between different pages and groups of games. There are multiple methods to paginate data, such as using `LIMIT` and `OFFSET` clauses, or cursor-based pagination, but I have opted to use the `ROW_NUMBER()` function.

`ROW_NUMBER()` is a window function that assigns a sequential integer to a query's result set. If I were to query the entire table, each row would be assigned an integer that could be used to check if the row is in the bounds for the current page, and therefore be displayed. Moreover, the use of an `ORDER BY` clause enables sorting of the output rows, allowing the user to choose what order the games are presented in based on an attribute such as number of moves. A `PARTITION BY` clause will also be used to group the results base on an attribute such as winner prior to sorting, if the user wants to search for games based on multiple criteria with greater ease.

The start row and end row will be passed as parameters to the placeholders in the SQL statement, calculated by multiplying the page number by the number of games per page.

```

1   SELECT * FROM
2     (SELECT ROW_NUMBER() OVER (
3       PARTITION BY attribute1
4       ORDER BY attribute2 ASC
5     ) AS row_num, * FROM games)
6   WHERE row_num >= ? AND row_num <= ?

```

Security

Security measures such as database file permissions and encryption are common for a SQL database. However, since SQLite is a serverless database, and my program runs without any need for an internet connection, the risk of vulnerabilities is greatly reduced. Additionally, the game data stored on my database is frankly inconsequential, so going to great lengths to protect it wouldn't be to best use of my time. Nevertheless, my SQL Python-binding does support the user of placeholders for parameters, thereby addressing the risk of SQL injection attacks.

2.3.2 Linked Lists

Another data structure I intend to implement is linked lists. This will be integrated into widgets such as the carousel or multiple icon button widget, since these will contain a variable number of items, and where $O(1)$ random access is not a priority. Since moving back and forth between nodes is a must for a carousel widget, the linked list will be doubly-linked, with each node containing to its previous and next node. The list will also need to loop, with the next pointer of the last node pointing back to the first node, making it a circular linked list.

The following pseudocode outlines the basic functionality of the linked list:

Algorithm 9 Circular doubly linked list pseudocode

```

function INSERT_AT_FRONT(node)
    if head is none then
        head ← node
        node.next ← node.previous ← head
    else
        node.next ← head
        node.previous ← head.previous
        head.previous.next ← node
        head.previous ← node

        head ← node
    end if
end function

```

Require: $\text{LEN}(list) > 0$

```

function DATA_IN_LIST(data)
    current_node ← head.next
    while current_node ≠ head do
        if current_node.data = data then
            return True
        end if
        current_node ← current_node.next
    end while
    return False
end function

```

Require: Data in list

```

function REMOVE(data)
    current_node ← head
    while current_node.data ≠ data do
        current_node ← current_node.next
    end while

    current_node.previous.next ← current_node.next
    current_node.next.previous ← current_node.previous

    delete current_node
end function

```

2.3.3 Stack

Being a data structure with LIFO ordering, a stack is used for handling moves in the review screen. Starting with full stack of moves, every move undone pops an element off the stack to be processed. This move is then pushed onto a second stack. Therefore, cycling between moves requires pushing and popping between the two stacks, as shown in Figure 2.23. The same functionality can be achieved using a queue, but I have chosen to use two stacks as it is simpler

to implement, as being able to quickly check the number of items in each will come in handy.

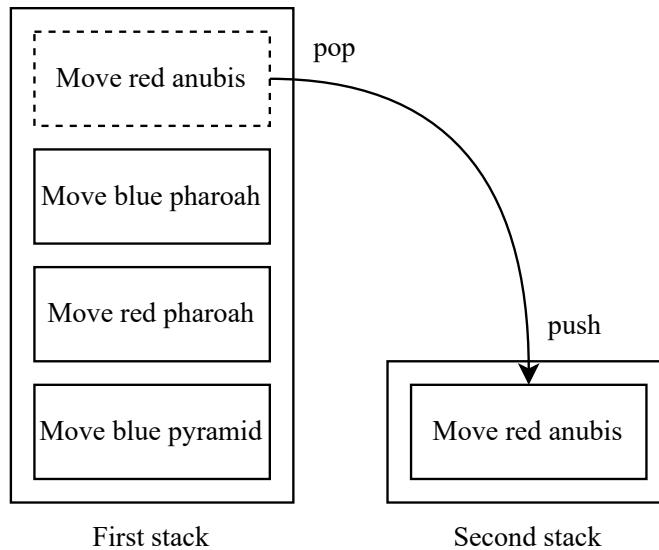


Figure 2.23: *Move red anubis* is undone and pushed onto the second stack

2.4 Classes

I will be using an Object-Oriented Programming (OOP) paradigm for my program. OOP reduces repetition of code, as inheritance can be used to abstract repetitive code into a base class, as shown in my widgets implementation. Testing and debugging classes will make my workflow more efficient. This section documents the base classes I am going to implement in my program.

State

Since there will be multiple screens in my program as demonstrated in Figure 2.1, the State base class will be used to handle the logic for each screen. For each screen, void functions will be inherited and overwritten, each containing their own logic for that specific screen. For example, all screens will call the startup function in Table 2.2 to initialise variables needed for that screen. This polymorphism approach allows me to use another Control class to enable easy switching between screens, without worrying about the internal logic of that screen. Virtual methods also allow methods such as `draw` to be abstracted to the State superclass, reducing code in the inherited subclasses, while allowing them to override the methods and add their own logic.

Method Name	Description
<code>startup</code>	Initialise variables and functions when state set as displayed screen
<code>cleanup</code>	Cleanup any variables and functions when state removed from screen
<code>draw</code>	Draw to display
<code>update</code>	Update any variables for every game tick
<code>handle_resize</code>	Scale GUI when window resized
<code>get_event</code>	Receive pygame events as argument and process them

Table 2.2: Methods for State class

Widget

I will be implementing my own widget system for creating the game GUI. This allows me to fully customise all graphical elements on the screen, and also create a resizing system that adheres to Objective 6. The default pygame rescaling options also simply resize elements without accounting for aspect ratios or resolution, and I could not find a library that suits my needs. Having a bespoke GUI implementation also justifies my use of Pygame over other Python frameworks.

I will be utilising the Pygame sprite system for my GUI. All GUI widgets will be subclasses inheriting from the base Widget class, which itself is a subclass of the Pygame sprite class. Since Pygame sprites are drawn via a spritegroup class, I will also have to create a custom subclass inheriting that as well. As with the State class, polymorphism will allow the spritegroup class to render all widgets regardless of their functionality. Each widget will override their base methods, especially the draw (set_image) method, for their own needs. Additionally, I will use getter and setter methods, used with the `@property` decorator in python, to compute attributes mainly used for resizing widgets. This allows me to expose common variables, and to reduce code repetition.

Method Name	Description
set_image	Render widget to internal image attribute for pygame sprite class
set_geometry	Set position and size of image
set_screen_size	Set screen size for resizing purposes
get_event	Receives pygame events and processes them
screen_size*	Returns screen size in pixels
position*	Returns topleft of widget rect
size*	Returns size of widget in pixels
margin*	Returns distance between border and actual widget image
border_width*	Returns border width
border_radius*	Returns border radius for rounded corners
font_size*	Returns font size for text-based widgets

* represents getter method / property

Table 2.3: Methods for Widget class

I will also employ multiple inheritance to combine different base class functionalities together. For example, I will create a pressable base class, designed to be subclassed along with the widget class. This will provide attributes and methods for widgets that support clicking and dragging. Following Python's Method Resolution Order (MRO), additional base classes should be referenced first, having priority over the base Widget class.

Method Name	Description
get_event	Receives Pygame events and sets current state accordingly
set_state	Sets current Pressable state, called by <code>get_event</code>
set_colours	Set fill colour according to widget Pressable state
current_state*	Returns current Pressable state (e.g. hovered, pressed etc.)

Method Name | Description

* represents getter method / property

Table 2.4: Methods for example Pressable class

Game

For my game screen, I will be utilising the Model-View-Controller architectural pattern (MVC). MVC defines three interconnected parts, the model processing information, the view showing the information, and the controlling receiving user inputs and connecting the two. This will allow me to decompose the development process into individual parts for the game logic, graphics and user input, speeding up the development process and making testing easier. It also allows me to implement multiple views, for the pause and win screens as well. For MVC, I will have to implement a game model class, a game controller class, and three classes for each view (game, pause, win). Using aggregation, these will be initially connected and handled by the game state class. For the following methods, I have only showed those pertinent to the MVC pattern:

Method Name	Description
get_event	Receives Pygame events and passes them onto the correct part's event handler
handle_game_event	Receives events and notifies the game model and game view
handle_pause_event	Receives events and notifies the pause view
handle_win_event	Receives events and notifies the win view
...	...

Table 2.5: Methods for Controller class

Method Name	Description
process_model_event	Receives events from the model and calls the relevant method to display that information
convert_mouse_pos	Sends controller class information of widget under mouse
draw	Draw information to display
handle_resize	Scale GUI when window resized
...	...

Table 2.6: Methods for View class

Method Name	Description
register_listener	Subscribes method on view instance to an event type, so that the method receives and processes that event everytime <code>alert_listener</code> is called
alert_listener	Sends event to all subscribed instances
toggle_win	Sends event for win view
toggle_pause	Sends event for pause view
...	...

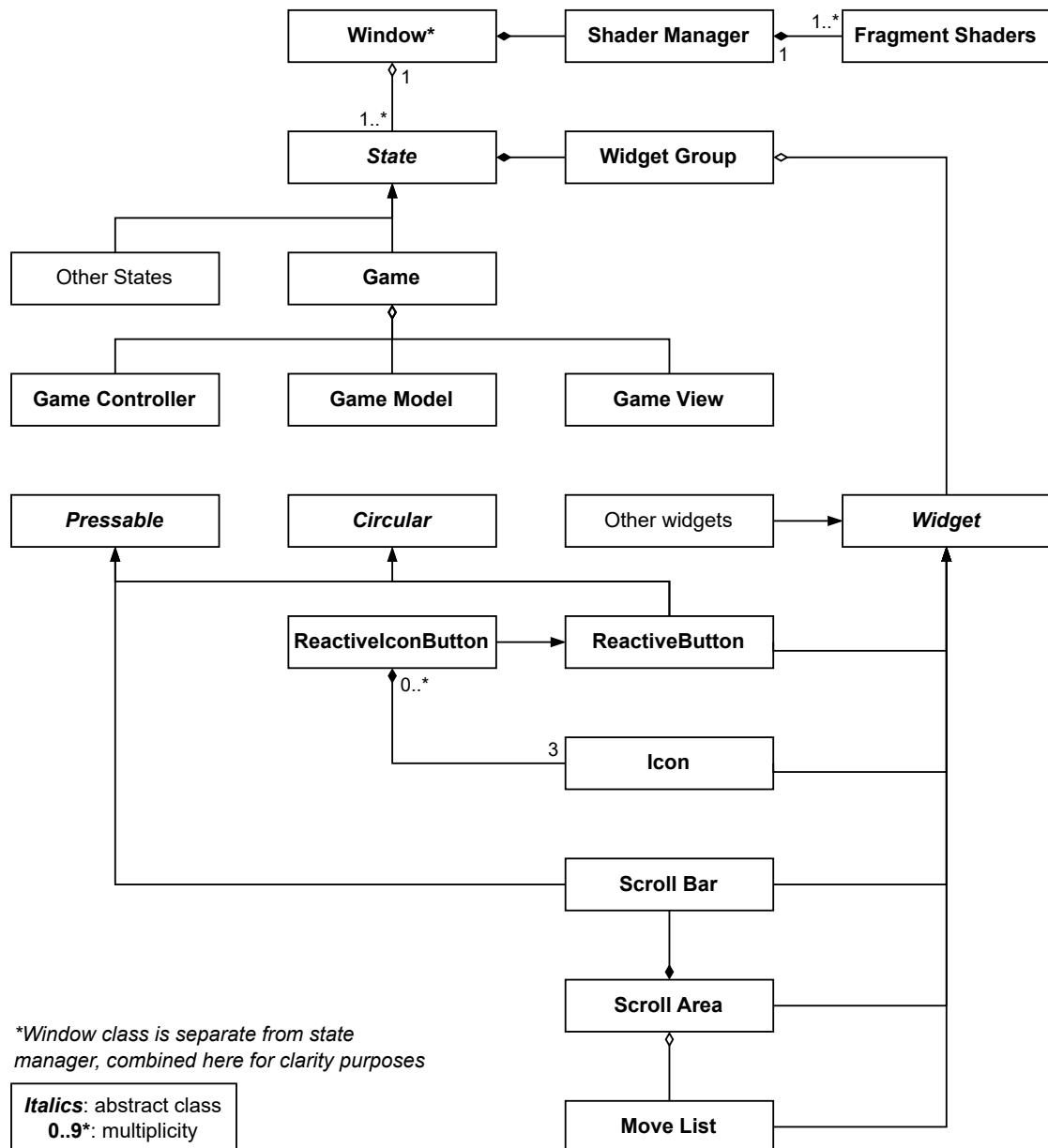
Method Name | Description

Table 2.7: Methods for Model class

Shaders

To use ModernGL with Pygame, I have created classes for each fragment shader, controlled by a main shader manager class. The fragment shader classes will rely on composition: The shader manager creates the fragment shader class; Every fragment shader class takes their shader manager parent instance as an argument, and runs methods on it to produce the final output.

2.4.1 Class Diagram



Chapter 3

Technical Solution

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3.1 File Tree Diagram

To help navigate through the source code, I have included the following directory tree diagram, and put appropriate comments to explain the general purpose of code contained within specific directories and Python files.

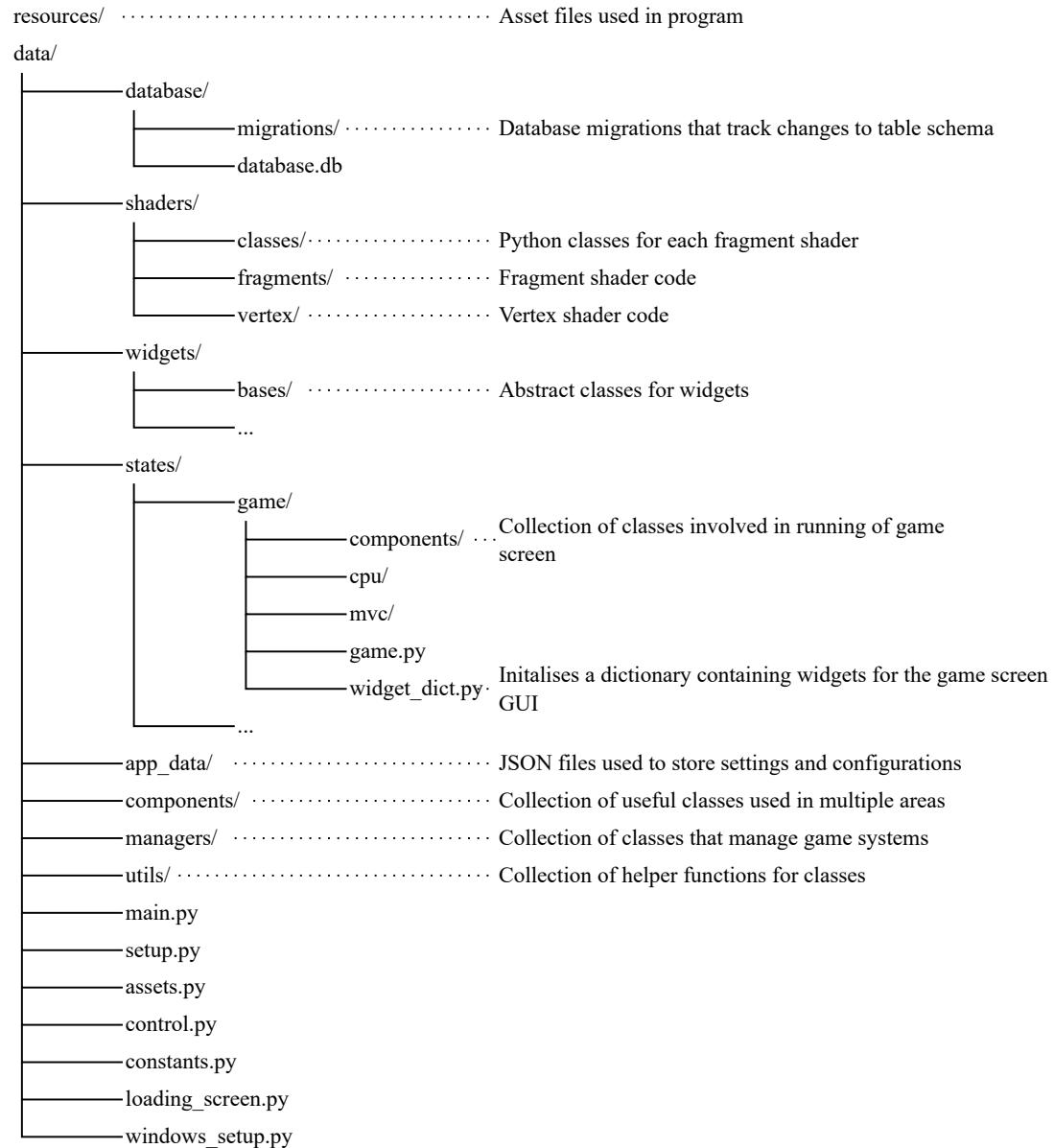


Figure 3.1: File tree diagram

3.2 Summary of Complexity

- Alpha-beta pruning and transposition table improvements for Minimax (3.6.2 and 3.6.3)
- Shadow mapping and coordinate transformations (3.9.3)
- Recursive Depth-First Search tree traversal (3.3.4 and 3.6.1)
- Circular doubly-linked list and stack (3.4.3 and 3.9.4)
- Multipass shaders and gaussian blur (3.9.2)
- Aggregate and Window SQL functions (3.8.2)
- OOP techniques (3.4.3 and 3.4.4)
- Multithreading (3.3.2 and 3.6.5)
- Bitboards (3.5.5)
- Zobrist hashing (3.6.6)
- (File handling and JSON parsing) (3.3.3)
- (Dictionary recursion) (3.3.4)
- (Dot product) (3.3.3 and 3.9.2)

3.3 Overview

3.3.1 Main

The file `main.py` is run by the root file `run.py`. Here resources-intensive classes such as the state and asset files are initialised, while the program displays a loading screen to hide the loading process. The main game loop is then executed.

`main.py`

```

1 from sys import platform
2 # Initialises Pygame
3 import data.setup
4
5 # Windows OS requires some configuration for Pygame to scale GUI continuously
6     # while window is being resized
6 if platform == 'win32':
7     import data.windows_setup as win_setup
8
9 from data.loading_screen import LoadingScreen
10
11 states = [None, None]
12
13 def load_states():
14     """
15         Initialises instances of all screens, executed on another thread with results
16         being stored to the main thread by modifying a mutable such as the states list
17     """
18     from data.control import Control
19     from data.states.game.game import Game
      from data.states.menu.menu import Menu

```

```

20     from data.states.settings import Settings
21     from data.states.config.config import Config
22     from data.states.browser import Browser
23     from data.states.review.review import Review
24     from data.states.editor.editor import Editor
25
26     state_dict = {
27         'menu': Menu(),
28         'game': Game(),
29         'settings': Settings(),
30         'config': Config(),
31         'browser': Browser(),
32         'review': Review(),
33         'editor': Editor()
34     }
35
36     app = Control()
37
38     states[0] = app
39     states[1] = state_dict
40
41 loading_screen = LoadingScreen(load_states)
42
43 def main():
44     """
45     Executed by run.py, starts main game loop
46     """
47     app, state_dict = states
48
49     if platform == 'win32':
50         win_setup.set_win_resize_func(app.update_window)
51
52     app.setup_states(state_dict, 'menu')
53     app.main_game_loop()

```

3.3.2 Loading Screen

Multithreading is used to separate the loading screen GUI from the resources intensive actions in `main.py`, to keep the GUI responsive. The easing function `easeOutBack` is also used to animate the logo.

`loading_screen.py`

```

1 import pygame
2 import threading
3 import sys
4 from pathlib import Path
5 from data.utils.load_helpers import load_gfx, load_sfx
6 from data.managers.window import window
7 from data.managers.audio import audio
8
9 FPS = 30
10 start_ticks = pygame.time.get_ticks()
11 logo_gfx_path = (Path(__file__).parent / '../resources/graphics/gui/icons/logo/
12     logo.png').resolve()
12 sfx_path_1 = (Path(__file__).parent / '../resources/sfx/loading_screen/
13     loading_screen_1.wav').resolve()
13 sfx_path_2 = (Path(__file__).parent / '../resources/sfx/loading_screen/
14     loading_screen_2.wav').resolve()
14
15 def easeOutBack(progress):

```

```

16     """
17     Represents a cubic function for easing the logo position.
18     Starts quickly and has small overshoot, then ends slowly.
19
20     Args:
21         progress (float): x-value for cubic function ranging from 0-1.
22
23     Returns:
24         float:  $2.70x^3 + 1.70x^2 + 0x + 1$ , where x is time elapsed.
25     """
26     c2 = 1.70158
27     c3 = 2.70158
28
29     return c3 * ((progress - 1) ** 3) + c2 * ((progress - 1) ** 2) + 1
30
31 class LoadingScreen:
32     def __init__(self, target_func):
33         """
34             Creates new thread, and sets the load_state() function as its target.
35             Then starts draw loop for the loading screen.
36
37             Args:
38                 target_func (Callable): function to be run on thread.
39             """
40         self._clock = pygame.time.Clock()
41         self._thread = threading.Thread(target=target_func)
42         self._thread.start()
43
44         self._logo_surface = load_gfx(logo_gfx_path)
45         self._logo_surface = pygame.transform.scale(self._logo_surface, (96, 96))
46         audio.play_sfx(load_sfx(sfx_path_1))
47         audio.play_sfx(load_sfx(sfx_path_2))
48
49         self.run()
50
51     @property
52     def logo_position(self):
53         duration = 1000
54         displacement = 50
55         elapsed_ticks = pygame.time.get_ticks() - start_ticks
56         progress = min(1, elapsed_ticks / duration)
57         center_pos = ((window.screen.size[0] - self._logo_surface.size[0]) / 2, (
58             window.screen.size[1] - self._logo_surface.size[1]) / 2)
59
59         return (center_pos[0], center_pos[1] + displacement - displacement *
60             easeOutBack(progress))
60
61     @property
62     def logo_opacity(self):
63         return min(255, (pygame.time.get_ticks() - start_ticks) / 5)
64
65     @property
66     def duration_not_over(self):
67         return (pygame.time.get_ticks() - start_ticks) < 1500
68
69     def event_loop(self):
70         """
71             Handles events for the loading screen, no user input is taken except to
72             quit the game.
73         """
74         for event in pygame.event.get():
75             if event.type == pygame.QUIT:

```

```

75             pygame.quit()
76             sys.exit()
77
78     def draw(self):
79         """
80         Draws logo to screen.
81         """
82         window.screen.fill((0, 0, 0))
83
84         self._logo_surface.set_alpha(self.logo_opacity)
85         window.screen.blit(self._logo_surface, self.logo_position)
86
87         window.update()
88
89     def run(self):
90         """
91         Runs while the thread is still setting up our screens, or the minimum
92         loading screen duration is not reached yet.
93         """
94         while self._thread.is_alive() or self.duration_not_over:
95             self.event_loop()
96             self.draw()
97             self._clock.tick(FPS)

```

3.3.3 Helper functions

These files provide useful functions for different classes.

`asset_helpers.py` (Functions used for assets and pygame Surfaces)

```

1  import pygame
2  from PIL import Image
3  from functools import cache
4  from random import sample, randint
5  import math
6
7  @cache
8  def scale_and_cache(image, target_size):
9      """
10     Caches image when resized repeatedly.
11
12     Args:
13         image (pygame.Surface): Image surface to be resized.
14         target_size (tuple[float, float]): New image size.
15
16     Returns:
17         pygame.Surface: Resized image surface.
18     """
19     return pygame.transform.scale(image, target_size)
20
21 @cache
22 def smoothscale_and_cache(image, target_size):
23     """
24     Same as scale_and_cache, but with the Pygame smoothscale function.
25
26     Args:
27         image (pygame.Surface): Image surface to be resized.
28         target_size (tuple[float, float]): New image size.
29
30     Returns:
31         pygame.Surface: Resized image surface.
32     """

```

```

33     return pygame.transform.smoothscale(image, target_size)
34
35 def gif_to_frames(path):
36     """
37     Uses the PIL library to break down GIFs into individual frames.
38
39     Args:
40         path (str): Directory path to GIF file.
41
42     Yields:
43         PIL.Image: Single frame.
44     """
45     try:
46         image = Image.open(path)
47
48         first_frame = image.copy().convert('RGBA')
49         yield first_frame
50         image.seek(1)
51
52         while True:
53             current_frame = image.copy()
54             yield current_frame
55             image.seek(image.tell() + 1)
56     except EOFError:
57         pass
58
59 def get_perimeter_sample(image_size, number):
60     """
61     Used for particle drawing class, generates roughly equally distributed points
62     around a rectangular image surface's perimeter.
63
64     Args:
65         image_size (tuple[float, float]): Image surface size.
66         number (int): Number of points to be generated.
67
68     Returns:
69         list[tuple[int, int], ...]: List of random points on perimeter of image
70         surface.
71     """
72     perimeter = 2 * (image_size[0] + image_size[1])
73     # Flatten perimeter to a single number representing the distance from the top-
74     # middle of the surface going clockwise, and create a list of equally spaced
75     # points
76     perimeter_offsets = [(image_size[0] / 2) + (i * perimeter / number) for i in
77     range(0, number)]
78     pos_list = []
79
80     for perimeter_offset in perimeter_offsets:
81         # For every point, add a random offset
82         max_displacement = int(perimeter / (number * 4))
83         perimeter_offset += randint(-max_displacement, max_displacement)
84
85         if perimeter_offset > perimeter:
86             perimeter_offset -= perimeter
87
88         # Convert 1D distance back into 2D points on image surface perimeter
89         if perimeter_offset < image_size[0]:
90             pos_list.append((perimeter_offset, 0))
91         elif perimeter_offset < image_size[0] + image_size[1]:
92             pos_list.append((image_size[0], perimeter_offset - image_size[0]))
93         elif perimeter_offset < image_size[0] + image_size[1] + image_size[0]:
94             pos_list.append((perimeter_offset - image_size[0] - image_size[1],

```

```

    image_size[1]))
90     else:
91         pos_list.append((0, perimeter - perimeter_offset))
92     return pos_list
93
94 def get_angle_between_vectors(u, v, deg=True):
95     """
96     Uses the dot product formula to find the angle between two vectors.
97
98     Args:
99         u (list[int, int]): Vector 1.
100        v (list[int, int]): Vector 2.
101        deg (bool, optional): Return results in degrees. Defaults to True.
102
103    Returns:
104        float: Angle between vectors.
105    """
106    dot_product = sum(i * j for (i, j) in zip(u, v))
107    u_magnitude = math.sqrt(u[0] ** 2 + u[1] ** 2)
108    v_magnitude = math.sqrt(v[0] ** 2 + v[1] ** 2)
109
110    cos_angle = dot_product / (u_magnitude * v_magnitude)
111    radians = math.acos(min(max(cos_angle, -1), 1))
112
113    if deg:
114        return math.degrees(radians)
115    else:
116        return radians
117
118 def get_rotational_angle(u, v, deg=True):
119     """
120     Get bearing angle relative to positive x-axis centered on second vector.
121
122     Args:
123         u (list[int, int]): Vector 1.
124         v (list[int, int]): Vector 2, set as center of axes.
125         deg (bool, optional): Return results in degrees. Defaults to True.
126
127     Returns:
128        float: Bearing angle between vectors.
129    """
130    radians = math.atan2(u[1] - v[1], u[0] - v[0])
131
132    if deg:
133        return math.degrees(radians)
134    else:
135        return radians
136
137 def get_vector(src_vertex, dest_vertex):
138     """
139     Get vector describing translation between two points.
140
141     Args:
142         src_vertex (list[int, int]): Source vertex.
143         dest_vertex (list[int, int]): Destination vertex.
144
145     Returns:
146        tuple[int, int]: Vector between the two points.
147    """
148    return (dest_vertex[0] - src_vertex[0], dest_vertex[1] - src_vertex[1])
149
150 def get_next_corner(vertex, image_size):

```

```

151 """
152     Used in particle drawing system, finds coordinates of the next corner going
153     clockwise, given a point on the perimeter.
154
155     Args:
156         vertex (list[int, int]): Point on perimeter.
157         image_size (list[int, int]): Image size.
158
159     Returns:
160         list[int, int]: Coordinates of corner on perimeter.
161     """
162     corners = [(0, 0), (image_size[0], 0), (image_size[0], image_size[1]), (0,
163     image_size[1])]
164
165     if vertex in corners:
166         return corners[(corners.index(vertex) + 1) % len(corners)]
167
168     if vertex[1] == 0:
169         return (image_size[0], 0)
170     elif vertex[0] == image_size[0]:
171         return image_size
172     elif vertex[1] == image_size[1]:
173         return (0, image_size[1])
174     elif vertex[0] == 0:
175         return (0, 0)
176
177     def pil_image_to_surface(pil_image):
178         """
179             Args:
180                 pil_image (PIL.Image): Image to be converted.
181
182             Returns:
183                 pygame.Surface: Converted image surface.
184         """
185         return pygame.image.frombytes(pil_image.tobytes(), pil_image.size, pil_image.
186         mode).convert()
187
188     def calculate_frame_index(elapsed_milliseconds, start_index, end_index, fps):
189         """
190             Determine frame of animated GIF to be displayed.
191
192             Args:
193                 elapsed_milliseconds (int): Milliseconds since GIF started playing.
194                 start_index (int): Start frame of GIF.
195                 end_index (int): End frame of GIF.
196                 fps (int): Number of frames to be played per second.
197
198             Returns:
199                 int: Displayed frame index of GIF.
200         """
201         ms_per_frame = int(1000 / fps)
202         return start_index + ((elapsed_milliseconds // ms_per_frame) % (end_index -
203         start_index))
204
205     def draw_background(screen, background, current_time=0):
206         """
207             Draws background to screen
208
209             Args:
210                 screen (pygame.Surface): Screen to be drawn to
211                 background (list[pygame.Surface, ...] | pygame.Surface): Background to be
212                 drawn, if GIF, list of surfaces indexed to select frame to be drawn

```

```

208     current_time (int, optional): Used to calculate frame index for GIF.
209     Defaults to 0.
210 """
211     if isinstance(background, list):
212         # Animated background passed in as list of surfaces, calculate_frame_index()
213         # used to get index of frame to be drawn
214         frame_index = calculate_frame_index(current_time, 0, len(background), fps
215 =8)
216         scaled_background = scale_and_cache(background[frame_index], screen.size)
217         screen.blit(scaled_background, (0, 0))
218     else:
219         scaled_background = scale_and_cache(background, screen.size)
220         screen.blit(scaled_background, (0, 0))
221
222 def get_highlighted_icon(icon):
223 """
224     Used for pressable icons, draws overlay on icon to show as pressed.
225
226     Args:
227         icon (pygame.Surface): Icon surface.
228
229     Returns:
230         pygame.Surface: Icon with overlay drawn on top.
231 """
232     icon_copy = icon.copy()
233     overlay = pygame.Surface((icon.get_width(), icon.get_height()), pygame.
234 SRCALPHA)
235     overlay.fill((0, 0, 0, 128))
236     icon_copy.blit(overlay, (0, 0))
237     return icon_copy

```

data_helpers.py (Functions used for file handling and JSON parsing)

```

1 import json
2 from pathlib import Path
3
4 module_path = Path(__file__).parent
5 default_file_path = (module_path / '../app_data/default_settings.json').resolve()
6 user_file_path = (module_path / '../app_data/user_settings.json').resolve()
7 themes_file_path = (module_path / '../app_data/themes.json').resolve()
8
9 def load_json(path):
10 """
11     Args:
12         path (str): Path to JSON file.
13
14     Raises:
15         Exception: Invalid file.
16
17     Returns:
18         dict: Parsed JSON file.
19 """
20     try:
21         with open(path, 'r') as f:
22             file = json.load(f)
23
24         return file
25     except:
26         raise Exception('Invalid JSON file (data_helpers.py)')
27
28 def get_user_settings():

```

```

29     return load_json(user_file_path)
30
31 def get_default_settings():
32     return load_json(default_file_path)
33
34 def get_themes():
35     return load_json(themes_file_path)
36
37 def update_user_settings(data):
38     """
39     Rewrites JSON file for user settings with new data.
40
41     Args:
42         data (dict): Dictionary storing updated user settings.
43
44     Raises:
45         Exception: Invalid file.
46     """
47     try:
48         with open(user_file_path, 'w') as f:
49             json.dump(data, f, indent=4)
50     except:
51         raise Exception('Invalid JSON file (data_helpers.py)')

widget_helpers.py (Files used for creating widgets)

1 import pygame
2 from math import sqrt
3
4 def create_slider(size, fill_colour, border_width, border_colour):
5     """
5     Creates surface for sliders.
6
7     Args:
8         size (list[int, int]): Image size.
9         fill_colour (pygame.Color): Fill (inner) colour.
10        border_width (float): Border width.
11        border_colour (pygame.Color): Border colour.
12
13    Returns:
14        pygame.Surface: Slider image surface.
15    """
16    gradient_surface = pygame.Surface(size, pygame.SRCALPHA)
17    border_rect = pygame.FRect((0, 0, gradient_surface.width, gradient_surface.height))
18
19    # Draws rectangle with a border radius half of image height, to draw an
20    # rectangle with semicircular cap (obround)
21    pygame.draw.rect(gradient_surface, fill_colour, border_rect, border_radius=int(
22        size[1] / 2))
23    pygame.draw.rect(gradient_surface, border_colour, border_rect, width=int(
24        border_width), border_radius=int(size[1] / 2))
25
26    return gradient_surface
27
28 def create_slider_gradient(size, border_width, border_colour):
29     """
30     Draws surface for colour slider, with a full colour gradient as fill colour.
31     Args:
32         size (list[int, int]): Image size.

```

```
32         border_width (float): Border width.
33         border_colour (pygame.Color): Border colour.
34
35     Returns:
36         pygame.Surface: Slider image surface.
37     """
38     gradient_surface = pygame.Surface(size, pygame.SRCALPHA)
39
40     first_round_end = gradient_surface.height / 2
41     second_round_end = gradient_surface.width - first_round_end
42     gradient_y_mid = gradient_surface.height / 2
43
44     # Iterate through length of slider
45     for i in range(gradient_surface.width):
46         draw_height = gradient_surface.height
47
48         if i < first_round_end or i > second_round_end:
49             # Draw semicircular caps if x-distance less than or greater than
50             # radius of cap (half of image height)
51             distance_from_cutoff = min(abs(first_round_end - i), abs(i -
52             second_round_end))
53             draw_height = calculate_gradient_slice_height(distance_from_cutoff,
54             gradient_surface.height / 2)
55
56             # Get colour from distance from left side of slider
57             color = pygame.Color(0)
58             color.hsva = (int(360 * i / gradient_surface.width), 100, 100, 100)
59
60             draw_rect = pygame.FRect((0, 0, 1, draw_height - 2 * border_width))
61             draw_rect.center = (i, gradient_y_mid)
62
63             pygame.draw.rect(gradient_surface, color, draw_rect)
64
65     border_rect = pygame.FRect((0, 0, gradient_surface.width, gradient_surface.
66     height))
67     pygame.draw.rect(gradient_surface, border_colour, border_rect, width=int(
68     border_width), border_radius=int(size[1] / 2))
69
70     return gradient_surface
71
72 def calculate_gradient_slice_height(distance, radius):
73     """
74     Calculate height of vertical slice of semicircular slider cap.
75
76     Args:
77         distance (float): x-distance from center of circle.
78         radius (float): Radius of semicircle.
79
80     Returns:
81         float: Height of vertical slice.
82     """
83     return sqrt(radius ** 2 - distance ** 2) * 2 + 2
84
85 def create_slider_thumb(radius, colour, border_colour, border_width):
86     """
87     Creates surface with bordered circle.
88
89     Args:
90         radius (float): Radius of circle.
91         colour (pygame.Color): Fill colour.
92         border_colour (pygame.Color): Border colour.
93         border_width (float): Border width.
```

```
89
90     Returns:
91         pygame.Surface: Circle surface.
92     """
93     thumb_surface = pygame.Surface((radius * 2, radius * 2), pygame.SRCALPHA)
94     pygame.draw.circle(thumb_surface, border_colour, (radius, radius), radius,
95     width=int(border_width))
96     pygame.draw.circle(thumb_surface, colour, (radius, radius), (radius -
97     border_width))
98
99     return thumb_surface
100
101 def create_square_gradient(side_length, colour):
102     """
103     Creates a square gradient for the colour picker widget, gradient transitioning
104     between saturation and value.
105     Uses smoothscale to blend between colour values for individual pixels.
106
107     Args:
108         side_length (float): Length of a square side.
109         colour (pygame.Color): Colour with desired hue value.
110
111     Returns:
112         pygame.Surface: Square gradient surface.
113     """
114     square_surface = pygame.Surface((side_length, side_length))
115
116     mix_1 = pygame.Surface((1, 2))
117     mix_1.fill((255, 255, 255))
118     mix_1.set_at((0, 1), (0, 0, 0))
119     mix_1 = pygame.transform.smoothscale(mix_1, (side_length, side_length))
120
121     hue = colour.hsva[0]
122     saturated_rgb = pygame.Color(0)
123     saturated_rgb.hsva = (hue, 100, 100)
124
125     mix_2 = pygame.Surface((2, 1))
126     mix_2.fill((255, 255, 255))
127     mix_2.set_at((1, 0), saturated_rgb)
128     mix_2 = pygame.transform.smoothscale(mix_2, (side_length, side_length))
129
130     mix_1.blit(mix_2, (0, 0), special_flags=pygame.BLEND_MULT)
131
132     square_surface.blit(mix_1, (0, 0))
133
134     return square_surface
135
136 def create_switch(size, colour):
137     """
138     Creates surface for switch toggle widget.
139
140     Args:
141         size (list[int, int]): Image size.
142         colour (pygame.Color): Fill colour.
143
144     Returns:
145         pygame.Surface: Switch surface.
146     """
147     switch_surface = pygame.Surface((size[0], size[1]), pygame.SRCALPHA)
148     pygame.draw.rect(switch_surface, colour, (0, 0, size[0], size[1]),
149     border_radius=int(size[1] / 2))
```

```

147     return switch_surface
148
149 def create_text_box(size, border_width, colours):
150     """
151     Creates bordered textbox with shadow, flat, and highlighted vertical regions.
152
153     Args:
154         size (list[int, int]): Image size.
155         border_width (float): Border width.
156         colours (list[pygame.Color, ...]): List of 4 colours, representing border
157         colour, shadow colour, flat colour and highlighted colour.
158
159     Returns:
160         pygame.Surface: Textbox surface.
161     """
162
163     surface = pygame.Surface(size, pygame.SRCALPHA)
164
165     pygame.draw.rect(surface, colours[0], (0, 0, *size))
166     pygame.draw.rect(surface, colours[2], (border_width, border_width, size[0] - 2
167         * border_width, size[1] - 2 * border_width))
168     pygame.draw.rect(surface, colours[3], (border_width, border_width, size[0] - 2
169         * border_width, border_width))
170     pygame.draw.rect(surface, colours[1], (border_width, size[1] - 2 *
171         border_width, size[0] - 2 * border_width, border_width))
172
173     return surface

```

3.3.4 Theme

The theme manager file is responsible for providing an instance where the colour palette and dimensions for the GUI can be accessed.

theme.py

```

1 from data.utils.data_helpers import get_themes, get_user_settings
2
3 themes = get_themes()
4 user_settings = get_user_settings()
5
6 def flatten_dictionary_generator(dictionary, parent_key=None):
6     """
6     Recursive depth-first search to yield all items in a dictionary.
6
6     Args:
6         dictionary (dict): Dictionary to be iterated through.
6         parent_key (str, optional): Prefix added to every key. Defaults to None.
6
6     Yields:
6         dict | tuple[str, str]: Another dictionary or key, value pair.
6     """
6
6     for key, value in dictionary.items():
6         if parent_key:
6             new_key = parent_key + key.capitalize()
6         else:
6             new_key = key
6
6         if isinstance(value, dict):
6             yield from flatten_dictionary(value, new_key).items()
6         else:
6             yield new_key, value

```

```

28 def flatten_dictionary(dictionary, parent_key=''):
29     return dict(flatten_dictionary_generator(dictionary, parent_key))
30
31 class ThemeManager:
32     def __init__(self):
33         self.__dict__.update(flatten_dictionary(themes['colours']))
34         self.__dict__.update(flatten_dictionary(themes['dimensions']))
35
36     def __getitem__(self, arg):
37         """
38             Override default class's __getitem__ dunder method, to make retrieving an
39             instance attribute nicer with [] notation.
40
41             Args:
42                 arg (str): Attribute name.
43
44             Raises:
45                 KeyError: Instance does not have requested attribute.
46
47             Returns:
48                 str | int: Instance attribute.
49
50         item = self.__dict__.get(arg)
51
52         if item is None:
53             raise KeyError('({}.__getitem__) Requested theme item not
54             found:', arg)
55
56     return item
57
58 theme = ThemeManager()

```

3.4 GUI

3.4.1 Laser

The LaserDraw class draws the laser in both the game and review screens.

`laser_draw.py`

```

1 import pygame
2 from data.utils.board_helpers import coords_to_screen_pos
3 from data.constants import EMPTY_BB, ShaderType, Colour
4 from data.managers.animation import animation
5 from data.managers.window import window
6 from data.managers.audio import audio
7 from data.assets import GRAPHICS, SFX
8 from data.constants import LaserType
9
10 type_to_image = {
11     LaserType.END: ['laser_end_1', 'laser_end_2'],
12     LaserType.STRAIGHT: ['laser_straight_1', 'laser_straight_2'],
13     LaserType.CORNER: ['laser_corner_1', 'laser_corner_2']
14 }
15
16 GLOW_SCALE_FACTOR = 1.5
17
18 class LaserDraw:
19     def __init__(self, board_position, board_size):
20         self._board_position = board_position
21         self._square_size = board_size[0] / 10

```

```

22         self._laser_lists = []
23
24     @property
25     def firing(self):
26         return len(self._laser_lists) > 0
27
28     def add_laser(self, laser_result, laser_colour):
29         """
30             Adds a laser to the board.
31
32             Args:
33                 laser_result (Laser): Laser class instance containing laser trajectory
34                 info.
35                 laser_colour (Colour.RED | Colour.BLUE): Active colour of laser.
36             """
37
38         laser_path = laser_result.laser_path.copy()
39         laser_types = [LaserType.END]
40         # List of angles in degree to rotate the laser image surface when drawn
41         laser_rotation = [laser_path[0][1]]
42         laser_lights = []
43
44         # Iterates through every square laser passes through
45         for i in range(1, len(laser_path)):
46             previous_direction = laser_path[i-1][1]
47             current_coords, current_direction = laser_path[i]
48
49             if current_direction == previous_direction:
50                 laser_types.append(LaserType.STRAIGHT)
51                 laser_rotation.append(current_direction)
52             elif current_direction == previous_direction.get_clockwise():
53                 laser_types.append(LaserType.CORNER)
54                 laser_rotation.append(current_direction)
55             elif current_direction == previous_direction.get_anticlockwise():
56                 laser_types.append(LaserType.CORNER)
57                 laser_rotation.append(current_direction.get_anticlockwise())
58
59             # Adds a shader ray effect on the first and last square of the laser
60             # trajectory
61             if i in [1, len(laser_path) - 1]:
62                 abs_position = coords_to_screen_pos(current_coords, self.
63                 _board_position, self._square_size)
64                 laser_lights.append([
65                     (abs_position[0] / window.size[0], abs_position[1] / window.
66                     size[1]),
67                     0.35,
68                     (0, 0, 255) if laser_colour == Colour.BLUE else (255, 0, 0),
69                 ])
70
71             # Sets end laser draw type if laser hits a piece
72             if laser_result.hit_square_bitboard != EMPTY_BB:
73                 laser_types[-1] = LaserType.END
74                 laser_path[-1] = (laser_path[-1][0], laser_path[-2][1].get_opposite())
75                 laser_rotation[-1] = laser_path[-2][1].get_opposite()
76
77                 audio.play_sfx(SFX['piece_destroy'])
78
79             laser_path = [(coords, rotation, type) for (coords, dir), rotation, type
80             in zip(laser_path, laser_rotation, laser_types)]
81             self._laser_lists.append((laser_path, laser_colour))
82
83             window.clear_effect(ShaderType.RAYS)
84             window.set_effect(ShaderType.RAYS, lights=laser_lights)

```

```

79         animation.set_timer(1000, self.remove_laser)
80
81     audio.play_sfx(SFX['laser_1'])
82     audio.play_sfx(SFX['laser_2'])
83
84     def remove_laser(self):
85         """
86             Removes a laser from the board.
87         """
88         self._laser_lists.pop(0)
89
90         if len(self._laser_lists) == 0:
91             window.clear_effect(ShaderType.RAYS)
92
93     def draw_laser(self, screen, laser_list, glow=True):
94         """
95             Draws every laser on the screen.
96
97             Args:
98                 screen (pygame.Surface): The screen to draw on.
99                 laser_list (list): The list of laser segments to draw.
100                glow (bool, optional): Whether to draw a glow effect. Defaults to True
101
102            """
103        laser_path, laser_colour = laser_list
104        laser_list = []
105        glow_list = []
106
107        for coords, rotation, type in laser_path:
108            square_x, square_y = coords_to_screen_pos(coords, self._board_position
109            , self._square_size)
110
111            image = GRAPHICS[type_to_image[type][laser_colour]]
112            rotated_image = pygame.transform.rotate(image, rotation.to_angle())
113            scaled_image = pygame.transform.scale(rotated_image, (self.
114                _square_size + 1, self._square_size + 1)) # +1 to prevent rounding creating
115                black lines
116            laser_list.append((scaled_image, (square_x, square_y)))
117
118            # Scales up the laser image surface as a glow surface
119            scaled_glow = pygame.transform.scale(rotated_image, (self._square_size
120                * GLOW_SCALE_FACTOR, self._square_size * GLOW_SCALE_FACTOR))
121            offset = self._square_size * ((GLOW_SCALE_FACTOR - 1) / 2)
122            glow_list.append((scaled_glow, (square_x - offset, square_y - offset)))
123
124
125    def draw(self, screen):
126        """
127            Draws all lasers on the screen.
128
129            Args:
130                screen (pygame.Surface): The screen to draw on.
131            """
132            for laser_list in self._laser_lists:
133                self.draw_laser(screen, laser_list)
134

```

```

135     def handle_resize(self, board_position, board_size):
136         """
137             Handles resizing of the board.
138
139         Args:
140             board_position (tuple[int, int]): The new position of the board.
141             board_size (tuple[int, int]): The new size of the board.
142         """
143         self._board_position = board_position
144         self._square_size = board_size[0] / 10

```

3.4.2 Particles

The `ParticlesDraw` class draws particles in both the game and review screens. The particles are either fragmented pieces when destroyed, or laser particles emitted from the Sphinx. Particles are given custom velocity, rotation, opacity and size parameters.

`particles_draw.py`

```

1 import pygame
2 from random import randint
3 from data.utils.asset_helpers import get_perimeter_sample, get_vector,
4     get_angle_between_vectors, get_next_corner
5 from data.states.game.components.piece_sprite import PieceSprite
6
7 class ParticlesDraw:
8     def __init__(self, gravity=0.2, rotation=180, shrink=0.5, opacity=150):
9         self._particles = []
10        self._glow_particles = []
11
12        self._gravity = gravity
13        self._rotation = rotation
14        self._shrink = shrink
15        self._opacity = opacity
16
17    def fragment_image(self, image, number):
18        image_size = image.get_rect().size
19        """
20            1. Takes an image surface and samples random points on the perimeter.
21            2. Iterates through points, and depending on the nature of two consecutive
22                points, finds a corner between them.
23            3. Draws a polygon with the points as the vertices to mask out the area
24                not in the fragment.
25
26        Args:
27            image (pygame.Surface): Image to fragment.
28            number (int): The number of fragments to create.
29
30        Returns:
31            list[pygame.Surface]: List of image surfaces with fragment of original
32            surface drawn on top.
33        """
34        center = image.get_rect().center
35        points_list = get_perimeter_sample(image_size, number)
36        fragment_list = []
37
38        points_list.append(points_list[0])
39
40        # Iterate through points_list, using the current point and the next one
41        for i in range(len(points_list) - 1):
42            vertex_1 = points_list[i]

```

```

39         vertex_2 = points_list[i + 1]
40         vector_1 = get_vector(center, vertex_1)
41         vector_2 = get_vector(center, vertex_2)
42         angle = get_angle_between_vectors(vector_1, vector_2)
43
44         cropped_image = pygame.Surface(image_size, pygame.SRCALPHA)
45         cropped_image.fill((0, 0, 0, 0))
46         cropped_image.blit(image, (0, 0))
47
48         corners_to_draw = None
49
50         if vertex_1[0] == vertex_2[0] or vertex_1[1] == vertex_2[1]: # Points
51             on the same side
52                 corners_to_draw = 4
53
54             elif abs(vertex_1[0] - vertex_2[0]) == image_size[0] or abs(vertex_1
55                 [1] - vertex_2[1]) == image_size[1]: # Points on opposite sides
56                 corners_to_draw = 2
57
58             elif angle < 180: # Points on adjacent sides
59                 corners_to_draw = 3
60
61         else:
62             corners_to_draw = 1
63
64         corners_list = []
65         for j in range(corners_to_draw):
66             if len(corners_list) == 0:
67                 corners_list.append(get_next_corner(vertex_2, image_size))
68             else:
69                 corners_list.append(get_next_corner(corners_list[-1],
70                     image_size))
71
72         pygame.draw.polygon(cropped_image, (0, 0, 0, 0), (center, vertex_2, *
73             corners_list, vertex_1))
74
75         fragment_list.append(cropped_image)
76
77     return fragment_list
78
79 def add_captured_piece(self, piece, colour, rotation, position, size):
80     """
81     Adds a captured piece to fragment into particles.
82
83     Args:
84         piece (Piece): The piece type.
85         colour (Colour): The active colour of the piece.
86         rotation (int): The rotation of the piece.
87         position (tuple[int, int]): The position where particles originate
88         from.
89         size (tuple[int, int]): The size of the piece.
90     """
91
92     piece_sprite = PieceSprite(piece, colour, rotation)
93     piece_sprite.set_geometry((0, 0), size)
94     piece_sprite.set_image()
95
96     particles = self.fragment_image(piece_sprite.image, 5)
97
98     for particle in particles:
99         self.add_particle(particle, position)
100
101 def add_sparks(self, radius, colour, position):

```

```

96     """
97     Adds laser spark particles.
98
99     Args:
100         radius (int): The radius of the sparks.
101         colour (Colour): The active colour of the sparks.
102         position (tuple[int, int]): The position where particles originate
103         from.
104         """
105         for i in range(randint(10, 15)):
106             velocity = [randint(-15, 15) / 10, randint(-20, 0) / 10]
107             random_colour = [min(max(val + randint(-20, 20), 0), 255) for val in
108                 colour]
109             self._particles.append([None, [radius, random_colour], [*position],
110             velocity, 0])
111
112     def add_particle(self, image, position):
113         """
114             Adds a particle.
115
116             Args:
117                 image (pygame.Surface): The image of the particle.
118                 position (tuple): The position of the particle.
119             """
120             velocity = [randint(-15, 15) / 10, randint(-20, 0) / 10]
121
122             # Each particle is stored with its attributes: [surface, copy of surface,
123             position, velocity, lifespan]
124             self._particles.append([image, image.copy(), [*position], velocity, 0])
125
126     def update(self):
127         """
128             Updates each particle and its attributes.
129
130             for i in range(len(self._particles) - 1, -1, -1):
131                 particle = self._particles[i]
132
133                 #update position
134                 particle[2][0] += particle[3][0]
135                 particle[2][1] += particle[3][1]
136
137                 #update lifespan
138                 self._particles[i][4] += 0.01
139
140                 if self._particles[i][4] >= 1:
141                     self._particles.pop(i)
142                     continue
143
144                 if isinstance(particle[1], pygame.Surface): # Particle is a piece
145                     # Update velocity
146                     particle[3][1] += self._gravity
147
148                     # Update size
149                     image_size = particle[1].get_rect().size
150                     end_size = ((1 - self._shrink) * image_size[0], (1 - self._shrink)
151                     * image_size[1])
152                     target_size = (image_size[0] - particle[4] * (image_size[0] -
153                     end_size[0]), image_size[1] - particle[4] * (image_size[1] -
154                     end_size[1]))
155
156                     # Update rotation
157                     rotation = (self._rotation if particle[3][0] <= 0 else -self.
158                     _rotation) * particle[4]

```

```

151
152     updated_image = pygame.transform.scale(pygame.transform.rotate(
153         particle[1], rotation), target_size)
154
155     elif isinstance(particle[1], list): # Particle is a spark
156         # Update size
157         end_radius = (1 - self._shrink) * particle[1][0]
158         target_radius = particle[1][0] - particle[4] * (particle[1][0] -
159             end_radius)
160
161         updated_image = pygame.Surface((target_radius * 2, target_radius *
162             2), pygame.SRCALPHA)
163         pygame.draw.circle(updated_image, particle[1][1], (target_radius,
164             target_radius), target_radius)
165
166         # Update opacity
167         alpha = 255 - particle[4] * (255 - self._opacity)
168
169     updated_image.fill((255, 255, 255, alpha), None, pygame.
170         BLEND_RGBA_MULT)
171
172     particle[0] = updated_image
173
174 def draw(self, screen):
175     """
176     Draws the particles, indexing the surface and position attributes for each
177     particle.
178
179     Args:
180         screen (pygame.Surface): The screen to draw on.
181     """
182
183     screen.blit([
184         (particle[0], particle[2]) for particle in self._particles
185     ])

```

3.4.3 Widget Bases

Widget bases are the base classes for my widgets system. They contain both attributes and getter methods that provide basic functionality such as size and position, and abstract methods to be overridden. These bases are also designed to be used with multiple inheritance, where multiple bases can be combined to add functionality to the final widget. Encapsulation also allows me to simplify interactions between widgets, as using getter methods instead of protected attributes allows me to add logic while accessing an attribute, such as in `widget.py`, where the logic to fetch the parent surface instead of the windows screen is hidden within the base class.

Widget

All widgets are a subclass of the `Widget` class.

`widget.py`

```

1 import pygame
2 from data.constants import SCREEN_SIZE
3 from data.managers.theme import theme
4 from data.assets import DEFAULT_FONT
5
6 DEFAULT_SURFACE_SIZE = SCREEN_SIZE
7 REQUIRED_KWARGS = ['relative_position', 'relative_size']
8

```

```

9  class _Widget(pygame.sprite.Sprite):
10     def __init__(self, **kwargs):
11         """
12             Every widget has the following attributes:
13
14             surface (pygame.Surface): The surface the widget is drawn on.
15             raw_surface_size (tuple[int, int]): The initial size of the window screen,
16                 remains constant.
17             parent (_Widget, optional): The parent widget position and size is
18                 relative to.
19
20                 Relative to current surface:
21                 relative_position (tuple[float, float]): The position of the widget
22                     relative to its surface.
23                 relative_size (tuple[float, float]): The scale of the widget relative to
24                     its surface.
25
26                 Remains constant, relative to initial screen size:
27                 relative_font_size (float, optional): The relative font size of the widget
28
29                 relative_margin (float): The relative margin of the widget.
30                 relative_border_width (float): The relative border width of the widget.
31                 relative_border_radius (float): The relative border radius of the widget.
32
33                 anchor_x (str): The horizontal anchor direction ('left', 'right', 'center').
34
35                 anchor_y (str): The vertical anchor direction ('top', 'bottom', 'center').
36                 fixed_position (tuple[int, int], optional): The fixed position of the
37                     widget in pixels.
38                 border_colour (pygame.Color): The border color of the widget.
39                 text_colour (pygame.Color): The text color of the widget.
40                 fill_colour (pygame.Color): The fill color of the widget.
41                 font (pygame.freetype.Font): The font used for the widget.
42
43                 super().__init__()
44
45                 for required_kwarg in REQUIRED_KWARGS:
46                     if required_kwarg not in kwargs:
47                         raise KeyError(f'({_Widget.__init__}) Required keyword "{
48                         required_kwarg}" not in base kwargs')
49
50                     self._surface = None # Set in WidgetGroup, as needs to be reassigned every
51                     frame
52                     self._raw_surface_size = DEFAULT_SURFACE_SIZE
53
54                     self._parent = kwargs.get('parent')
55
56                     self._relative_font_size = None # Set in subclass
57
58                     self._relative_position = kwargs.get('relative_position')
59                     self._relative_margin = theme['margin'] / self._raw_surface_size[1]
                     self._relative_border_width = theme['borderWidth'] / self.
                     _raw_surface_size[1]
                     self._relative_border_radius = theme['borderRadius'] / self.
                     _raw_surface_size[1]
56
57                     self._border_colour = pygame.Color(theme['borderPrimary'])
58                     self._text_colour = pygame.Color(theme['textPrimary'])
59                     self._fill_colour = pygame.Color(theme['fillPrimary'])
                     self._font = DEFAULT_FONT
56
57                     self._anchor_x = kwargs.get('anchor_x') or 'left'

```

```

60         self._anchor_y = kwargs.get('anchor_y') or 'top'
61         self._fixed_position = kwargs.get('fixed_position')
62         scale_mode = kwargs.get('scale_mode') or 'both'
63
64     if kwargs.get('relative_size'):
65         match scale_mode:
66             case 'height':
67                 self._relative_size = kwargs.get('relative_size')
68             case 'width':
69                 self._relative_size = ((kwargs.get('relative_size')[0] * self.
70                     surface_size[0]) / self.surface_size[1], (kwargs.get('relative_size')[1] *
71                     self.surface_size[0]) / self.surface_size[1])
72             case 'both':
73                 self._relative_size = ((kwargs.get('relative_size')[0] * self.
74                     surface_size[0]) / self.surface_size[1], kwargs.get('relative_size')[1])
75             case _:
76                 raise ValueError('_Widget.__init__) Unknown scale mode:', scale_mode)
77         else:
78             self._relative_size = (1, 1)
79
80     if 'margin' in kwargs:
81         self._relative_margin = kwargs.get('margin') / self._raw_surface_size[1]
82
83         if (self._relative_margin * 2) > min(self._relative_size[0], self._relative_size[1]):
84             raise ValueError('_Widget.__init__) Margin larger than specified size!')
85
86     if 'border_width' in kwargs:
87         self._relative_border_width = kwargs.get('border_width') / self._raw_surface_size[1]
88
89     if 'border_radius' in kwargs:
90         self._relative_border_radius = kwargs.get('border_radius') / self._raw_surface_size[1]
91
92     if 'border_colour' in kwargs:
93         self._border_colour = pygame.Color(kwargs.get('border_colour'))
94
95     if 'fill_colour' in kwargs:
96         self._fill_colour = pygame.Color(kwargs.get('fill_colour'))
97
98     if 'text_colour' in kwargs:
99         self._text_colour = pygame.Color(kwargs.get('text_colour'))
100
101     @property
102     def surface_size(self):
103         """
104             Gets the size of the surface widget is drawn on.
105             Can be either the window size, or another widget size if assigned to a parent.
106
107             Returns:
108                 tuple[int, int]: The size of the surface.
109             """
110             if self._parent:
111                 return self._parent.size

```

```

112         else:
113             return self._raw_surface_size
114
115     @property
116     def position(self):
117         """
118             Gets the position of the widget.
119             Accounts for fixed position attribute, where widget is positioned in
120             pixels regardless of screen size.
121             Accounts for anchor direction, where position attribute is calculated
122             relative to one side of the screen.
123
124             Returns:
125                 tuple[int, int]: The position of the widget.
126             """
127
128         x, y = None, None
129         if self._fixed_position:
130             x, y = self._fixed_position
131         if x is None:
132             x = self._relative_position[0] * self.surface_size[0]
133         if y is None:
134             y = self._relative_position[1] * self.surface_size[1]
135
136         if self._anchor_x == 'left':
137             x = x
138         elif self._anchor_x == 'right':
139             x = self.surface_size[0] - x - self.size[0]
140         elif self._anchor_x == 'center':
141             x = (self.surface_size[0] / 2 - self.size[0] / 2) + x
142
143         if self._anchor_y == 'top':
144             y = y
145         elif self._anchor_y == 'bottom':
146             y = self.surface_size[1] - y - self.size[1]
147         elif self._anchor_y == 'center':
148             y = (self.surface_size[1] / 2 - self.size[1] / 2) + y
149
150         # Position widget relative to parent, if exists.
151         if self._parent:
152             return (x + self._parent.position[0], y + self._parent.position[1])
153         else:
154             return (x, y)
155
156     @property
157     def size(self):
158         return (self._relative_size[0] * self.surface_size[1], self._relative_size
159             [1] * self.surface_size[1])
160
161     @property
162     def margin(self):
163         return self._relative_margin * self._raw_surface_size[1]
164
165     @property
166     def border_width(self):
167         return self._relative_border_width * self._raw_surface_size[1]
168
169     @property
170     def border_radius(self):
171         return self._relative_border_radius * self._raw_surface_size[1]
172
173     @property
174     def font_size(self):

```

```

171         return self._relative_font_size * self.surface_size[1]
172
173     def set_image(self):
174         """
175             Abstract method to draw widget.
176         """
177         raise NotImplementedError
178
179     def set_geometry(self):
180         """
181             Sets the position and size of the widget.
182         """
183         self.rect = self.image.get_rect()
184
185         if self._anchor_x == 'left':
186             if self._anchor_y == 'top':
187                 self.rect.topleft = self.position
188             elif self._anchor_y == 'bottom':
189                 self.rect.topleft = self.position
190             elif self._anchor_y == 'center':
191                 self.rect.topleft = self.position
192         elif self._anchor_x == 'right':
193             if self._anchor_y == 'top':
194                 self.rect.topleft = self.position
195             elif self._anchor_y == 'bottom':
196                 self.rect.topleft = self.position
197             elif self._anchor_y == 'center':
198                 self.rect.topleft = self.position
199         elif self._anchor_x == 'center':
200             if self._anchor_y == 'top':
201                 self.rect.topleft = self.position
202             elif self._anchor_y == 'bottom':
203                 self.rect.topleft = self.position
204             elif self._anchor_y == 'center':
205                 self.rect.topleft = self.position
206
207     def set_surface_size(self, new_surface_size):
208         """
209             Sets the new size of the surface widget is drawn on.
210
211             Args:
212                 new_surface_size (tuple[int, int]): The new size of the surface.
213
214         """
215         self._raw_surface_size = new_surface_size
216
217     def process_event(self, event):
218         """
219             Abstract method to handle events.
220
221             Args:
222                 event (pygame.Event): The event to process.
223
224         """
225         raise NotImplementedError

```

Circular

The Circular class provides functionality to support widgets which rotate between text/icons.

circular.py

```

1 from data.components.circular_linked_list import CircularLinkedList
2

```

```
3 class _Circular:
4     def __init__(self, items_dict, **kwargs):
5         # The key, value pairs are stored within a dictionary, while the keys to
6         # access them are stored within circular linked list.
7         self._items_dict = items_dict
8         self._keys_list = CircularLinkedList(list(items_dict.keys()))
9
10    @property
11    def current_key(self):
12        """
13            Gets the current head node of the linked list, and returns a key stored as
14            the node data.
15            Returns:
16                Data of linked list head.
17        """
18        return self._keys_list.get_head().data
19
20    @property
21    def current_item(self):
22        """
23            Gets the value in self._items_dict with the key being self.current_key.
24            Returns:
25                Value stored with key being current head of linked list.
26        """
27        return self._items_dict[self.current_key]
28
29    def set_next_item(self):
30        """
31            Sets the next item in as the current item.
32        """
33        self._keys_list.shift_head()
34
35    def set_previous_item(self):
36        """
37            Sets the previous item as the current item.
38        """
39        self._keys_list.unshift_head()
40
41    def set_to_key(self, key):
42        """
43            Sets the current item to the specified key.
44
45            Args:
46                key: The key to set as the current item.
47
48            Raises:
49                ValueError: If no nodes within the circular linked list contains the
50                key as its data.
51
52        if self._keys_list.data_in_list(key) is False:
53            raise ValueError('(_Circular.set_to_key) Key not found:', key)
54
55        for _ in range(len(self._items_dict)):
56            if self.current_key == key:
57                self.set_image()
58                self.set_geometry()
59                return
60
61        self.set_next_item()
```

Circular Linked List

The `CircularLinkedList` class implements a circular doubly-linked list. Used for the internal logic of the `Circular` class.

`circular_linked_list.py`

```

1  class Node:
2      def __init__(self, data):
3          self.data = data
4          self.next = None
5          self.previous = None
6
7  class CircularLinkedList:
8      def __init__(self, list_to_convert=None):
9          """
10             Initialises a CircularLinkedList object.
11
12             Args:
13                 list_to_convert (list, optional): Creates a linked list from existing
14                 items. Defaults to None.
15                 """
16
17         self._head = None
18
19         if list_to_convert:
20             for item in list_to_convert:
21                 self.insert_at_end(item)
22
23     def __str__(self):
24         """
25             Returns a string representation of the circular linked list.
26
27             Returns:
28                 str: Linked list formatted as string.
29                 """
30
31         if self._head is None:
32             return '| empty |'
33
34         characters = '| -> '
35         current_node = self._head
36         while True:
37             characters += str(current_node.data) + ' -> '
38             current_node = current_node.next
39
40         if current_node == self._head:
41             characters += '|'
42
43     def insert_at_beginning(self, data):
44         """
45             Inserts a node at the beginning of the circular linked list.
46
47             Args:
48                 data: The data to insert.
49                 """
50
51         new_node = Node(data)
52
53         if self._head is None:
54             self._head = new_node
55             new_node.next = self._head
56             new_node.previous = self._head
57         else:
58             new_node.next = self._head

```

```

56         new_node.previous = self._head.previous
57         self._head.previous.next = new_node
58         self._head.previous = new_node
59
60         self._head = new_node
61
62     def insert_at_end(self, data):
63         """
64             Inserts a node at the end of the circular linked list.
65
66         Args:
67             data: The data to insert.
68         """
69         new_node = Node(data)
70
71         if self._head is None:
72             self._head = new_node
73             new_node.next = self._head
74             new_node.previous = self._head
75         else:
76             new_node.next = self._head
77             new_node.previous = self._head.previous
78             self._head.previous.next = new_node
79             self._head.previous = new_node
80
81     def insert_at_index(self, data, index):
82         """
83             Inserts a node at a specific index in the circular linked list.
84             The head node is taken as index 0.
85
86         Args:
87             data: The data to insert.
88             index (int): The index to insert the data at.
89
90         Raises:
91             ValueError: Index is out of range.
92         """
93         if index < 0:
94             raise ValueError('Invalid index! (CircularLinkedList.insert_at_index)')
95
96         if index == 0 or self._head is None:
97             self.insert_at_beginning(data)
98         else:
99             new_node = Node(data)
100            current_node = self._head
101            count = 0
102
103            while count < index - 1 and current_node.next != self._head:
104                current_node = current_node.next
105                count += 1
106
107            if count == (index - 1):
108                new_node.next = current_node.next
109                new_node.previous = current_node
110                current_node.next = new_node
111            else:
112                raise ValueError('Index out of range! (CircularLinkedList.
113                insert_at_index)')
114
115     def delete(self, data):
116         """

```

```
116     Deletes a node with the specified data from the circular linked list.
117
118     Args:
119         data: The data to delete.
120
121     Raises:
122         ValueError: No nodes in the list contain the specified data.
123     """
124     if self._head is None:
125         return
126
127     current_node = self._head
128
129     while current_node.data != data:
130         current_node = current_node.next
131
132         if current_node == self._head:
133             raise ValueError('Data not found in circular linked list! (' +
CircularLinkedList.delete)')
134
135         if self._head.next == self._head:
136             self._head = None
137         else:
138             current_node.previous.next = current_node.next
139             current_node.next.previous = current_node.previous
140
141     def data_in_list(self, data):
142         """
143             Checks if the specified data is in the circular linked list.
144
145             Args:
146                 data: The data to check.
147
148             Returns:
149                 bool: True if the data is in the list, False otherwise.
150         """
151         if self._head is None:
152             return False
153
154         current_node = self._head
155         while True:
156             if current_node.data == data:
157                 return True
158
159             current_node = current_node.next
160             if current_node == self._head:
161                 return False
162
163     def shift_head(self):
164         """
165             Shifts the head of the circular linked list to the next node.
166         """
167         self._head = self._head.next
168
169     def unshift_head(self):
170         """
171             Shifts the head of the circular linked list to the previous node.
172         """
173         self._head = self._head.previous
174
175     def get_head(self):
176         """
```

```

177     Gets the head node of the circular linked list.
178
179     Returns:
180         Node: The head node.
181     """
182     return self._head

```

3.4.4 Widgets

Each state contains a `WIDGET_DICT` map, which contains and initialises each widget with their own attributes, and provides references to run methods on them in the state code. Each `WIDGET_DICT` is passed into a `widgetGroup` object, which is responsible for drawing, resizing and handling all widgets for the current state. Below is a list of all the widgets I have implemented:

- BoardThumbnailButton
- MultipleIconButton
- ReactiveIconButton
- BoardThumbnail
- ReactiveButton
- VolumeSlider
- ColourPicker
- ColourButton
- BrowserStrip
- PieceDisplay
- BrowserItem
- TextButton
- IconButton
- ScrollArea
- Chessboard
- TextInput
- Rectangle
- MoveList
- Dropdown
- Carousel
- Switch
- Timer
- Text
- Icon
- (`_ColourDisplay`)
- (`_ColourSquare`)
- (`_ColourSlider`)
- (`_SliderThumb`)
- (`_Scrollbar`)

CustomEvent

The `CustomEvent` class is used to pass data between states and widgets. An event argument is passed into interactive widgets; When a widget wants to pass data back to the state, it returns the event, and adds any attributes that is required. The state then receives and handles these returned events accordingly.

`custom_event.py`

```

1 from data.constants import GameEventType, SettingsEventType, ConfigEventType,
2     BrowserEventType, EditorEventType
3
4 required_args = {
5     GameEventType.BOARD_CLICK: ['coords'],
6     GameEventType.ROTATE_PIECE: ['rotation_direction'],
7     GameEventType.SET_LASER: ['laser_result'],
8     GameEventType.UPDATE_PIECES: ['move_notation'],
9     GameEventType.TIMER_END: ['active_colour'],
10    GameEventType.PIECE_DROP: ['coords', 'piece', 'colour', 'rotation',
11        'remove_overlay'],
12    SettingsEventType.COLOUR_SLIDER_SLIDE: ['colour'],
13    SettingsEventType.PRIMARY_COLOUR_PICKER_CLICK: ['colour'],
14    SettingsEventType.SECONDARY_COLOUR_PICKER_CLICK: ['colour'],
15    SettingsEventType.DROPDOWN_CLICK: ['selected_word'],

```

```

14     SettingsEventType.VOLUME_SLIDER_CLICK: ['volume', 'volume_type'],
15     SettingsEventType.SHADER_PICKER_CLICK: ['data'],
16     SettingsEventType.PARTICLES_CLICK: ['toggled'],
17     SettingsEventType.OPENGL_CLICK: ['toggled'],
18     ConfigEventType.TIME_TYPE: ['time'],
19     ConfigEventType.FEN_STRING_TYPE: ['time'],
20     ConfigEventType.CPU_DEPTH_CLICK: ['data'],
21     ConfigEventType.PVC_CLICK: ['data'],
22     ConfigEventType.PRESET_CLICK: ['fen_string'],
23     BrowserEventType.BROWSER_STRIP_CLICK: ['selected_index'],
24     BrowserEventType.PAGE_CLICK: ['data'],
25     EditorEventType.PICK_PIECE_CLICK: ['piece', 'active_colour'],
26     EditorEventType.ROTATE_PIECE_CLICK: ['rotation_direction'],
27 }
28
29 class CustomEvent():
30     def __init__(self, type, **kwargs):
31         self.__dict__.update(kwargs)
32         self.type = type
33
34     @classmethod
35     def create_event(event_cls, event_type, **kwargs):
36         """
37             @classmethod Factory method used to instance CustomEvent object, to check
38             for required keyword arguments
39
40             Args:
41                 event_cls (CustomEvent): Reference to own class.
42                 event_type: The state EventType.
43
44             Raises:
45                 ValueError: If required keyword argument for passed event type not
46                 present.
47                 ValueError: If keyword argument passed is not required for passed
48                 event type.
49
50             Returns:
51                 CustomEvent: Initialised CustomEvent instance.
52             """
53
54         if event_type in required_args:
55
56             for required_arg in required_args[event_type]:
57                 if required_arg not in kwargs:
58                     raise ValueError(f"Argument '{required_arg}' required for {event_type.name} event ({GameEvent.create_event})")
59
60             for kwarg in kwargs:
61                 if kwarg not in required_args[event_type]:
62                     raise ValueError(f"Argument '{kwarg}' not included in
63             required_args dictionary for event '{event_type}'! ({GameEvent.create_event})")
64
65         return event_cls(event_type, **kwargs)
66
67     else:
68         return event_cls(event_type)

```

ReactiveIconButton

The `ReactiveIconButton` widget is a pressable button that changes the icon displayed when it is hovered or pressed.

```

reactive_icon_button.py

1 from data.widgets.reactive_button import ReactiveButton
2 from data.constants import WidgetState
3 from data.widgets.icon import Icon
4
5 class ReactiveIconButton(ReactiveButton):
6     def __init__(self, base_icon, hover_icon, press_icon, **kwargs):
7         # Composition is used here, to initialise the Icon widgets for each widget
8         state
9             widgets_dict = {
10                 WidgetState.BASE: Icon(
11                     parent=kwargs.get('parent'),
12                     relative_size=kwargs.get('relative_size'),
13                     relative_position=(0, 0),
14                     icon=base_icon,
15                     fill_colour=(0, 0, 0, 0),
16                     border_width=0,
17                     margin=0,
18                     fit_icon=True,
19                 ),
20                 WidgetState.HOVER: Icon(
21                     parent=kwargs.get('parent'),
22                     relative_size=kwargs.get('relative_size'),
23                     relative_position=(0, 0),
24                     icon=hover_icon,
25                     fill_colour=(0, 0, 0, 0),
26                     border_width=0,
27                     margin=0,
28                     fit_icon=True,
29                 ),
30                 WidgetState.PRESS: Icon(
31                     parent=kwargs.get('parent'),
32                     relative_size=kwargs.get('relative_size'),
33                     relative_position=(0, 0),
34                     icon=press_icon,
35                     fill_colour=(0, 0, 0, 0),
36                     border_width=0,
37                     margin=0,
38                     fit_icon=True,
39                 )
40             }
41             super().__init__(
42                 widgets_dict=widgets_dict,
43                 **kwargs
44             )

```

ReactiveButton

The `ReactiveButton` widget is the parent class for `ReactiveIconButton`. It provides the methods for clicking, rotating between widget states, positioning etc.

`reactive_button.py`

```

1 from data.components.custom_event import CustomEvent
2 from data.widgets.bases.pressable import _Pressable
3 from data.widgets.bases.circular import _Circular
4 from data.widgets.bases.widget import _Widget
5 from data.constants import WidgetState
6
7 class ReactiveButton(_Pressable, _Circular, _Widget):

```

```

8     def __init__(self, widgets_dict, event, center=False, **kwargs):
9         # Multiple inheritance used here, to combine the functionality of multiple
10        super().__init__(
11            self,
12            event=event,
13            hover_func=lambda: self.set_to_key(WidgetState.HOVER),
14            down_func=lambda: self.set_to_key(WidgetState.PRESS),
15            up_func=lambda: self.set_to_key(WidgetState.BASE),
16            **kwargs
17        )
18        # Aggregation used to cycle between external widgets
19        _Circular.__init__(self, items_dict=widgets_dict)
20        _Widget.__init__(self, **kwargs)
21
22        self._center = center
23
24        self.initialise_new_colours(self._fill_colour)
25
26    @property
27    def position(self):
28        """
29            Overrides position getter method, to always position icon in the center if
30            self._center is True.
31
32            Returns:
33            list[int, int]: Position of widget.
34        """
35        position = super().position
36
37        if self._center:
38            self._size_diff = (self.size[0] - self.rect.width, self.size[1] - self.
39            rect.height)
40            return (position[0] + self._size_diff[0] / 2, position[1] + self.
41            _size_diff[1] / 2)
42        else:
43            return position
44
45    def set_image(self):
46        """
47            Sets current icon to image.
48        """
49        self.current_item.set_image()
50        self.image = self.current_item.image
51
52    def set_geometry(self):
53        """
54            Sets size and position of widget.
55        """
56        super().set_geometry()
57        self.current_item.set_geometry()
58        self.current_item.rect.topleft = self.rect.topleft
59
60    def set_surface_size(self, new_surface_size):
61        """
62            Overrides base method to resize every widget state icon, not just the
63            current one.
64
65            Args:
66                new_surface_size (list[int, int]): New surface size.
67            """
68        super().set_surface_size(new_surface_size)

```

```
65         for item in self._items_dict.values():
66             item.set_surface_size(new_surface_size)
67
68     def process_event(self, event):
69         """
70         Processes Pygame events.
71
72         Args:
73             event (pygame.Event): Event to process.
74
75         Returns:
76             CustomEvent: CustomEvent of current item, with current key included
77         """
78         widget_event = super().process_event(event)
79         self.current_item.process_event(event)
80
81         if widget_event:
82             return CustomEvent(**vars(widget_event), data=self.current_key)
```

ColourSlider

The `ColourSlider` widget is instanced in the `ColourPicker` class. It provides a slider for changing between hues for the colour picker, using the functionality of the `SliderThumb` class.

`colour_slider.py`

```
1 import pygame
2 from data.utils.widget_helpers import create_slider_gradient
3 from data.utils.asset_helpers import smoothscale_and_cache
4 from data.widgets.slider_thumb import _SliderThumb
5 from data.widgets.bases.widget import _Widget
6 from data.constants import WidgetState
7
8 class _ColourSlider(_Widget):
9     def __init__(self, relative_width, **kwargs):
10         super().__init__(relative_size=(relative_width, relative_width * 0.2), **
11                         kwargs)
12
13         # Initialise slider thumb.
14         self._thumb = _SliderThumb(radius=self.size[1] / 2, border_colour=self.
15                                     _border_colour)
16
17         self._selected_percent = 0
18         self._last_mouse_x = None
19
20         self._gradient_surface = create_slider_gradient(self.gradient_size, self.
21                                                       border_width, self._border_colour)
22         self._empty_surface = pygame.Surface(self.size, pygame.SRCALPHA)
23
24     @property
25     def gradient_size(self):
26         return (self.size[0] - 2 * (self.size[1] / 2), self.size[1] / 2)
27
28     @property
29     def gradient_position(self):
30         return (self.size[1] / 2, self.size[1] / 4)
31
32     @property
33     def thumb_position(self):
34         return (self.gradient_size[0] * self._selected_percent, 0)
```

```

34     def selected_colour(self):
35         colour = pygame.Color(0)
36         colour.hsva = (int(self._selected_percent * 360), 100, 100, 100)
37         return colour
38
39     def calculate_gradient_percent(self, mouse_pos):
40         """
41             Calculate what percentage slider thumb is at based on change in mouse
42             position.
43
44             Args:
45                 mouse_pos (list[int, int]): Position of mouse on window screen.
46
47             Returns:
48                 float: Slider scroll percentage.
49
50             if self._last_mouse_x is None:
51                 return
52
53             x_change = (mouse_pos[0] - self._last_mouse_x) / (self.gradient_size[0] -
54             2 * self.border_width)
55             return max(0, min(self._selected_percent + x_change, 1))
56
57     def relative_to_global_position(self, position):
58         """
59             Transforms position from being relative to widget rect, to window screen.
60
61             Args:
62                 position (list[int, int]): Position relative to widget rect.
63
64             Returns:
65                 list[int, int]: Position relative to window screen.
66
67             relative_x, relative_y = position
68             return (relative_x + self.position[0], relative_y + self.position[1])
69
70     def set_colour(self, new_colour):
71         """
72             Sets selected_percent based on the new colour's hue.
73
74             Args:
75                 new_colour (pygame.Color): New slider colour.
76
77             colour = pygame.Color(new_colour)
78             hue = colour.hsva[0]
79             self._selected_percent = hue / 360
80             self.set_image()
81
82     def set_image(self):
83         """
84             Draws colour slider to widget image.
85
86             # Scales initialised gradient surface instead of redrawing it everytime
87             set_image is called
88             gradient_scaled = smoothscale_and_cache(self._gradient_surface, self.
89             gradient_size)
90
91             self.image = pygame.transform.scale(self._empty_surface, (self.size))
92             self.image.blit(gradient_scaled, self.gradient_position)
93
94             # Resets thumb colour, image and position, then draws it to the widget
95             image

```

```

91         self._thumb.initialise_new_colours(self.selected_colour)
92         self._thumb.set_surface(radius=self.size[1] / 2, border_width=self.
93             border_width)
94         self._thumb.set_position(self.relative_to_global_position((self.
95             thumb_position[0], self.thumb_position[1])))
96
97     thumb_surface = self._thumb.get_surface()
98     self.image.blit(thumb_surface, self.thumb_position)
99
100    def process_event(self, event):
101        """
102            Processes Pygame events.
103
104            Args:
105                event (pygame.Event): Event to process.
106
107            Returns:
108                pygame.Color: Current colour slider is displaying.
109
110        if event.type not in [pygame.MOUSEMOTION, pygame.MOUSEBUTTONDOWN, pygame.
111            MOUSEBUTTONUP]:
112            return
113
114        # Gets widget state before and after event is processed by slider thumb
115        before_state = self._thumb.state
116        self._thumb.process_event(event)
117        after_state = self._thumb.state
118
119        # If widget state changes (e.g. hovered -> pressed), redraw widget
120        if before_state != after_state:
121            self.set_image()
122
123        if event.type == pygame.MOUSEMOTION:
124            if self._thumb.state == WidgetState.PRESS:
125                # Recalculates slider colour based on mouse position change
126                selected_percent = self.calculate_gradient_percent(event.pos)
127                self._last_mouse_x = event.pos[0]
128
129                if selected_percent is not None:
130                    self._selected_percent = selected_percent
131
132        return self.selected_colour
133
134    if event.type == pygame.MOUSEBUTTONUP:
135        # When user stops scrolling, return new slider colour
136        self._last_mouse_x = None
137        return self.selected_colour
138
139    if event.type == pygame.MOUSEBUTTONDOWN or before_state != after_state:
140        # Redraws widget when slider thumb is hovered or pressed
141        return self.selected_colour

```

TextInput

The TextInput widget is used for inputting fen strings and time controls.
`text_input.py`

```

1 import pyperclip
2 import pygame
3 from data.constants import WidgetState, CursorMode, INPUT_COLOURS
4 from data.components.custom_event import CustomEvent

```

```

5  from data.widgets.bases.pressable import _Pressable
6  from data.managers.logs import initialise_logger
7  from data.managers.animation import animation
8  from data.widgets.bases.box import _Box
9  from data.managers.cursor import cursor
10 from data.managers.theme import theme
11 from data.widgets.text import Text
12
13 logger = initialise_logger(__name__)
14
15 class TextInput(_Box, _Pressable, Text):
16     def __init__(self, event, blinking_interval=530, validator=(lambda x: True),
17                  default='', placeholder='PLACEHOLDER TEXT', placeholder_colour=(200, 200, 200),
18                  cursor_colour=theme['textSecondary'], **kwargs):
19         self._cursor_index = None
20         # Multiple inheritance used here, adding the functionality of pressing,
21         # and custom box colours, to the text widget
22         _Box.__init__(self, box_colours=INPUT_COLOURS)
23         _Pressable.__init__(
24             self,
25             event=None,
26             hover_func=lambda: self.set_state_colour(WidgetState.HOVER),
27             down_func=lambda: self.set_state_colour(WidgetState.PRESS),
28             up_func=lambda: self.set_state_colour(WidgetState.BASE),
29             sfx=None
30         )
31         Text.__init__(self, text="", center=False, box_colours=INPUT_COLOURS[
32             WidgetState.BASE], **kwargs)
33         self.initialise_new_colours(self._fill_colour)
34         self.set_state_colour(WidgetState.BASE)
35
36         pygame.key.set_repeat(500, 50)
37
38         self._blinking_fps = 1000 / blinking_interval
39         self._cursor_colour = cursor.colour
40         self._cursor.colour_copy = cursor.colour
41         self._placeholder.colour = placeholder.colour
42         self._text.colour_copy = self._text.colour
43
44         self._placeholder_text = placeholder
45         self._is_placeholder = None
46         if default:
47             self._text = default
48             self.is_placeholder = False
49         else:
50             self._text = self._placeholder_text
51             self.is_placeholder = True
52
53         self._event = event
54         self._validator = validator
55         self._blinking_cooldown = 0
56
57         self._empty_cursor = pygame.Surface((0, 0), pygame.SRCALPHA)
58
59         self.resize_text()
60         self.set_image()
61         self.set_geometry()
62
63     @property
64     # Encapsulated getter method
65     def is_placeholder(self):

```

```
63         return self._is_placeholder
64
65     @is_placeholder.setter
66     # Encapsulated setter method, used to replace text colour if placeholder text
67     # is shown
68     def is_placeholder(self, is_true):
69         self._is_placeholder = is_true
70
71         if is_true:
72             self._text_colour = self._placeholder_colour
73         else:
74             self._text_colour = self._text_colour_copy
75
76     @property
77     def cursor_size(self):
78         cursor_height = (self.size[1] - self.border_width * 2) * 0.75
79         return (cursor_height * 0.1, cursor_height)
80
81     @property
82     def cursor_position(self):
83         current_width = (self.margin / 2)
84         for index, metrics in enumerate(self._font.get_metrics(self._text, size=
85             self.font_size)):
86             if index == self._cursor_index:
87                 return (current_width - self.cursor_size[0], (self.size[1] - self.
88                     cursor_size[1]) / 2)
89
90         glyph_width = metrics[4]
91         current_width += glyph_width
92         return (current_width - self.cursor_size[0], (self.size[1] - self.
93             cursor_size[1]) / 2)
94
95     @property
96     def text(self):
97         if self.is_placeholder:
98             return ''
99
100        return self._text
101
102    def relative_x_to_cursor_index(self, relative_x):
103        """
104            Calculates cursor index using mouse position relative to the widget
105            position.
106
107        Args:
108            relative_x (int): Horizontal distance of the mouse from the left side
109            of the widget.
110
111        Returns:
112            int: Cursor index.
113
114        """
115        current_width = 0
116
117        for index, metrics in enumerate(self._font.get_metrics(self._text, size=
118            self.font_size)):
119            glyph_width = metrics[4]
120
121            if current_width >= relative_x:
122                return index
123
124            current_width += glyph_width
```

```

118         return len(self._text)
119
120     def set_cursor_index(self, mouse_pos):
121         """
122             Sets cursor index based on mouse position.
123
124         Args:
125             mouse_pos (list[int, int]): Mouse position relative to window screen.
126
127         if mouse_pos is None:
128             self._cursor_index = mouse_pos
129             return
130
131         relative_x = mouse_pos[0] - (self.margin / 2) - self.rect.left
132         relative_x = max(0, relative_x)
133         self._cursor_index = self.relative_x_to_cursor_index(relative_x)
134
135     def focus_input(self, mouse_pos):
136         """
137             Draws cursor and sets cursor index when user clicks on widget.
138
139         Args:
140             mouse_pos (list[int, int]): Mouse position relative to window screen.
141
142         if self.is_placeholder:
143             self._text = ''
144             self.is_placeholder = False
145
146             self.set_cursor_index(mouse_pos)
147             self.set_image()
148             cursor.set_mode(CursorMode.IBEAM)
149
150     def unfocus_input(self):
151         """
152             Removes cursor when user unselects widget.
153
154         if self._text == '':
155             self._text = self._placeholder_text
156             self.is_placeholder = True
157             self.resize_text()
158
159             self.set_cursor_index(None)
160             self.set_image()
161             cursor.set_mode(CursorMode.ARROW)
162
163     def set_text(self, new_text):
164         """
165             Called by a state object to change the widget text externally.
166
167         Args:
168             new_text (str): New text to display.
169
170         Returns:
171             CustomEvent: Object containing the new text to alert state of a text
172             update.
173
174             super().set_text(new_text)
175             return CustomEvent(**vars(self._event), text=self.text)
176
177     def process_event(self, event):
178         """
179             Processes Pygame events.

```

```

179
180     Args:
181         event (pygame.Event): Event to process.
182
183     Returns:
184         CustomEvent: Object containing the new text to alert state of a text
185         update.
186         """
187
188         previous_state = self.get_widget_state()
189         super().process_event(event)
190         current_state = self.get_widget_state()
191
192         match event.type:
193             case pygame.MOUSEMOTION:
194                 if self._cursor_index is None:
195                     return
196
197                 # If mouse is hovering over widget, turn mouse cursor into an I-
198                 # beam
199                 if self.rect.collidepoint(event.pos):
200                     if cursor.get_mode() != CursorMode.IBEAM:
201                         cursor.set_mode(CursorMode.IBEAM)
202
203             else:
204                 if cursor.get_mode() == CursorMode.IBEAM:
205                     cursor.set_mode(CursorMode.ARROW)
206
207             return
208
209             case pygame.MOUSEBUTTONDOWN:
210                 # When user selects widget
211                 if previous_state == WidgetState.PRESS:
212                     self.focus_input(event.pos)
213
214                 # When user unselects widget
215                 if current_state == WidgetState.BASE and self._cursor_index is not
216                 None:
217                     self.unfocus_input()
218
219             return CustomEvent(**vars(self._event), text=self.text)
220
221             case pygame.KEYDOWN:
222                 if self._cursor_index is None:
223                     return
224
225                 # Handling Ctrl-C and Ctrl-V shortcuts
226                 if event.mod & (pygame.KMOD_CTRL):
227                     if event.key == pygame.K_c:
228                         pyperclip.copy(self.text)
229                         logger.info(f'COPIED {self.text}')
230
231                     elif event.key == pygame.K_v:
232                         pasted_text = pyperclip.paste()
233                         pasted_text = ''.join(char for char in pasted_text if 32
234                         <= ord(char) <= 127)
235                         self._text = self._text[:self._cursor_index] + pasted_text
236                         + self._text[self._cursor_index:]
237                         self._cursor_index += len(pasted_text)
238
239                 elif event.key == pygame.K_BACKSPACE or event.key == pygame.
240                 K_DELETE:
241                     self._text = ''
242                     self._cursor_index = 0
243
244                     self.resize_text()

```

```

235         self.set_image()
236         self.set_geometry()
237
238     return
239
240     match event.key:
241         case pygame.K_BACKSPACE:
242             if self._cursor_index > 0:
243                 self._text = self._text[:self._cursor_index - 1] +
244                     self._text[self._cursor_index:]
245                 self._cursor_index = max(0, self._cursor_index - 1)
246
247         case pygame.K_RIGHT:
248             self._cursor_index = min(len(self._text), self.
249             _cursor_index + 1)
250
251         case pygame.K_LEFT:
252             self._cursor_index = max(0, self._cursor_index - 1)
253
254         case pygame.K_ESCAPE:
255             self.unfocus_input()
256             return CustomEvent(**vars(self._event), text=self.text)
257
258         case pygame.K_RETURN:
259             self.unfocus_input()
260             return CustomEvent(**vars(self._event), text=self.text)
261
262         case _:
263             if not event.unicode:
264                 return
265
266             potential_text = self._text[:self._cursor_index] + event.
267             unicode + self._text[self._cursor_index:]
268
269             # Validator lambda function used to check if inputted text
270             # is valid before displaying
271             # e.g. Time control input has a validator function
272             # checking if text represents a float
273             if self._validator(potential_text) is False:
274                 return
275
276             self._text = potential_text
277             self._cursor_index += 1
278
279             self._blinking_cooldown += 1
280             animation.set_timer(500, lambda: self.subtract_blinking_cooldown
281             (1))
282
283             self.resize_text()
284             self.set_image()
285             self.set_geometry()
286
287     def subtract_blinking_cooldown(self, cooldown):
288         """
289             Subtracts blinking cooldown after certain timeframe. When
290             blinking_cooldown is 1, cursor is able to be drawn.
291
292         Args:
293             cooldown (float): Duration before cursor can no longer be drawn.
294         """
295         self._blinking_cooldown = self._blinking_cooldown - cooldown
296
297

```

```

290     def set_image(self):
291         """
292             Draws text input widget to image.
293         """
294         super().set_image()
295
296         if self._cursor_index is not None:
297             scaled_cursor = pygame.transform.scale(self._empty_cursor, self.
298             cursor_size)
299             scaled_cursor.fill(self._cursor_colour)
300             self.image.blit(scaled_cursor, self.cursor_position)
301
302     def update(self):
303         """
304             Overrides based update method, to handle cursor blinking.
305         """
306         super().update()
307         # Calculate if cursor should be shown or not
308         cursor_frame = animation.calculate_frame_index(0, 2, self._blinking_fps)
309         if cursor_frame == 1 and self._blinking_cooldown == 0:
310             self._cursor_colour = (0, 0, 0, 0)
311         else:
312             self._cursor_colour = self._cursor_colour_copy
313         self.set_image()

```

3.5 Game

3.5.1 Model

game_model.py

```

1  from data.states.game.components.fen_parser import encode_fen_string
2  from data.constants import Colour, GameEventType, EMPTY_BB
3  from data.states.game.widget_dict import GAME_WIDGETS
4  from data.states.game.cpu.cpu_thread import CPUMThread
5  from data.states.game.cpu.engines import ABMinimaxCPU
6  from data.components.custom_event import CustomEvent
7  from data.utils.bitboard_helpers import is_occupied
8  from data.states.game.components.board import Board
9  from data.utils import input_helpers as ip_helpers
10 from data.states.game.components.move import Move
11 from data.managers.logs import initialise_logger
12
13 logger = initialise_logger(__name__)
14
15 class GameModel:
16     def __init__(self, game_config):
17         self._listeners = {
18             'game': [],
19             'win': [],
20             'pause': [],
21         }
22         self._board = Board(fen_string=game_config['FEN_STRING'])
23
24         self.states = {
25             'CPU_ENABLED': game_config['CPU_ENABLED'],
26             'CPU_DEPTH': game_config['CPU_DEPTH'],
27             'AWAITING_CPU': False,
28             'WINNER': None,
29             'PAUSED': False,

```

```

30         'ACTIVE_COLOUR': game_config['COLOUR'],
31         'TIME_ENABLED': game_config['TIME_ENABLED'],
32         'TIME': game_config['TIME'],
33         'START_FEN_STRING': game_config['FEN_STRING'],
34         'MOVES': [],
35         'ZOBRIST_KEYS': []
36     }
37
38     self._cpu = ABMinimaxCPU(self.states['CPU_DEPTH'], self.cpu_callback,
39     verbose=False)
40     self._cpu_thread = CPUThread(self._cpu)
41     self._cpu_thread.start()
42     self._cpu_move = None
43
44     logger.info(f'Initialising CPU depth of {self.states["CPU_DEPTH"]}')
45
46     def register_listener(self, listener, parent_class):
47         """
48         Registers listener method of another MVC class.
49
50         Args:
51             listener (callable): Listener callback function.
52             parent_class (str): Class name.
53
54         self._listeners[parent_class].append(listener)
55
56     def alert_listeners(self, event):
57         """
58
59         Alerts all registered classes of an event by calling their listener
60         function.
61
62         Args:
63             event (GameEventType): Event to pass as argument.
64
65         Raises:
66             Exception: If an unrecognised event tries to be passed onto listeners.
67
68         for parent_class, listeners in self._listeners.items():
69             match event.type:
70                 case GameEventType.UPDATE_PIECES:
71                     if parent_class in 'game':
72                         for listener in listeners: listener(event)
73
74                 case GameEventType.SET_LASER:
75                     if parent_class == 'game':
76                         for listener in listeners: listener(event)
77
78                 case GameEventType.PAUSE_CLICK:
79                     if parent_class in ['pause', 'game']:
80                         for listener in listeners:
81                             listener(event)
82
83             case _:
84                 raise Exception('Unhandled event type (GameModel.
85         alert_listeners)')
86
87     def set_winner(self, colour=None):
88         """
89         Sets winner.
90
91         Args:

```

```
88         colour (Colour, optional): Describes winnner colour, or draw. Defaults
89         to None.
90         """
91         self.states['WINNER'] = colour
92
93     def toggle_paused(self):
94         """
95             Toggles pause screen, and alerts pause view.
96         """
97         self.states['PAUSED'] = not self.states['PAUSED']
98         game_event = CustomEvent.create_event(GameEventType.PAUSE_CLICK)
99         self.alert_listeners(game_event)
100
101    def get_terminal_move(self):
102        """
103            Debugging method for inputting a move from the terminal.
104
105        Returns:
106            Move: Parsed move.
107        """
108        while True:
109            try:
110                move_type = ip_helpers.parse_move_type(input('Input move type (m/r
111): '))
112                src_square = ip_helpers.parse_notation(input("From: "))
113                dest_square = ip_helpers.parse_notation(input("To: "))
114                rotation = ip_helpers.parse_rotation(input("Enter rotation (a/b/c/
115 d): "))
116                return Move.instance_from_notation(move_type, src_square,
117                dest_square, rotation)
118            except ValueError as error:
119                logger.warning('Input error (Board.get_move): ' + str(error))
120
121    def make_move(self, move):
122        """
123            Takes a Move object and applies it to the board.
124
125        Args:
126            move (Move): Move to apply.
127
128        colour = self._board.bitboards.get_colour_on(move.src)
129        piece = self._board.bitboards.get_piece_on(move.src, colour)
130        # Apply move and get results of laser trajectory
131        laser_result = self._board.apply_move(move, add_hash=True)
132
133        self.alert_listeners(CustomEvent.create_event(GameEventType.SET LASER,
134        laser_result=laser_result))
135
136        # Sets new active colour and checks for a win
137        self.states['ACTIVE_COLOUR'] = self._board.get_active_colour()
138        self.set_winner(self._board.check_win())
139
140        move_notation = move.to_notation(colour, piece, laser_result,
141        hit_square_bitboard)
142
143        self.alert_listeners(CustomEvent.create_event(GameEventType.UPDATE_PIECES,
144        move_notation=move_notation))
145
146        # Adds move to move history list for review screen
147        self.states['MOVES'].append({
148            'time': {
149                Colour.BLUE: GAME_WIDGETS['blue_timer'].get_time(),
150                Colour.WHITE: GAME_WIDGETS['white_timer'].get_time(),
151            }
152        })
```

```

143         Colour.RED: GAME_WIDGETS['red_timer'].get_time()
144     },
145     'move': move_notation,
146     'laserResult': laser_result
147   })
148
149   def make_cpu_move(self):
150     """
151       Starts CPU calculations on the separate thread.
152     """
153     self.states['AWAITING_CPU'] = True
154     self._cpu_thread.start_cpu(self.get_board())
155
156   def cpu_callback(self, move):
157     """
158       Callback function passed to CPU thread. Called when CPU stops processing.
159
160       Args:
161         move (Move): Move that CPU found.
162     """
163     if self.states['WINNER'] is None:
164       # CPU move passed back to main thread by reassigning variable
165       self._cpu_move = move
166       self.states['AWAITING_CPU'] = False
167
168   def check_cpu(self):
169     """
170       Constantly checks if CPU calculations are finished, so that make_move can
171       be run on the main thread.
172     """
173     if self._cpu_move is not None:
174       self.make_move(self._cpu_move)
175       self._cpu_move = None
176
177   def kill_thread(self):
178     """
179       Interrupt and kill CPU thread.
180     """
181     self._cpu_thread.kill_thread()
182     self.states['AWAITING_CPU'] = False
183
184   def is_selectable(self, bitboard):
185     """
186       Checks if square is occupied by a piece of the current active colour.
187
188       Args:
189         bitboard (int): Bitboard representing single square.
190
191       Returns:
192         bool: True if square is occupied by a piece of the current active
193         colour. False if not.
194     """
195     return is_occupied(self._board.bitboards.combined_colour_bitboards[self.
196     states['ACTIVE_COLOUR']], bitboard)
197
198   def get_available_moves(self, bitboard):
199     """
200       Gets all surrounding empty squares. Used for drawing overlay.
201
202       Args:
203         bitboard (int): Bitboard representing single center square.

```

```

202     Returns:
203         int: Bitboard representing all empty surrounding squares.
204     """
205     if (bitboard & self._board.get_all_active_pieces()) != EMPTY_BB:
206         return self._board.get_valid_squares(bitboard)
207
208     return EMPTY_BB
209
210     def get_piece_list(self):
211         """
212             Returns:
213                 list[Piece, ...]: Array of all pieces on the board.
214             """
215         return self._board.get_piece_list()
216
217     def get_piece_info(self, bitboard):
218         """
219             Args:
220                 bitboard (int): Square containing piece.
221
222             Returns:
223                 tuple[Colour, Rotation, Piece]: Piece information.
224             """
225         colour = self._board.bitboards.get_colour_on(bitboard)
226         rotation = self._board.bitboards.get_rotation_on(bitboard)
227         piece = self._board.bitboards.get_piece_on(bitboard, colour)
228         return (piece, colour, rotation)
229
230     def get_fen_string(self):
231         return encode_fen_string(self._board.bitboards)
232
233     def get_board(self):
234         return self._board

```

3.5.2 View

game_view.py

```

1 import pygame
2 from data.constants import GameEventType, Colour, StatusText, Miscellaneous,
3     ShaderType
4 from data.states.game.components.overlay_draw import OverlayDraw
5 from data.states.game.components.capture_draw import CaptureDraw
6 from data.states.game.components.piece_group import PieceGroup
7 from data.states.game.components.laser_draw import LaserDraw
8 from data.states.game.components.father import DragAndDrop
9 from data.utils.bitboard_helpers import bitboard_to_coords
10 from data.utils.board_helpers import screen_pos_to_coords
11 from data.states.game.widget_dict import GAME_WIDGETS
12 from data.components.custom_event import CustomEvent
13 from data.components.widget_group import WidgetGroup
14 from data.managers.window import window
15 from data.managers.audio import audio
16 from data.assets import SFX
17
18 class GameView:
19     def __init__(self, model):
20         self._model = model
21         self._hide_pieces = False
22         self._selected_coords = None
23         self._event_to_func_map = {

```

```

23             GameEventType.UPDATE_PIECES: self.handle_update_pieces,
24             GameEventType.SET LASER: self.handle_set_laser,
25             GameEventType.PAUSE_CLICK: self.handle_pause,
26         }
27
28     # Register model event handling with process_model_event()
29     self._model.register_listener(self.process_model_event, 'game')
30
31     # Initialise WidgetGroup with map of widgets
32     self._widget_group = WidgetGroup(GAME_WIDGETS)
33     self._widget_group.handle_resize(window.size)
34     self.initialise_widgets()
35
36     self._laser_draw = LaserDraw(self.board_position, self.board_size)
37     self._overlay_draw = OverlayDraw(self.board_position, self.board_size)
38     self._drag_and_drop = DragAndDrop(self.board_position, self.board_size)
39     self._capture_draw = CaptureDraw(self.board_position, self.board_size)
40     self._piece_group = PieceGroup()
41     self.handle_update_pieces()
42
43     self.set_status_text(StatusText.PLAYER_MOVE)
44
45     @property
46     def board_position(self):
47         return GAME_WIDGETS['chessboard'].position
48
49     @property
50     def board_size(self):
51         return GAME_WIDGETS['chessboard'].size
52
53     @property
54     def square_size(self):
55         return self.board_size[0] / 10
56
57     def initialise_widgets(self):
58         """
59             Run methods on widgets stored in GAME_WIDGETS dictionary to reset them.
60         """
61         GAME_WIDGETS['move_list'].reset_move_list()
62         GAME_WIDGETS['move_list'].kill()
63         GAME_WIDGETS['help'].kill()
64         GAME_WIDGETS['tutorial'].kill()
65
66         GAME_WIDGETS['scroll_area'].set_image()
67
68         GAME_WIDGETS['chessboard'].refresh_board()
69
70         GAME_WIDGETS['blue_piece_display'].reset_piece_list()
71         GAME_WIDGETS['red_piece_display'].reset_piece_list()
72
73     def set_status_text(self, status):
74         """
75             Sets text on status text widget.
76
77             Args:
78                 status (StatusText): The game stage for which text should be displayed
79             for.
80         """
81         match status:
82             case StatusText.PLAYER_MOVE:
83                 GAME_WIDGETS['status_text'].set_text(f"{self._model.states['ACTIVE_COLOUR'].name}'s turn to move")

```

```

83         case StatusText.CPU_MOVE:
84             GAME_WIDGETS['status_text'].set_text(f"CPU calculating a crazy
move...")
85         case StatusText.WIN:
86             if self._model.states['WINNER'] == Miscellaneous.DRAW:
87                 GAME_WIDGETS['status_text'].set_text(f"Game is a draw! Boring
...")
88             else:
89                 GAME_WIDGETS['status_text'].set_text(f"{self._model.states['
WINNER'].name} won!")
90         case StatusText.DRAW:
91             GAME_WIDGETS['status_text'].set_text(f"Game is a draw! Boring...")
92
93     def handle_resize(self):
94         """
95             Handles resizing of the window.
96         """
97         self._overlay_draw.handle_resize(self.board_position, self.board_size)
98         self._capture_draw.handle_resize(self.board_position, self.board_size)
99         self._piece_group.handle_resize(self.board_position, self.board_size)
100        self._laser_draw.handle_resize(self.board_position, self.board_size)
101        self._laser_draw.handle_resize(self.board_position, self.board_size)
102        self._widget_group.handle_resize(window.size)
103
104        if self._laser_draw.firing:
105            self.update_laser_mask()
106
107    def handle_update_pieces(self, event=None):
108        """
109            Callback function to update pieces after move.
110
111            Args:
112                event (GameEventType, optional): If updating pieces after player move,
event contains move information. Defaults to None.
113                toggle_timers (bool, optional): Toggle timers on and off for new
active colour. Defaults to True.
114
115            piece_list = self._model.get_piece_list()
116            self._piece_group.initialise_pieces(piece_list, self.board_position, self.
board_size)
117
118            if event:
119                GAME_WIDGETS['move_list'].append_to_move_list(event.move_notation)
120                GAME_WIDGETS['scroll_area'].set_image()
121                audio.play_sfx(SFX['piece_move'])
122
123            if self._model.states['ACTIVE_COLOUR'] == Colour.BLUE:
124                self.set_status_text(StatusText.PLAYER_MOVE)
125            elif self._model.states['CPU_ENABLED'] is False:
126                self.set_status_text(StatusText.PLAYER_MOVE)
127            else:
128                self.set_status_text(StatusText.CPU_MOVE)
129
130            if self._model.states['TIME_ENABLED']:
131                self.toggle_timer(self._model.states['ACTIVE_COLOUR'], True)
132                self.toggle_timer(self._model.states['ACTIVE_COLOUR'].get_flipped_
colour(), False)
133
134            if self._model.states['WINNER'] is not None:
135                self.handle_game_end()
136
137    def handle_game_end(self, play_sfx=True):

```

```

138         self.toggle_timer(self._model.states['ACTIVE_COLOUR'], False)
139         self.toggle_timer(self._model.states['ACTIVE_COLOUR'].get_flipped_colour()
140             , False)
141
142         if self._model.states['WINNER'] == Miscellaneous.DRAW:
143             self.set_status_text(StatusText.DRAW)
144         else:
145             self.set_status_text(StatusText.WIN)
146
147         if play_sfx:
148             audio.play_sfx(SFX['sphinx_destroy_1'])
149             audio.play_sfx(SFX['sphinx_destroy_2'])
150             audio.play_sfx(SFX['sphinx_destroy_3'])
151
152     def handle_set_laser(self, event):
153         """
154         Callback function to draw laser after move.
155
156         Args:
157             event (GameEventType): Contains laser trajectory information.
158
159         laser_result = event.laser_result
160
161         # If laser has hit a piece
162         if laser_result.hit_square_bitboard:
163             coords_to_remove = bitboard_to_coords(laser_result.hit_square_bitboard
164             )
165             self._piece_group.remove_piece(coords_to_remove)
166
167             if laser_result.piece_colour == Colour.BLUE:
168                 GAME_WIDGETS['red_piece_display'].add_piece(laser_result.piece_hit
169             )
170             elif laser_result.piece_colour == Colour.RED:
171                 GAME_WIDGETS['blue_piece_display'].add_piece(laser_result.
172                 piece_hit)
173
174             # Draw piece capture GFX
175             self._capture_draw.add_capture(
176                 laser_result.piece_hit,
177                 laser_result.piece_colour,
178                 laser_result.piece_rotation,
179                 coords_to_remove,
180                 laser_result.laser_path[0][0],
181                 self._model.states['ACTIVE_COLOUR']
182             )
183
184     def handle_pause(self, event=None):
185         """
186         Callback function for pausing timer.
187
188         Args:
189             event (None): Event argument not used.
190
191         is_active = not(self._model.states['PAUSED'])
192         self.toggle_timer(self._model.states['ACTIVE_COLOUR'], is_active)
193
194     def initialise_timers(self):
195         """

```

```

195     Initialises both timers with the correct amount of time and starts the
196     timer for the active colour.
197     """
198     if self._model.states['TIME_ENABLED']:
199         GAME_WIDGETS['blue_timer'].set_time(self._model.states['TIME'] * 60 *
200         1000)
201         GAME_WIDGETS['red_timer'].set_time(self._model.states['TIME'] * 60 *
202         1000)
203     else:
204         GAME_WIDGETS['blue_timer'].kill()
205         GAME_WIDGETS['red_timer'].kill()
206
207     self.toggle_timer(self._model.states['ACTIVE_COLOUR'], True)
208
209
210     def toggle_timer(self, colour, is_active):
211         """
212             Stops or resumes timer.
213
214             Args:
215                 colour (Colour): Timer to toggle.
216                 is_active (bool): Whether to pause or resume timer.
217             """
218
219         if colour == Colour.BLUE:
220             GAME_WIDGETS['blue_timer'].set_active(is_active)
221         elif colour == Colour.RED:
222             GAME_WIDGETS['red_timer'].set_active(is_active)
223
224     def update_laser_mask(self):
225         """
226             Uses pygame.mask to create a mask for the pieces.
227             Used for occluding the ray shader.
228         """
229         temp_surface = pygame.Surface(window.size, pygame.SRCALPHA)
230         self._piece_group.draw(temp_surface)
231         mask = pygame.mask.from_surface(temp_surface, threshold=127)
232         mask_surface = mask.to_surface(unsetcolor=(0, 0, 0, 255), setcolor=(255,
233         0, 0, 255))
234
235         window.set_apply_arguments(ShaderType.RAYS, occlusion=mask_surface)
236
237     def draw(self):
238         """
239             Draws GUI and pieces onto the screen.
240         """
241         self._widget_group.update()
242         self._capture_draw.update()
243
244         self._widget_group.draw()
245         self._overlay_draw.draw(window.screen)
246
247         if self._hide_pieces is False:
248             self._piece_group.draw(window.screen)
249
250             self._laser_draw.draw(window.screen)
251             self._drag_and_drop.draw(window.screen)
252             self._capture_draw.draw(window.screen)
253
254     def process_model_event(self, event):
255         """
256             Registered listener function for handling GameModel events.
257             Each event is mapped to a callback function, and the appropriate one is run
258         """

```

```

252
253     Args:
254         event (GameEventType): Game event to process.
255
256     Raises:
257         KeyError: If an unrecognised event type is passed as the argument.
258     """
259     try:
260         self._event_to_func_map.get(event.type)(event)
261     except:
262         raise KeyError('Event type not recognized in Game View (GameView.
process_model_event):', event.type)
263
264     def set_overlay_coords(self, available_coords_list, selected_coord):
265         """
266             Set board coordinates for potential moves overlay.
267
268         Args:
269             available_coords_list (list[tuple[int, int]], ...): Array of
coordinates
270                 selected_coord (list[int, int]): Coordinates of selected piece.
271         """
272         self._selected_coords = selected_coord
273         self._overlay_draw.set_selected_coords(selected_coord)
274         self._overlay_draw.set_available_coords(available_coords_list)
275
276     def get_selected_coords(self):
277         return self._selected_coords
278
279     def set_dragged_piece(self, piece, colour, rotation):
280         """
281             Passes information of the dragged piece to the dragging drawing class.
282
283         Args:
284             piece (Piece): Piece type of dragged piece.
285             colour (Colour): Colour of dragged piece.
286             rotation (Rotation): Rotation of dragged piece.
287         """
288         self._drag_and_drop.set_dragged_piece(piece, colour, rotation)
289
290     def remove_dragged_piece(self):
291         """
292             Stops drawing dragged piece when user lets go of piece.
293         """
294         self._drag_and_drop.remove_dragged_piece()
295
296     def convert_mouse_pos(self, event):
297         """
298             Passes information of what mouse cursor is interacting with to a
GameController object.
299
300         Args:
301             event (pygame.Event): Mouse event to process.
302
303         Returns:
304             CustomEvent | None: Contains information what mouse is doing.
305         """
306         clicked_coords = screen_pos_to_coords(event.pos, self.board_position, self
.board_size)
307
308         if event.type == pygame.MOUSEBUTTONDOWN:
309             if clicked_coords:

```

```

310         return CustomEvent.create_event(GameEventType.BOARD_CLICK, coords=
311                                         clicked_coords)
312
313     else:
314         return None
315
316     elif event.type == pygame.MOUSEBUTTONUP:
317         if self._drag_and_drop.dragged_sprite:
318             piece, colour, rotation = self._drag_and_drop.get_dragged_info()
319             piece_dragged = self._drag_and_drop.remove_dragged_piece()
320             return CustomEvent.create_event(GameEventType.PIECE_DROP, coords=
321                                             clicked_coords, piece=piece, colour=colour, rotation=rotation, remove_overlay=
322                                             piece_dragged)
323
324     def add_help_screen(self):
325         """
326         Draw help overlay when player clicks on the help button.
327         """
328         self._widget_group.add(GAME_WIDGETS['help'])
329         self._widget_group.handle_resize(window.size)
330
331     def add_tutorial_screen(self):
332         """
333         Draw tutorial overlay when player clicks on the tutorial button.
334         """
335         self._widget_group.add(GAME_WIDGETS['tutorial'])
336         self._widget_group.handle_resize(window.size)
337         self._hide_pieces = True
338
339     def remove_help_screen(self):
340         GAME_WIDGETS['help'].kill()
341
342     def remove_tutorial_screen(self):
343         GAME_WIDGETS['tutorial'].kill()
344         self._hide_pieces = False
345
346     def process_widget_event(self, event):
347         """
348         Passes Pygame event to WidgetGroup to allow individual widgets to process
349         events.
350
351         Args:
352             event (pygame.Event): Event to process.
353
354         Returns:
355             CustomEvent | None: A widget event.
356         """
357
358         return self._widget_group.process_event(event)

```

3.5.3 Controller

game_controller.py

```

1 import pygame
2 from data.constants import GameEventType, MoveType, StatusText, Miscellaneous
3 from data.utils import bitboard_helpers as bb_helpers
4 from data.states.game.components.move import Move
5 from data.managers.logs import initialise_logger
6
7 logger = initialise_logger(__name__)
8

```

```

9  class GameController:
10     def __init__(self, model, view, win_view, pause_view, to_menu, to_review,
11      to_new_game):
12         self._model = model
13         self._view = view
14         self._win_view = win_view
15         self._pause_view = pause_view
16
17         self._to_menu = to_menu
18         self._to_review = to_review
19         self._to_new_game = to_new_game
20
21         self._view.initialise_timers()
22         self._win_view.set_win_type('CAPTURE')
23
24     def cleanup(self, next):
25         """
26             Handles game quit, either leaving to main menu or restarting a new game.
27
28             Args:
29                 next (str): New state to switch to.
30
31         self._model.kill_thread()
32
33         if next == 'menu':
34             self._to_menu()
35         elif next == 'game':
36             self._to_new_game()
37         elif next == 'review':
38             self._to_review()
39
40     def make_move(self, move):
41         """
42             Handles player move.
43
44             Args:
45                 move (Move): Move to make.
46
47         self._model.make_move(move)
48         self._view.set_overlay_coords([], None)
49
50         if self._model.states['CPU_ENABLED']:
51             self._model.make_cpu_move()
52
53     def handle_pause_event(self, event):
54         """
55             Processes events when game is paused.
56
57             Args:
58                 event (GameEventType): Event to process.
59
59             Raises:
60                 Exception: If event type is unrecognised.
61
62         game_event = self._pause_view.convert_mouse_pos(event)
63
64         if game_event is None:
65             return
66
67         match game_event.type:
68             case GameEventType.PAUSE_CLICK:
69                 self._model.toggle_paused()

```

```
70
71     case GameEventType.MENU_CLICK:
72         self.cleanup('menu')
73
74     case _:
75         raise Exception('Unhandled event type (GameController.handle_event
76 )')
77
78     def handle_winner_event(self, event):
79         """
80         Processes events when game is over.
81
82         Args:
83             event (GameEventType): Event to process.
84
85         Raises:
86             Exception: If event type is unrecognised.
87
88         game_event = self._win_view.convert_mouse_pos(event)
89
90         if game_event is None:
91             return
92
93         match game_event.type:
94             case GameEventType.MENU_CLICK:
95                 self.cleanup('menu')
96                 return
97
98             case GameEventType.GAME_CLICK:
99                 self.cleanup('game')
100                return
101
102             case GameEventType.REVIEW_CLICK:
103                 self.cleanup('review')
104
105             case _:
106                 raise Exception('Unhandled event type (GameController.handle_event
107 )')
108
109     def handle_game_widget_event(self, event):
110         """
111         Processes events for game GUI widgets.
112
113         Args:
114             event (GameEventType): Event to process.
115
116         Raises:
117             Exception: If event type is unrecognised.
118
119         Returns:
120             CustomEvent | None: A widget event.
121
122         widget_event = self._view.process_widget_event(event)
123
124         if widget_event is None:
125             return None
126
127         match widget_event.type:
128             case GameEventType.ROTATE_PIECE:
129                 src_coords = self._view.get_selected_coords()
130
131                 if src_coords is None:
```

```

130         logger.info('None square selected')
131         return
132
133         move = Move.instance_from_coords(MoveType.ROTATE, src_coords,
134             src_coords, rotation_direction=widget_event.rotation_direction)
135         self.make_move(move)
136
137     case GameEventType.RESIGN_CLICK:
138         self._model.set_winner(self._model.states['ACTIVE_COLOUR'].
139             get_flipped_colour())
140         self._view.handle_game_end(play_sfx=False)
141         self._win_view.set_win_type('RESIGN')
142
143     case GameEventType.DRAW_CLICK:
144         self._model.set_winner(Miscellaneous.DRAW)
145         self._view.handle_game_end(play_sfx=False)
146         self._win_view.set_win_type('DRAW')
147
148     case GameEventType.TIMER_END:
149         if self._model.states['TIME_ENABLED']:
150             self._model.set_winner(widget_event.active_colour.
151                 get_flipped_colour())
152             self._win_view.set_win_type('TIME')
153             self._view.handle_game_end(play_sfx=False)
154
155     case GameEventType.MENU_CLICK:
156         self.cleanup('menu')
157
158     case GameEventType.HELP_CLICK:
159         self._view.add_help_screen()
160
161     case _:
162         raise Exception('Unhandled event type (GameController.handle_event')
163
164     return widget_event.type
165
166 def check_cpu(self):
167     """
168     Checks if CPU calculations are finished every frame.
169     """
170     if self._model.states['CPU_ENABLED'] and self._model.states['AWAITING_CPU']
171     ] is False:
172         self._model.check_cpu()
173
174 def handle_game_event(self, event):
175     """
176     Processes Pygame events for main game.
177
178     Args:
179         event (pygame.Event): If event type is unrecognised.
180
181     Raises:
182         Exception: If event type is unrecognised.
183
184     # Pass event for widgets to process
185     widget_event = self.handle_game_widget_event(event)

```

```

186     if event.type in [pygame.MOUSEBUTTONDOWN, pygame.MOUSEBUTTONUP, pygame.
187 KEYDOWN]:
188         if event.type != pygame.KEYDOWN:
189             game_event = self._view.convert_mouse_pos(event)
190         else:
191             game_event = None
192
193     if game_event is None:
194         if widget_event is None:
195             if event.type in [pygame.MOUSEBUTTONUP, pygame.KEYDOWN]:
196                 # If user releases mouse click not on a widget
197                 self._view.remove_help_screen()
198                 self._view.remove_tutorial_screen()
199             if event.type == pygame.MOUSEBUTTONUP:
200                 # If user releases mouse click on neither a widget or
201 board
202                 self._view.set_overlay_coords(None, None)
203
204     return
205
206     match game_event.type:
207         case GameEventType.BOARD_CLICK:
208             if self._model.states['AWAITING_CPU']:
209                 return
210
211             clicked_coords = game_event.coords
212             clicked_bitboard = bb_helpers.coords_to_bitboard(
213                 clicked_coords)
214             selected_coords = self._view.get_selected_coords()
215
216             if selected_coords:
217                 if clicked_coords == selected_coords:
218                     # If clicking on an already selected square, start
219                     # dragging piece on that square
220                     self._view.set_dragged_piece(*self._model.
221 get_piece_info(clicked_bitboard))
222                     return
223
224             selected_bitboard = bb_helpers.coords_to_bitboard(
225                 selected_coords)
226             available_bitboard = self._model.get_available_moves(
227                 selected_bitboard)
228
229             if bb_helpers.is_occupied(clicked_bitboard,
230 available_bitboard):
231                 # If the newly clicked square is not the same as the
232                 # old one, and is an empty surrounding square, make a move
233                 move = Move.instance_from_coords(MoveType.MOVE,
234 selected_coords, clicked_coords)
235                 self.make_move(move)
236             else:
237                 # If the newly clicked square is not the same as the
238                 # old one, but is an invalid square, unselect the currently selected square
239                 self._view.set_overlay_coords(None, None)
240
241             # Select hovered square if it is same as active colour
242             elif self._model.is_selectable(clicked_bitboard):
243                 available_bitboard = self._model.get_available_moves(
244                 clicked_bitboard)
245                 self._view.set_overlay_coords(bb_helpers.
246 bitboard_to_coords_list(available_bitboard), clicked_coords)

```

```

234             self._view.set_dragged_piece(*self._model.get_piece_info(
235                 clicked_bitboard))
236
237         case GameEventType.PIECE_DROP:
238             hovered_coords = game_event.coords
239
240             # if piece is dropped onto the board
241             if hovered_coords:
242                 hovered_bitboard = bb_helpers.coords_to_bitboard(
243                     hovered_coords)
244
245                 selected_coords = self._view.get_selected_coords()
246                 selected_bitboard = bb_helpers.coords_to_bitboard(
247                     selected_coords)
248
249                 available_bitboard = self._model.get_available_moves(
250                     selected_bitboard)
251
252                 if bb_helpers.is_occupied(hovered_bitboard,
253                     available_bitboard):
254                     # Make a move if mouse is hovered over an empty
255                     # surrounding square
256                     move = Move.instance_from_coords(MoveType.MOVE,
257                         selected_coords, hovered_coords)
258
259                     self.make_move(move)
260
261                     if game_event.remove_overlay:
262                         self._view.set_overlay_coords(None, None)
263
264                     self._view.remove_dragged_piece()
265
266             case _:
267                 raise Exception('Unhandled event type (GameController.
268 handle_event)', game_event.type)
269
270     def handle_event(self, event):
271         """
272             Pass a Pygame event to the correct handling function according to the
273             game state.
274
275             Args:
276                 event (pygame.Event): Event to process.
277             """
278
279             if event.type in [pygame.MOUSEBUTTONDOWN, pygame.MOUSEBUTTONUP, pygame.
280 MOUSEMOTION, pygame.KEYDOWN]:
281                 if self._model.states['PAUSED']:
282                     self.handle_pause_event(event)
283                 elif self._model.states['WINNER'] is not None:
284                     self.handle_winner_event(event)
285                 else:
286                     self.handle_game_event(event)
287
288             if event.type == pygame.KEYDOWN:
289                 if event.key == pygame.K_ESCAPE:
290                     self._model.toggle_paused()
291                 elif event.key == pygame.K_l:
292                     logger.info('\nSTOPPING CPU')
293                     self._model._cpu_thread.stop_cpu() #temp

```

3.5.4 Board

The `Board` class implements the Laser Chess board, and is responsible for handling moves, captures, and win conditions.

`board.py`

```

1  from data.states.game.components.move import Move
2  from data.states.game.components.laser import Laser
3
4  from data.constants import Colour, Piece, Rank, File, MoveType, RotationDirection,
   Miscellaneous, A_FILE_MASK, J_FILE_MASK, ONE_RANK_MASK, EIGHT_RANK_MASK,
   EMPTY_BB
5  from data.states.game.components.bitboard_collection import BitboardCollection
6  from data.utils import bitboard_helpers as bb_helpers
7  from collections import defaultdict
8
9  class Board:
10     def __init__(self, fen_string="sc3ncfcnspb2/2pc7/3Pd6/pa1Pc1rbra1pb1Pd/
11                  pb1Pd1RaRb1pa1Pc/6pb3/7Pa2/2PdNaFaNa3Sa b"):
12         self.bitboards = BitboardCollection(fen_string)
13         self.hash_list = [self.bitboards.get_hash()]
14
15     def __str__(self):
16         """
17             Returns a string representation of the board.
18
19             Returns:
20                 str: Board formatted as string.
21
22         characters = '8 '
23         pieces = defaultdict(int)
24
25         for rank_idx, rank in enumerate(reversed(Rank)):
26             for file_idx, file in enumerate(File):
27                 mask = 1 << (rank * 10 + file)
28                 blue_piece = self.bitboards.get_piece_on(mask, Colour.BLUE)
29                 red_piece = self.bitboards.get_piece_on(mask, Colour.RED)
30
31                 if blue_piece:
32                     pieces[blue_piece.value.upper()] += 1
33                     characters += f'{blue_piece.upper()} '
34                 elif red_piece:
35                     pieces[red_piece.value] += 1
36                     characters += f'{red_piece} '
37                 else:
38                     characters += '. '
39
40                 characters += f'\n\n{7 - rank_idx} '
41         characters += 'A B C D E F G H I J\n\n'
42         characters += str(dict(pieces))
43         characters += f'\nCURRENT PLAYER TO MOVE: {self.bitboards.active_colour.
44                         name}\n'
45         return characters
46
47     def get_piece_list(self):
48         """
49             Converts the board bitboards to a list of pieces.
50
51             Returns:
52                 list: List of Pieces.
53
54         return self.bitboards.convert_to_piece_list()

```

```

53
54     def get_active_colour(self):
55         """
56         Gets the active colour.
57
58         Returns:
59             Colour: The active colour.
60         """
61         return self.bitboards.active_colour
62
63     def to_hash(self):
64         """
65         Gets the hash of the current board state.
66
67         Returns:
68             int: A Zobrist hash.
69         """
70         return self.bitboards.get_hash()
71
72     def check_win(self):
73         """
74         Checks for a Pharaoh capture or threefold-repetition.
75
76         Returns:
77             Colour | Miscellaneous: The winning colour, or Miscellaneous.DRAW.
78         """
79         for colour in Colour:
80             if self.bitboards.get_piece_bitboard(Piece.PHAROAH, colour) == EMPTY_BB:
81                 return colour.get_flipped_colour()
82
83             if self.hash_list.count(self.hash_list[-1]) >= 3:
84                 return Miscellaneous.DRAW
85
86         return None
87
88     def apply_move(self, move, fire_laser=True, add_hash=False):
89         """
90         Applies a move to the board.
91
92         Args:
93             move (Move): The move to apply.
94             fire_laser (bool): Whether to fire the laser after the move.
95             add_hash (bool): Whether to add the board state hash to the hash list.
96
97         Returns:
98             Laser: The laser trajectory result.
99         """
100        piece_symbol = self.bitboards.get_piece_on(move.src, self.bitboards.
101                                                active_colour)
102
103        if piece_symbol is None:
104            raise ValueError('Invalid move - no piece found on source square')
105        elif piece_symbol == Piece.SPHINX:
106            raise ValueError('Invalid move - sphinx piece is immovable')
107
108        if move.move_type == MoveType.MOVE:
109            possible_moves = self.get_valid_squares(move.src)
110            if bb_helpers.is_occupied(move.dest, possible_moves) is False:
111                raise ValueError('Invalid move - destination square is occupied')
112
113        piece_rotation = self.bitboards.get_rotation_on(move.src)

```

```

113
114     self.bitboards.update_move(move.src, move.dest)
115     self.bitboards.update_rotation(move.src, move.dest, piece_rotation)
116
117     elif move.move_type == MoveType.ROTATE:
118         piece_symbol = self.bitboards.get_piece_on(move.src, self.bitboards.
119             active_colour)
120         piece_rotation = self.bitboards.get_rotation_on(move.src)
121
122         if move.rotation_direction == RotationDirection.CLOCKWISE:
123             new_rotation = piece_rotation.get_clockwise()
124         elif move.rotation_direction == RotationDirection.ANTICLOCKWISE:
125             new_rotation = piece_rotation.get_anticlockwise()
126
127         self.bitboards.update_rotation(move.src, move.src, new_rotation)
128
129     laser = None
130     if fire_laser:
131         laser = self.fire_laser(add_hash)
132
133     if add_hash:
134         self.hash_list.append(self.bitboards.get_hash())
135
136     self.bitboards.flip_colour()
137
138     return laser
139
140     def undo_move(self, move, laser_result):
141         """
142             Undoes a move on the board.
143
144             Args:
145                 move (Move): The move to undo.
146                 laser_result (Laser): The laser trajectory result.
147             """
148
149         self.bitboards.flip_colour()
150
151         if laser_result.hit_square_bitboard:
152             # Get info of destroyed piece, and add it to the board again
153             src = laser_result.hit_square_bitboard
154             piece = laser_result.piece_hit
155             colour = laser_result.piece_colour
156             rotation = laser_result.piece_rotation
157
158             self.bitboards.set_square(src, piece, colour)
159             self.bitboards.clear_rotation(src)
160             self.bitboards.set_rotation(src, rotation)
161
162             # Create new Move object that is the inverse of the passed move
163             if move.move_type == MoveType.MOVE:
164                 reversed_move = Move.instance_from_bitboards(MoveType.MOVE, move.dest,
165                     move.src)
166                 elif move.move_type == MoveType.ROTATE:
167                     reversed_move = Move.instance_from_bitboards(MoveType.ROTATE, move.src,
168                     move.src, move.rotation_direction.get_opposite())
169
170             self.apply_move(reversed_move, fire_laser=False)
171             self.bitboards.flip_colour()
172
173     def remove_piece(self, square_bitboard):
174         """
175             Removes a piece from a given square.

```

```

172
173     Args:
174         square_bitboard (int): The bitboard representation of the square.
175         """
176         self.bitboards.clear_square(square_bitboard, Colour.BLUE)
177         self.bitboards.clear_square(square_bitboard, Colour.RED)
178         self.bitboards.clear_rotation(square_bitboard)
179
180     def get_valid_squares(self, src_bitboard, colour=None):
181         """
182             Gets valid squares for a piece to move to.
183
184         Args:
185             src_bitboard (int): The bitboard representation of the source square.
186             colour (Colour, optional): The active colour of the piece.
187
188         Returns:
189             int: The bitboard representation of valid squares.
190             """
191         target_top_left = (src_bitboard & A_FILE_MASK & EIGHT_RANK_MASK) << 9
192         target_top_middle = (src_bitboard & EIGHT_RANK_MASK) << 10
193         target_top_right = (src_bitboard & J_FILE_MASK & EIGHT_RANK_MASK) << 11
194         target_middle_right = (src_bitboard & J_FILE_MASK) << 1
195
196         target_bottom_right = (src_bitboard & J_FILE_MASK & ONE_RANK_MASK) >> 9
197         target_bottom_middle = (src_bitboard & ONE_RANK_MASK) >> 10
198         target_bottom_left = (src_bitboard & A_FILE_MASK & ONE_RANK_MASK)>> 11
199         target_middle_left = (src_bitboard & A_FILE_MASK) >> 1
200
201         possible_moves = target_top_left | target_top_middle | target_top_right |
202         target_middle_right | target_bottom_right | target_bottom_middle |
203         target_bottom_left | target_middle_left
204
205         if colour is not None:
206             valid_possible_moves = possible_moves & ~self.bitboards.
207             combined_colour_bitboards[colour]
208         else:
209             valid_possible_moves = possible_moves & ~self.bitboards.
210             combined_all_bitboard
211
212             return valid_possible_moves
213
214     def get_mobility(self, colour):
215         """
216             Gets all valid squares for a given colour.
217
218         Args:
219             colour (Colour): The colour of the pieces.
220
221         Returns:
222             int: The bitboard representation of all valid squares.
223             """
224         active_pieces = self.get_all_active_pieces(colour)
225         possible_moves = 0
226
227         for square in bb_helpers.occupied_squares(active_pieces):
228             possible_moves += bb_helpers.pop_count(self.get_valid_squares(square))
229
230         return possible_moves
231
232     def get_all_active_pieces(self, colour=None):
233         """

```

```

230         Gets all active pieces for the current player.
231
232     Args:
233         colour (Colour): Active colour of pieces to retrieve. Defaults to None
234
235     Returns:
236         int: The bitboard representation of all active pieces.
237         """
238     if colour is None:
239         colour = self.bitboards.active_colour
240
241     active_pieces = self.bitboards.combined_colour_bitboards[colour]
242     sphinx_bitboard = self.bitboards.get_piece_bitboard(Piece.SPHINX, colour)
243     return active_pieces ^ sphinx_bitboard
244
245     def fire_laser(self, remove_hash):
246         """
247             Fires the laser and removes hit pieces.
248
249         Args:
250             remove_hash (bool): Whether to clear the hash list if a piece is hit.
251
252         Returns:
253             Laser: The result of firing the laser.
254             """
255         laser = Laser(self.bitboards)
256
257         if laser.hit_square_bitboard:
258             self.remove_piece(laser.hit_square_bitboard)
259
260             if remove_hash:
261                 self.hash_list = [] # Remove all hashes for threefold repetition,
262                 as the position is impossible to be repeated after a piece is removed
263                 return laser
264
265     def generate_square_moves(self, src):
266         """
267             Generates all valid moves for a piece on a given square.
268
269         Args:
270             src (int): The bitboard representation of the source square.
271
272         Yields:
273             Move: A valid move for the piece.
274             """
275         for dest in bb_helpers.occupied_squares(self.get_valid_squares(src)):
276             yield Move(MoveType.MOVE, src, dest)
277
278     def generate_all_moves(self, colour):
279         """
280             Generates all valid moves for a given colour.
281
282         Args:
283             colour (Colour): The colour of the pieces.
284
285         Yields:
286             Move: A valid move for the active colour.
287             """
288         sphinx_bitboard = self.bitboards.get_piece_bitboard(Piece.SPHINX, colour)
289         # Remove source squares for Sphinx pieces, as they cannot be moved
290         sphinx_masked_bitboard = self.bitboards.combined_colour_bitboards[colour]
```

```

^ sphinx_bitboard
290
291     for square in bb_helpers.occupied_squares(sphinx_masked_bitboard):
292         # Generate movement moves
293         yield from self.generate_square_moves(square)
294
295         # Generate rotational moves
296         for rotation_direction in RotationDirection:
297             yield Move(MoveType.ROTATE, square, rotation_direction=
rotation_direction)

```

3.5.5 Bitboards

The BitboardCollection class uses helper functions found in bitboard_helpers.py such as pop_count, to initialise and manage bitboard transformations.

bitboard_collection.py

```

1  from data.constants import Rank, File, Piece, Colour, Rotation, RotationIndex,
   EMPTY_BB
2  from data.states.game.components.fen_parser import parse_fen_string
3  from data.states.game.cpu.zobrist_hasher import ZobristHasher
4  from data.utils import bitboard_helpers as bb_helpers
5  from data.managers.logs import initialise_logger
6
7  logger = initialise_logger(__name__)
8
9  class BitboardCollection:
10     def __init__(self, fen_string):
11         self.piece_bitboards = [{char: EMPTY_BB for char in Piece}, {char:
12             EMPTY_BB for char in Piece}]
13         self.combined_colour_bitboards = [EMPTY_BB, EMPTY_BB]
14         self.combined_all_bitboard = EMPTY_BB
15         self.rotation_bitboards = [EMPTY_BB, EMPTY_BB]
16         self.active_colour = Colour.BLUE
17         self._hasher = ZobristHasher()
18
19     try:
20         if fen_string:
21             self.piece_bitboards, self.combined_colour_bitboards, self.
22             combined_all_bitboard, self.rotation_bitboards, self.active_colour =
23             parse_fen_string(fen_string)
24             self.initialise_hash()
25         except ValueError as error:
26             logger.error('Please input a valid FEN string:', error)
27             raise error
28
29     def __str__(self):
30         """
31             Returns a string representation of the bitboards.
32
33             Returns:
34                 str: Bitboards formatted with piece type and colour shown.
35         """
36         characters = ''
37         for rank in reversed(Rank):
38             for file in File:
39                 bitboard = 1 << (rank * 10 + file)
40
41                 colour = self.get_colour_on(bitboard)
42                 piece = self.get_piece_on(bitboard, Colour.BLUE) or self.
43                 get_piece_on(bitboard, Colour.RED)

```

```
40
41             if piece is not None:
42                 characters += f'{piece.upper() if colour == Colour.BLUE
43             else piece} '
44             else:
45                 characters += '. '
46
47         characters += '\n\n'
48
49     return characters
50
51     def get_rotation_string(self):
52         """
53             Returns a string representation of the board rotations.
54
55             Returns:
56                 str: Board formatted with only rotations shown.
57
58         characters = ''
59         for rank in reversed(Rank):
60
61             for file in File:
62                 mask = 1 << (rank * 10 + file)
63                 rotation = self.get_rotation_on(mask)
64                 has_piece = bb_helpers.is_occupied(self.combined_all_bitboard,
65                 mask)
66
67                 if has_piece:
68                     characters += f'{rotation.upper()} '
69                 else:
70                     characters += '. '
71
72         characters += '\n\n'
73
74     def initialise_hash(self):
75         """
76             Initialises the Zobrist hash for the current board state.
77
78         for piece in Piece:
79             for colour in Colour:
80                 piece_bitboard = self.get_piece_bitboard(piece, colour)
81
82                 for occupied_bitboard in bb_helpers.occupied_squares(
83                 piece_bitboard):
84                     self._hasher.apply_piece_hash(occupied_bitboard, piece, colour
85                 )
86
87                 for bitboard in bb_helpers.loop_all_squares():
88                     rotation = self.get_rotation_on(bitboard)
89                     self._hasher.apply_rotation_hash(bitboard, rotation)
90
91                 if self.active_colour == Colour.RED:
92                     self._hasher.apply_red_move_hash()
93
94     def flip_colour(self):
95         """
96             Flips the active colour and updates the Zobrist hash.
97
98             self.active_colour = self.active_colour.get_flipped_colour()
```

```

98         if self.active_colour == Colour.RED:
99             self._hasher.apply_red_move_hash()
100
101     def update_move(self, src, dest):
102         """
103             Updates the bitboards for a move.
104
105         Args:
106             src (int): The bitboard representation of the source square.
107             dest (int): The bitboard representation of the destination square.
108         """
109         piece = self.get_piece_on(src, self.active_colour)
110
111         self.clear_square(src, Colour.BLUE)
112         self.clear_square(dest, Colour.BLUE)
113         self.clear_square(src, Colour.RED)
114         self.clear_square(dest, Colour.RED)
115
116         self.set_square(dest, piece, self.active_colour)
117
118     def update_rotation(self, src, dest, new_rotation):
119         """
120             Updates the rotation bitboards for a move.
121
122         Args:
123             src (int): The bitboard representation of the source square.
124             dest (int): The bitboard representation of the destination square.
125             new_rotation (Rotation): The new rotation.
126         """
127         self.clear_rotation(src)
128         self.set_rotation(dest, new_rotation)
129
130     def clear_rotation(self, bitboard):
131         """
132             Clears the rotation for a given square.
133
134         Args:
135             bitboard (int): The bitboard representation of the square.
136         """
137         old_rotation = self.get_rotation_on(bitboard)
138         rotation_1, rotation_2 = self.rotation_bitboards
139         self.rotation_bitboards[RotationIndex.FIRSTBIT] = bb_helpers.clear_square(
140             rotation_1, bitboard)
141         self.rotation_bitboards[RotationIndex.SECONDBIT] = bb_helpers.clear_square(
142             rotation_2, bitboard)
143
144         self._hasher.apply_rotation_hash(bitboard, old_rotation)
145
146     def clear_square(self, bitboard, colour):
147         """
148             Clears a square piece and rotation for a given colour.
149
150         Args:
151             bitboard (int): The bitboard representation of the square.
152             colour (Colour): The colour to clear.
153         """
154         piece = self.get_piece_on(bitboard, colour)
155
156         if piece is None:
157             return
158
159         piece_bitboard = self.get_piece_bitboard(piece, colour)

```

```

158     colour_bitboard = self.combined_colour_bitboards[colour]
159     all_bitboard = self.combined_all_bitboard
160
161     self.piece_bitboards[colour][piece] = bb_helpers.clear_square(
162         piece_bitboard, bitboard)
163     self.combined_colour_bitboards[colour] = bb_helpers.clear_square(
164         colour_bitboard, bitboard)
165     self.combined_all_bitboard = bb_helpers.clear_square(all_bitboard,
166         bitboard)
167
168     self._hasher.apply_piece_hash(bitboard, piece, colour)
169
170     def set_rotation(self, bitboard, rotation):
171         """
172             Sets the rotation for a given square.
173
174         Args:
175             bitboard (int): The bitboard representation of the square.
176             rotation (Rotation): The rotation to set.
177         """
178         rotation_1, rotation_2 = self.rotation_bitboards
179         self._hasher.apply_rotation_hash(bitboard, rotation)
180
181         match rotation:
182             case Rotation.UP:
183                 return
184             case Rotation.RIGHT:
185                 self.rotation_bitboards[RotationIndex.FIRSTBIT] = bb_helpers.
186                 set_square(rotation_1, bitboard)
187                 return
188             case Rotation.DOWN:
189                 self.rotation_bitboards[RotationIndex.SECONDBIT] = bb_helpers.
190                 set_square(rotation_2, bitboard)
191                 return
192             case Rotation.LEFT:
193                 self.rotation_bitboards[RotationIndex.FIRSTBIT] = bb_helpers.
194                 set_square(rotation_1, bitboard)
195                 self.rotation_bitboards[RotationIndex.SECONDBIT] = bb_helpers.
196                 set_square(rotation_2, bitboard)
197                 return
198             case _:
199                 raise ValueError('Invalid rotation input (bitboard.py):', rotation)
200
201     def set_square(self, bitboard, piece, colour):
202         """
203             Sets a piece on a given square.
204
205         Args:
206             bitboard (int): The bitboard representation of the square.
207             piece (Piece): The piece to set.
208             colour (Colour): The colour of the piece.
209         """
210
211         piece_bitboard = self.get_piece_bitboard(piece, colour)
212         colour_bitboard = self.combined_colour_bitboards[colour]
213         all_bitboard = self.combined_all_bitboard
214
215         self.piece_bitboards[colour][piece] = bb_helpers.set_square(piece_bitboard
216             , bitboard)
217         self.combined_colour_bitboards[colour] = bb_helpers.set_square(
218             colour_bitboard, bitboard)
219         self.combined_all_bitboard = bb_helpers.set_square(all_bitboard, bitboard)

```

```
210         self._hasher.apply_piece_hash(bitboard, piece, colour)
211
212     def get_piece_bitboard(self, piece, colour):
213         """
214             Gets the bitboard for a piece type for a given colour.
215
216         Args:
217             piece (Piece): The piece bitboard to get.
218             colour (Colour): The colour of the piece.
219
220         Returns:
221             int: The bitboard representation for all squares occupied by that
222             piece type.
223         """
224         return self.piece_bitboards[colour][piece]
225
226     def get_piece_on(self, target_bitboard, colour):
227         """
228             Gets the piece on a given square for a given colour.
229
230         Args:
231             target_bitboard (int): The bitboard representation of the square.
232             colour (Colour): The colour of the piece.
233
234         Returns:
235             Piece: The piece on the square, or None if square is empty.
236         """
237         if not (bb_helpers.is_occupied(self.combined_colour_bitboards[colour],
238             target_bitboard)):
239             return None
240
241         return next(
242             (piece for piece in Piece if
243                 bb_helpers.is_occupied(self.get_piece_bitboard(piece, colour),
244                 target_bitboard)),
245             None)
246
247     def get_rotation_on(self, target_bitboard):
248         """
249             Gets the rotation on a given square.
250
251         Args:
252             target_bitboard (int): The bitboard representation of the square.
253
254         Returns:
255             Rotation: The rotation on the square.
256         """
257         rotationBits = [bb_helpers.is_occupied(self.rotation_bitboards[
258             RotationIndex.SECONDBIT], target_bitboard), bb_helpers.is_occupied(self.
259             rotation_bitboards[RotationIndex.FIRSTBIT], target_bitboard)]
260
261         match rotationBits:
262             case [False, False]:
263                 return Rotation.UP
264             case [False, True]:
265                 return Rotation.RIGHT
266             case [True, False]:
267                 return Rotation.DOWN
268             case [True, True]:
269                 return Rotation.LEFT
```

```

267     def get_colour_on(self, target_bitboard):
268         """
269             Gets the colour of the piece on a given square.
270
271         Args:
272             target_bitboard (int): The bitboard representation of the square.
273
274         Returns:
275             Colour: The colour of the piece on the square.
276         """
277         for piece in Piece:
278             if self.get_piece_bitboard(piece, Colour.BLUE) & target_bitboard != EMPTY_BB:
279                 return Colour.BLUE
280             elif self.get_piece_bitboard(piece, Colour.RED) & target_bitboard != EMPTY_BB:
281                 return Colour.RED
282
283     def get_piece_count(self, piece, colour):
284         """
285             Gets the count of a given piece type and colour.
286
287         Args:
288             piece (Piece): The piece to count.
289             colour (Colour): The colour of the piece.
290
291         Returns:
292             int: The number of that piece of that colour on the board.
293         """
294         return bb_helpers.pop_count(self.get_piece_bitboard(piece, colour))
295
296     def get_hash(self):
297         """
298             Gets the Zobrist hash of the current board state.
299
300         Returns:
301             int: The Zobrist hash.
302         """
303         return self._hasher.hash
304
305     def convert_to_piece_list(self):
306         """
307             Converts all bitboards to a list of pieces.
308
309         Returns:
310             list: Board represented as a 2D list of Piece and Rotation objects.
311         """
312         piece_list = []
313
314         for i in range(80):
315             if x := self.get_piece_on(1 << i, Colour.BLUE):
316                 rotation = self.get_rotation_on(1 << i)
317                 piece_list.append((x.upper(), rotation))
318             elif y := self.get_piece_on(1 << i, Colour.RED):
319                 rotation = self.get_rotation_on(1 << i)
320                 piece_list.append((y, rotation))
321             else:
322                 piece_list.append(None)
323
324         return piece_list

```

3.6 CPU

This section includes my implementation for the CPU engine run on minimax, including its various improvements and accessory classes.

Every CPU engine class is a subclass of a `BaseCPU` abstract class, and therefore contains the same attribute and method names. This means polymorphism can be used again to easily test and vary the difficulty by switching out which CPU engine is used.

The method `find_move` is called by the CPU thread. `search` is then called recursively to traverse the minimax tree, and find an optimal move. The move is then returned to `find_move` and passed and run with the callback function.

3.6.1 Minimax

`minimax.py`

```

1  from data.states.game.cpu.base import BaseCPU
2  from data.constants import Score, Colour
3  from random import choice
4
5  class MinimaxCPU(BaseCPU):
6      def __init__(self, max_depth, callback, verbose=False):
7          super().__init__(callback, verbose)
8          self._max_depth = max_depth
9
10     def find_move(self, board, stop_event):
11         """
12             Finds the best move for the current board state.
13
14         Args:
15             board (Board): The current board state.
16             stop_event (threading.Event): Event used to kill search from an
17                 external class.
18         """
19         self.initialise_stats()
20         best_score, best_move = self.search(board, self._max_depth, stop_event)
21
22         if self._verbose:
23             self.print_stats(best_score, best_move)
24
25         self._callback(best_move)
26
27     def search(self, board, depth, stop_event):
28         """
29             Recursively DFS through minimax tree with evaluation score.
30
31         Args:
32             board (Board): The current board state.
33             depth (int): The current search depth.
34             stop_event (threading.Event): Event used to kill search from an
35                 external class.
36         Returns:
37             tuple[int, Move]: The best score and the best move found.
38         """
39         if (base_case := super().search(board, depth, stop_event)):
40             return base_case
41
42         best_move = None
43
44         # Blue is the maximising player

```

```

43         if board.get_active_colour() == Colour.BLUE:
44             max_score = -Score.INFINITE
45
46             for move in board.generate_all_moves(Colour.BLUE):
47                 laser_result = board.apply_move(move)
48
49                 new_score = self.search(board, depth - 1, stop_event)[0]
50
51                 # if depth < self._max_depth:
52                 #     print('DEPTH', depth, new_score, move)
53
54                 if new_score > max_score:
55                     max_score = new_score
56                     best_move = move
57
58                 if new_score == (Score.CHECKMATE + self._max_depth):
59                     board.undo_move(move, laser_result)
60                     return max_score, best_move
61
62             elif new_score == max_score:
63                 # If evaluated scores are equal, pick a random move
64                 best_move = choice([best_move, move])
65
66             board.undo_move(move, laser_result)
67
68         return max_score, best_move
69
70     else:
71         min_score = Score.INFINITE
72
73         for move in board.generate_all_moves(Colour.RED):
74             laser_result = board.apply_move(move)
75             # print('DEPTH', depth, move)
76             new_score = self.search(board, depth - 1, stop_event)[0]
77
78             if new_score < min_score:
79                 # print('setting new', new_score, move)
80                 min_score = new_score
81                 best_move = move
82
83                 if new_score == (-Score.CHECKMATE - self._max_depth):
84                     board.undo_move(move, laser_result)
85                     return min_score, best_move
86
87             elif new_score == min_score:
88                 best_move = choice([best_move, move])
89
90             board.undo_move(move, laser_result)
91
92         return min_score, best_move

```

3.6.2 Alpha-beta Pruning

`alpha_beta.py`

```

1  from data.states.game.cpu.move_orderer import MoveOrderer
2  from data.states.game.cpu.base import BaseCPU
3  from data.constants import Score, Colour
4  from random import choice

```

```
6 from data.utils.bitboard_helpers import print_bitboard
7 orderer = MoveOrderer()
8
9 class ABMinimaxCPU(BaseCPU):
10     def __init__(self, max_depth, callback, verbose=True):
11         super().__init__(callback, verbose)
12         self._max_depth = max_depth
13
14     def initialise_stats(self):
15         """
16             Initialises the number of prunes to the statistics dictionary to be logged
17
18         """
19         super().initialise_stats()
20         self._stats['beta_prunes'] = 0
21         self._stats['alpha_prunes'] = 0
22
23     def find_move(self, board, stop_event):
24         """
25             Finds the best move for the current board state.
26
27             Args:
28                 board (Board): The current board state.
29                 stop_event (threading.Event): Event used to kill search from an
30                 external class.
31
32             """
33         self.initialise_stats()
34         best_score, best_move = self.search(board, self._max_depth, -Score.INFINITE, Score.INFINITE, stop_event)
35
36         if self._verbose:
37             self.print_stats(best_score, best_move)
38
39         self._callback(best_move)
40
41     def search(self, board, depth, alpha, beta, stop_event, hint=None):
42         """
43             Recursively DFS through minimax tree while pruning branches using the
44             alpha and beta bounds.
45
46             Args:
47                 board (Board): The current board state.
48                 depth (int): The current search depth.
49                 alpha (int): The upper bound value.
50                 beta (int): The lower bound value.
51                 stop_event (threading.Event): Event used to kill search from an
52                 external class.
53
54             Returns:
55                 tuple[int, Move]: The best score and the best move found.
56
57             """
58         if (base_case := super().search(board, depth, stop_event)):
59             return base_case
60
61         best_move = None
62
63         # Blue is the maximising player
64         if board.get_active_colour() == Colour.BLUE:
65             max_score = -Score.INFINITE
66
67             for move in orderer.get_moves(board, hint):
68                 laser_result = board.apply_move(move)
```

```

63         new_score = self.search(board, depth - 1, alpha, beta, stop_event,
64             laser_result.pieces_on_trajectory)[0]
65
66         if new_score > max_score:
67             max_score = new_score
68             best_move = move
69
70         board.undo_move(move, laser_result)
71
72         alpha = max(alpha, max_score)
73
74         if beta <= alpha:
75             self._stats['alpha_prunes'] += 1
76             break
77
78     return max_score, best_move
79
80 else:
81     min_score = Score.INFINITE
82
83     for move in orderer.get_moves(board, hint):
84         laser_result = board.apply_move(move)
85         new_score = self.search(board, depth - 1, alpha, beta, stop_event,
86             laser_result.pieces_on_trajectory)[0]
87
88         if new_score < min_score:
89             min_score = new_score
90             best_move = move
91
92         board.undo_move(move, laser_result)
93
94         beta = min(beta, min_score)
95         if beta <= alpha:
96             self._stats['beta_prunes'] += 1

```

3.6.3 Transposition Table

For adding transposition table functionality to my other engine classes, I have decided to use a mixin design architecture. This allows me to reuse code by adding mixins to many different classes, and inject additional transposition table methods and functionality into other engines.

```

1 from data.states.game.cpu.engines.alpha_beta import ABMinimaxCPU, ABNegamaxCPU
2 from data.states.game.cpu.transposition_table import TranspositionTable
3
4 class TranspositionTableMixin:
5     def __init__(self, *args, **kwargs):
6         super().__init__(*args, **kwargs)
7         self._table = TranspositionTable()
8
9     def find_move(self, *args, **kwargs):
10        self._table = TranspositionTable()
11        super().find_move(*args, **kwargs)
12
13    def search(self, board, depth, alpha, beta, stop_event, hint=None):
14        """
15            Searches transposition table for a cached move before running a full
16            search if necessary.
17            Caches the searched result.

```

```

18     Args:
19         board (Board): The current board state.
20         depth (int): The current search depth.
21         alpha (int): The upper bound value.
22         beta (int): The lower bound value.
23         stop_event (threading.Event): Event used to kill search from an
24             external class.
25
26     Returns:
27         tuple[int, Move]: The best score and the best move found.
28         """
29         hash = board.to_hash()
30         score, move = self._table.get_entry(hash, depth, alpha, beta)
31
32         if score is not None:
33             self._stats['cache_hits'] += 1
34             self._stats['nodes'] += 1
35
36         return score, move
37     else:
38         # If board hash entry not found in cache, run a full search
39         score, move = super().search(board, depth, alpha, beta, stop_event,
40             hint)
41         self._table.insert_entry(score, move, hash, depth, alpha, beta)
42
43     return score, move
44
45 class TTMinimaxCPU(TranspositionTableMixin, ABMinimaxCPU):
46     def initialise_stats(self):
47         """
48             Initialises cache statistics to be logged.
49         """
50         super().initialise_stats()
51         self._stats['cache_hits'] = 0
52
53     def print_stats(self, score, move):
54         """
55             Logs the statistics for the search.
56
57         Args:
58             score (int): The best score found.
59             move (Move): The best move found.
60             """
61             # Calculate number of cached entries retrieved as a percentage of all
62             nodes

```

3.6.4 Evaluator

evaluator.py

```

1  from data.utils.bitboard_helpers import pop_count, occupied_squares,
2      bitboard_to_index
3  from data.states.game.components.psqt import PSQT, FLIP
4  from data.managers.logs import initialise_logger
5  from data.constants import Colour, Piece, Score
6
7  logger = initialise_logger(__name__)
8
8  class Evaluator:
9      def __init__(self, verbose=True):
10          self._verbose = verbose

```

```

11
12     def evaluate(self, board, absolute=False):
13         """
14             Evaluates and returns a numerical score for the board state.
15
16         Args:
17             board (Board): The current board state.
18             absolute (bool): Whether to always return the absolute score from the
19             active colour's perspective (for NegaMax).
20
21         Returns:
22             int: Score representing advantage/disadvantage for the player.
23         """
24         blue_score = (
25             self.evaluate_material(board, Colour.BLUE),
26             self.evaluate_position(board, Colour.BLUE),
27             self.evaluate_mobility(board, Colour.BLUE),
28             self.evaluate_pharaoh_safety(board, Colour.BLUE)
29         )
30
31         red_score = (
32             self.evaluate_material(board, Colour.RED),
33             self.evaluate_position(board, Colour.RED),
34             self.evaluate_mobility(board, Colour.RED),
35             self.evaluate_pharaoh_safety(board, Colour.RED)
36         )
37
38         if self._verbose:
39             logger.info(f'Material: {blue_score[0]} | {red_score[0]}')
40             logger.info(f'Position: {blue_score[1]} | {red_score[1]}')
41             logger.info(f'Mobility: {blue_score[2]} | {red_score[2]}')
42             logger.info(f'Safety: {blue_score[3]} | {red_score[3]}')
43             logger.info(f'Overall score: {sum(blue_score) - sum(red_score)}')
44
45         if absolute and board.get_active_colour() == Colour.RED:
46             return sum(red_score) - sum(blue_score)
47         else:
48             return sum(blue_score) - sum(red_score)
49
50     def evaluate_material(self, board, colour):
51         """
52             Evaluates the material score for a given colour.
53
54         Args:
55             board (Board): The current board state.
56             colour (Colour): The colour to evaluate.
57
58         Returns:
59             int: Sum of all piece scores.
60         """
61         return (
62             Score.SPHINX * board.bitboards.get_piece_count(Piece.SPHINX, colour) +
63             Score.PYRAMID * board.bitboards.get_piece_count(Piece.PYRAMID, colour)
64             +
65             Score.ANUBIS * board.bitboards.get_piece_count(Piece.ANUBIS, colour) +
66             Score.SCARAB * board.bitboards.get_piece_count(Piece.SCARAB, colour)
67         )
68
69     def evaluate_position(self, board, colour):
70         """
71             Evaluates the positional score for a given colour.

```

```

71     Args:
72         board (Board): The current board state.
73         colour (Colour): The colour to evaluate.
74
75     Returns:
76         int: Score representing positional advantage/disadvantage.
77     """
78     score = 0
79
80     for piece in Piece:
81         if piece == Piece.SPHINX:
82             continue
83
84         piece_bitboard = board.bitboards.get_piece_bitboard(piece, colour)
85
86         for bitboard in occupied_squares(piece_bitboard):
87             index = bitboard_to_index(bitboard)
88             # Flip PSQT if using from blue player's perspective
89             index = FLIP[index] if colour == Colour.BLUE else index
90
91             score += PSQT[piece][index] * Score.POSITION
92
93     return score
94
95 def evaluate_mobility(self, board, colour):
96     """
97     Evaluates the mobility score for a given colour.
98
99     Args:
100        board (Board): The current board state.
101        colour (Colour): The colour to evaluate.
102
103    Returns:
104        int: Score on numerical representation of mobility.
105    """
106    number_of_moves = board.get_mobility(colour)
107    return number_of_moves * Score.MOVE
108
109 def evaluate_pharaoh_safety(self, board, colour):
110     """
111     Evaluates the safety of the Pharaoh for a given colour.
112
113     Args:
114         board (Board): The current board state.
115         colour (Colour): The colour to evaluate.
116
117     Returns:
118         int: Score representing mobility of the Pharaoh.
119     """
120     pharaoh_bitboard = board.bitboards.get_piece_bitboard(Piece.PHAROAH,
121     colour)
122
123     if pharaoh_bitboard:
124         pharaoh_available_moves = pop_count(board.get_valid_squares(
125         pharaoh_bitboard, colour))
126         return (8 - pharaoh_available_moves) * Score.PHAROAH_SAFETY
127     else:
128         return 0

```

3.6.5 Multithreading

A CPUPhase is initialised with a CPU engine at the start of the game state, and run whenever it is the CPU's turn to move.

cpu_thread.py

```

1 import threading
2 import time
3 from data.managers.logs import initialise_logger
4
5 logger = initialise_logger(__name__)
6
7 class CPUPhase(threading.Thread):
8     def __init__(self, cpu, verbose=False):
9         super().__init__()
10        self._stop_event = threading.Event()
11        self._running = True
12        self._verbose = verbose
13        self.daemon = True
14
15        self._board = None
16        self._cpu = cpu
17
18    def kill_thread(self):
19        """
20            Kills the CPU and terminates the thread by stopping the run loop.
21        """
22        self.stop_cpu()
23        self._running = False
24
25    def stop_cpu(self):
26        """
27            Kills the CPU's move search.
28        """
29        self._stop_event.set()
30        self._board = None
31
32    def start_cpu(self, board):
33        """
34            Starts the CPU's move search.
35
36            Args:
37                board (Board): The current board state.
38        """
39        self._stop_event.clear()
40        self._board = board
41
42    def run(self):
43        """
44            Periodically checks if the board variable is set.
45            If it is, then starts CPU search.
46        """
47        while self._running:
48            if self._board and self._cpu:
49                self._cpu.find_move(self._board, self._stop_event)
50                self.stop_cpu()
51            else:
52                time.sleep(1)
53                if self._verbose:
54                    logger.debug(f'(CPUPhase.run) Thread {threading.get_native_id()} idling...')
```

3.6.6 Zobrist Hashing

`zobrist_hasher.py`

```

1  from random import randint
2  from data.utils.bitboard_helpers import bitboard_to_index
3  from data.constants import Piece, Colour, Rotation
4
5  # Initialise random values for each piece type on every square
6  # (5 x 2 colours) pieces + 4 rotations, for 80 squares
7  zobrist_table = [[randint(0, 2 ** 64) for i in range(14)] for j in range(80)]
8  # Hash for when the red player's move
9  red_move_hash = randint(0, 2 ** 64)
10
11 # Maps piece to the correct random value
12 piece_lookup = {
13     Colour.BLUE: {
14         piece: i for i, piece in enumerate(Piece)
15     },
16     Colour.RED: {
17         piece: i + 5 for i, piece in enumerate(Piece)
18     },
19 }
20
21 # Maps rotation to the correct random value
22 rotation_lookup = {
23     rotation: i + 10 for i, rotation in enumerate(Rotation)
24 }
25
26 class ZobristHasher:
27     def __init__(self):
28         self.hash = 0
29
30     def get_piece_hash(self, index, piece, colour):
31         """
32             Gets the random value for the piece type on the given square.
33
34         Args:
35             index (int): The index of the square.
36             piece (Piece): The piece on the square.
37             colour (Colour): The colour of the piece.
38
39         Returns:
40             int: A 64-bit value.
41         """
42         piece_index = piece_lookup[colour][piece]
43         return zobrist_table[index][piece_index]
44
45     def get_rotation_hash(self, index, rotation):
46         """
47             Gets the random value for theon the given square.
48
49         Args:
50             index (int): The index of the square.
51             rotation (Rotation): The rotation on the square.
52             colour (Colour): The colour of the piece.
53
54         Returns:
55             int: A 64-bit value.
56         """
57         rotation_index = rotation_lookup[rotation]
58         return zobrist_table[index][rotation_index]
```

```

59
60     def apply_piece_hash(self, bitboard, piece, colour):
61         """
62             Updates the Zobrist hash with a new piece.
63
64             Args:
65                 bitboard (int): The bitboard representation of the square.
66                 piece (Piece): The piece on the square.
67                 colour (Colour): The colour of the piece.
68         """
69         index = bitboard_to_index(bitboard)
70         piece_hash = self.get_piece_hash(index, piece, colour)
71         self.hash ^= piece_hash
72
73     def apply_rotation_hash(self, bitboard, rotation):
74         """Updates the Zobrist hash with a new rotation.
75
76             Args:
77                 bitboard (int): The bitboard representation of the square.
78                 rotation (Rotation): The rotation on the square.
79         """
80         index = bitboard_to_index(bitboard)
81         rotation_hash = self.get_rotation_hash(index, rotation)
82         self.hash ^= rotation_hash
83
84     def apply_red_move_hash(self):
85         """
86             Applies the Zobrist hash for the red player's move.
87         """
88         self.hash ^= red_move_hash

```

3.6.7 Cache

transposition_table.py

```

1 from data.constants import TranspositionFlag
2
3 class TranspositionEntry:
4     def __init__(self, score, move, flag, hash_key, depth):
5         self.score = score
6         self.move = move
7         self.flag = flag
8         self.hash_key = hash_key
9         self.depth = depth
10
11 class TranspositionTable:
12     def __init__(self, max_entries=100000):
13         self._max_entries = max_entries
14         self._table = dict()
15
16     def calculate_entry_index(self, hash_key):
17         """
18             Gets the dictionary key for a given Zobrist hash.
19
20             Args:
21                 hash_key (int): A Zobrist hash.
22
23             Returns:
24                 int: Key for the given hash.
25         """
26         # return hash_key % self._max_entries

```

```

27         return hash_key
28
29     def insert_entry(self, score, move, hash_key, depth, alpha, beta):
30         """
31             Inserts an entry into the transposition table.
32
33         Args:
34             score (int): The evaluation score.
35             move (Move): The best move found.
36             hash_key (int): The Zobrist hash key.
37             depth (int): The depth of the search.
38             alpha (int): The upper bound value.
39             beta (int): The lower bound value.
40
41         Raises:
42             Exception: Invalid depth or score.
43         """
44         if depth == 0 or alpha < score < beta:
45             flag = TranspositionFlag.EXACT
46             score = score
47         elif score <= alpha:
48             flag = TranspositionFlag.UPPER
49             score = alpha
50         elif score >= beta:
51             flag = TranspositionFlag.LOWER
52             score = beta
53         else:
54             raise Exception('(TranspositionTable.insert_entry)')
55
56         self._table[self.calculate_entry_index(hash_key)] = TranspositionEntry(
57             score, move, flag, hash_key, depth)
58
59         if len(self._table) > self._max_entries:
60             # Removes the longest-existing entry to free up space for more up-to-
61             # date entries
62             # Expression to remove leftmost item taken from https://docs.python.
63             # org/3/library/collections.html#ordereddict-objects
64             (k := next(iter(self._table))), self._table.pop(k))
65
66     def get_entry(self, hash_key, depth, alpha, beta):
67         """
68             Gets an entry from the transposition table.
69
70         Args:
71             hash_key (int): The Zobrist hash key.
72             depth (int): The depth of the search.
73             alpha (int): The alpha value for pruning.
74             beta (int): The beta value for pruning.
75
76         Returns:
77             tuple[int, Move] | tuple[None, None]: The evaluation score and the
78             best move found, if entry exists.
79         """
80         index = self.calculate_entry_index(hash_key)
81
82         if index not in self._table:
83             return None, None
84
85         entry = self._table[index]
86
87         if entry.hash_key == hash_key and entry.depth >= depth:
88             if entry.flag == TranspositionFlag.EXACT:

```

```

85             return entry.score, entry.move
86
87         if entry.flag == TranspositionFlag.LOWER and entry.score >= beta:
88             return entry.score, entry.move
89
90         if entry.flag == TranspositionFlag.UPPER and entry.score <= alpha:
91             return entry.score, entry.move
92
93     return None, None

```

3.7 States

Every state class calls their `startup` method when switched to, and `cleanup` when exited. Within the `startup` function, the state widgets dictionary is passed into a `WidgetGroup` object. The `process_event` method is called on the `WidgetGroup` every frame to process user input, and handle the returned events accordingly. The `WidgetGroup` object can therefore be thought of as a controller, and the state as the model, and the widgets as the view.

3.7.1 Review

The `Review` state uses this logic to allow users to scroll through moves in their past games.
`review.py`

```

1 import pygame
2 from collections import deque
3 from data.states.game.components.capture_draw import CaptureDraw
4 from data.states.game.components.piece_group import PieceGroup
5 from data.constants import ReviewEventType, Colour, ShaderType
6 from data.states.game.components.laser_draw import LaserDraw
7 from data.utils.bitboard_helpers import bitboard_to_coords
8 from data.states.review.widget_dict import REVIEW_WIDGETS
9 from data.utils.browser_helpers import get_winner_string
10 from data.states.game.components.board import Board
11 from data.components.game_entry import GameEntry
12 from data.managers.logs import initialise_logger
13 from data.managers.window import window
14 from data.control import _State
15 from data.assets import MUSIC
16
17 logger = initialise_logger(__name__)
18
19 class Review(_State):
20     def __init__(self):
21         super().__init__()
22
23         self._moves = deque()
24         self._popped_moves = deque()
25         self._game_info = {}
26
27         self._board = None
28         self._piece_group = None
29         self._laser_draw = None
30         self._capture_draw = None
31
32     def cleanup(self):
33         """
34             Cleanup function. Clears shader effects.
35         """

```

```

36         super().cleanup()
37
38     window.clear_apply_arguments(ShaderType.BLOOM)
39     window.clear_effect(ShaderType.RAYS)
40
41     return None
42
43     def startup(self, persist):
44         """
45             Startup function. Initialises all objects, widgets and game data.
46
47             Args:
48                 persist (dict): Dict containing game entry data.
49
50             super().startup(REVIEW_WIDGETS, MUSIC['review'])
51
52             window.set_apply_arguments(ShaderType.BASE, background_type=ShaderType.
53 BACKGROUND_WAVES)
53             window.set_apply_arguments(ShaderType.BLOOM, highlight_colours=[(pygame.
54 Color('0x95e0cc')).rgb, pygame.Color('0xf14e52').rgb], colour_intensity=0.8)
54             REVIEW_WIDGETS['help'].kill()
55
56             self._moves = deque(GameEntry.parse_moves(persist.pop('moves', '')))
57             self._popped_moves = deque()
58             self._game_info = persist
59
60             self._board = Board(self._game_info['start_fen_string'])
61             self._piece_group = PieceGroup()
62             self._laser_draw = LaserDraw(self.board_position, self.board_size)
63             self._capture_draw = CaptureDraw(self.board_position, self.board_size)
64
65             self.initialise_widgets()
66             self.simulate_all_moves()
67             self.refresh_pieces()
68             self.refresh_widgets()
69
70             self.draw()
71
72     @property
73     def board_position(self):
74         return REVIEW_WIDGETS['chessboard'].position
75
76     @property
77     def board_size(self):
78         return REVIEW_WIDGETS['chessboard'].size
79
80     @property
81     def square_size(self):
82         return self.board_size[0] / 10
83
84     def initialise_widgets(self):
85         """
86             Initializes the widgets for a new game.
87         """
88         REVIEW_WIDGETS['move_list'].reset_move_list()
89         REVIEW_WIDGETS['move_list'].kill()
90         REVIEW_WIDGETS['scroll_area'].set_image()
91
91         REVIEW_WIDGETS['winner_text'].set_text(f'WINNER: {get_winner_string(self.
92             _game_info["winner"])}')
93         REVIEW_WIDGETS['blue_piece_display'].reset_piece_list()
94         REVIEW_WIDGETS['red_piece_display'].reset_piece_list()

```

```

95         if self._game_info['time_enabled']:
96             REVIEW_WIDGETS['timer_disabled_text'].kill()
97         else:
98             REVIEW_WIDGETS['blue_timer'].kill()
99             REVIEW_WIDGETS['red_timer'].kill()
100
101     def refresh_widgets(self):
102         """
103             Refreshes the widgets after every move.
104         """
105
106         REVIEW_WIDGETS['move_number_text'].set_text(f'MOVE NO: {(len(self._moves))
107 / 2:.1f} / {(len(self._moves) + len(self._popped_moves)) / 2:.1f}')
108         REVIEW_WIDGETS['move_colour_text'].set_text(f'{self.calculate_colour().name} TO MOVE')
109
110         if self._game_info['time_enabled']:
111             if len(self._moves) == 0:
112                 REVIEW_WIDGETS['blue_timer'].set_time(float(self._game_info['time'])
113 ] * 60 * 1000)
114                 REVIEW_WIDGETS['red_timer'].set_time(float(self._game_info['time']
115 ]) * 60 * 1000)
116             else:
117                 REVIEW_WIDGETS['blue_timer'].set_time(float(self._moves[-1]['
blue_time']) * 60 * 1000)
118                 REVIEW_WIDGETS['red_timer'].set_time(float(self._moves[-1]['
red_time']) * 60 * 1000)
119
120         REVIEW_WIDGETS['scroll_area'].set_image()
121
122     def refresh_pieces(self):
123         """
124             Refreshes the pieces on the board.
125         """
126
127         self._piece_group.initialise_pieces(self._board.get_piece_list(), self.
128 board_position, self.board_size)
129
130     def simulate_all_moves(self):
131         """
132             Simulates all moves at the start of every game to obtain laser results and
133             fill up piece display and move list widgets.
134         """
135
136         for index, move_dict in enumerate(self._moves):
137             laser_result = self._board.apply_move(move_dict['move'], fire_laser=
138 True)
139             self._moves[index]['laser_result'] = laser_result
140
141             if laser_result.hit_square_bitboard:
142                 if laser_result.piece_colour == Colour.BLUE:
143                     REVIEW_WIDGETS['red_piece_display'].add_piece(laser_result.
144 piece_hit)
145                 elif laser_result.piece_colour == Colour.RED:
146                     REVIEW_WIDGETS['blue_piece_display'].add_piece(laser_result.
147 piece_hit)
148
149             REVIEW_WIDGETS['move_list'].append_to_move_list(move_dict['
unparsed_move'])
150
151     def calculate_colour(self):
152         """
153             Calculates the current active colour to move.
154

```

```
145     Returns:
146         Colour: The current colour to move.
147     """
148     if self._game_info['start_fen_string'][-1].lower() == 'b':
149         initial_colour = Colour.BLUE
150     elif self._game_info['start_fen_string'][-1].lower() == 'r':
151         initial_colour = Colour.RED
152
153     if len(self._moves) % 2 == 0:
154         return initial_colour
155     else:
156         return initial_colour.get_flipped_colour()
157
158     def handle_move(self, move, add_piece=True):
159         """
160             Handles applying or undoing a move.
161
162             Args:
163                 move (dict): The move to handle.
164                 add_piece (bool): Whether to add the captured piece to the display.
165             Defaults to True.
166         """
167         laser_result = move['laser_result']
168         active_colour = self.calculate_colour()
169         self._laser_draw.add_laser(laser_result, laser_colour=active_colour)
170
171         if laser_result.hit_square_bitboard:
172             if laser_result.piece_colour == Colour.BLUE:
173                 if add_piece:
174                     REVIEW_WIDGETS['red_piece_display'].add_piece(laser_result,
175                                         piece_hit)
176                 else:
177                     REVIEW_WIDGETS['red_piece_display'].remove_piece(laser_result,
178                                         piece_hit)
179             elif laser_result.piece_colour == Colour.RED:
180                 if add_piece:
181                     REVIEW_WIDGETS['blue_piece_display'].add_piece(laser_result,
182                                         piece_hit)
183                 else:
184                     REVIEW_WIDGETS['blue_piece_display'].remove_piece(laser_result
185                                         .piece_hit)
186
187         self._capture_draw.add_capture(
188             laser_result.piece_hit,
189             laser_result.piece_colour,
190             laser_result.piece_rotation,
191             bitboard_to_coords(laser_result.hit_square_bitboard),
192             laser_result.laser_path[0][0],
193             active_colour,
194             shake=False
195         )
196
197     def update_laser_mask(self):
198         """
199             Updates the laser mask for the light rays effect.
200         """
201         temp_surface = pygame.Surface(window.size, pygame.SRCALPHA)
202         self._piece_group.draw(temp_surface)
203         mask = pygame.mask.from_surface(temp_surface, threshold=127)
204         mask_surface = mask.to_surface(unsetcolor=(0, 0, 0, 255), setcolor=(255,
```

```

201         window.set_apply_arguments(ShaderType.RAYS, occlusion=mask_surface)
202
203     def get_event(self, event):
204         """
205         Processes Pygame events.
206
207         Args:
208             event (pygame.event.Event): The event to handle.
209
210         if event.type in [pygame.MOUSEBUTTONUP, pygame.KEYDOWN]:
211             REVIEW_WIDGETS['help'].kill()
212
213         widget_event = self._widget_group.process_event(event)
214
215         if widget_event is None:
216             return
217
218         match widget_event.type:
219             case None:
220                 return
221
222             case ReviewEventType.MENU_CLICK:
223                 self.next = 'menu'
224                 self.done = True
225
226             case ReviewEventType.PREVIOUS_CLICK:
227                 if len(self._moves) == 0:
228                     return
229
230                 # Pop last applied move off first stack
231                 move = self._moves.pop()
232                 # Pushed onto second stack
233                 self._popped_moves.append(move)
234
235                 # Undo last applied move
236                 self._board.undo_move(move['move'], laser_result=move['laser_result'])
237                 self.handle_move(move, add_piece=False)
238                 REVIEW_WIDGETS['move_list'].pop_from_move_list()
239
240                 self.refresh_pieces()
241                 self.refresh_widgets()
242                 self.update_laser_mask()
243
244             case ReviewEventType.NEXT_CLICK:
245                 if len(self._popped_moves) == 0:
246                     return
247
248                 # Peek at second stack to get last undone move
249                 move = self._popped_moves[-1]
250
251                 # Reapply last undone move
252                 self._board.apply_move(move['move'])
253                 self.handle_move(move, add_piece=True)
254                 REVIEW_WIDGETS['move_list'].append_to_move_list(move['unparsed_move'])
255
256                 # Pop last undone move from second stack
257                 self._popped_moves.pop()
258                 # Push onto first stack
259                 self._moves.append(move)
260

```

```

261         self.refresh_pieces()
262         self.refresh_widgets()
263         self.update_laser_mask()
264
265     case ReviewEventType.HELP_CLICK:
266         self._widget_group.add(REVIEW_WIDGETS['help'])
267         self._widget_group.handle_resize(window.size)
268
269     def handle_resize(self):
270         """
271             Handles resizing of the window.
272         """
273         super().handle_resize()
274         self._piece_group.handle_resize(self.board_position, self.board_size)
275         self._laser_draw.handle_resize(self.board_position, self.board_size)
276         self._capture_draw.handle_resize(self.board_position, self.board_size)
277
278         if self._laser_draw.firing:
279             self.update_laser_mask()
280
281     def draw(self):
282         """
283             Draws all components onto the window screen.
284         """
285         self._capture_draw.update()
286         self._widget_group.draw()
287         self._piece_group.draw(window.screen)
288         self._laser_draw.draw(window.screen)
289         self._capture_draw.draw(window.screen)

```

3.8 Database

This section outlines my database implementation using Python sqlite3.

3.8.1 DDL

As mentioned in Section 2.3.1, the `migrations` directory contains a collection of Python scripts that edit the game table schema. The files are named with their changes and datetime labelled for organisational purposes.

`create_games_table_19112024.py`

```

1 import sqlite3
2 from pathlib import Path
3
4 database_path = (Path(__file__).parent / '../database.db').resolve()
5
6 def upgrade():
7     """
8         Upgrade function to create games table.
9     """
10    connection = sqlite3.connect(database_path)
11    cursor = connection.cursor()
12
13    cursor.execute('''
14        CREATE TABLE games(
15            id INTEGER PRIMARY KEY,
16            cpu_enabled INTEGER NOT NULL,
17            cpu_depth INTEGER,

```

```

18         winner INTEGER,
19         time_enabled INTEGER NOT NULL,
20         time REAL,
21         number_of_ply INTEGER NOT NULL,
22         moves TEXT NOT NULL
23     )
24 )
25
26     connection.commit()
27     connection.close()
28
29 def downgrade():
30     """
31     Downgrade function to revert table creation.
32     """
33     connection = sqlite3.connect(database_path)
34     cursor = connection.cursor()
35
36     cursor.execute('''
37         DROP TABLE games
38     ''')
39
40     connection.commit()
41     connection.close()
42
43 upgrade()
44 # downgrade()

```

Using the ALTER command allows me to rename table columns.

```

change_fen_string_column_name_23122024.py
1 import sqlite3
2 from pathlib import Path
3
4 database_path = (Path(__file__).parent / '../database.db').resolve()
5
6 def upgrade():
7     """
8     Upgrade function to rename fen_string column.
9     """
10    connection = sqlite3.connect(database_path)
11    cursor = connection.cursor()
12
13    cursor.execute('''
14        ALTER TABLE games RENAME COLUMN fen_string TO final_fen_string
15    ''')
16
17    connection.commit()
18    connection.close()
19
20 def downgrade():
21     """
22     Downgrade function to revert fen_string column renaming.
23     """
24    connection = sqlite3.connect(database_path)
25    cursor = connection.cursor()
26
27    cursor.execute('''
28        ALTER TABLE games RENAME COLUMN final_fen_string TO fen_string
29    ''')
30

```

```
31     connection.commit()
32     connection.close()
33
34 upgrade()
35 # downgrade()
```

3.8.2 DML

```
database_helpers.py

1 import sqlite3
2 from pathlib import Path
3 from datetime import datetime
4
5 database_path = (Path(__file__).parent / '../database/database.db').resolve()
6
7 def insert_into_games(game_entry):
8     """
9     Inserts a new row into games table.
10
11    Args:
12        game_entry (GameEntry): GameEntry object containing game information.
13    """
14    connection = sqlite3.connect(database_path, detect_types=sqlite3.
15        PARSE_DECLTYPES)
16    connection.row_factory = sqlite3.Row
17    cursor = connection.cursor()
18
19    # Datetime added for created_dt column
20    game_entry = (*game_entry, datetime.now())
21
22    cursor.execute('''
23        INSERT INTO games (cpu_enabled, cpu_depth, winner, time_enabled, time,
24        number_of_ply, moves, start_fen_string, final_fen_string, created_dt)
25        VALUES (?, ?, ?, ?, ?, ?, ?, ?, ?, ?)
26        ''', game_entry)
27
28    connection.commit()
29
30    # Return inserted row
31    cursor.execute('''
32        SELECT * FROM games WHERE id = LAST_INSERT_ROWID()
33    ''')
34    inserted_row = cursor.fetchone()
35
36    connection.close()
37
38    return dict(inserted_row)
39
40 def get_all_games():
41     """
42     Get all rows in games table.
43
44     Returns:
45         list[dict]: List of game entries represented as dictionaries.
46     """
47     connection = sqlite3.connect(database_path, detect_types=sqlite3.
48        PARSE_DECLTYPES)
49     connection.row_factory = sqlite3.Row
50     cursor = connection.cursor()
```

```

49     cursor.execute('''
50         SELECT * FROM games
51     ''')
52     games = cursor.fetchall()
53
54     connection.close()
55
56     return [dict(game) for game in games]
57
58 def delete_all_games():
59     """
60     Delete all rows in games table.
61     """
62     connection = sqlite3.connect(database_path)
63     cursor = connection.cursor()
64
65     cursor.execute('''
66         DELETE FROM games
67     ''')
68
69     connection.commit()
70     connection.close()
71
72 def delete_game(id):
73     """
74     Deletes specific row in games table using id attribute.
75
76     Args:
77         id (int): Primary key for row.
78     """
79     connection = sqlite3.connect(database_path)
80     cursor = connection.cursor()
81
82     cursor.execute('''
83         DELETE FROM games WHERE id = ?
84     ''', (id,))
85
86     connection.commit()
87     connection.close()
88
89 def get_ordered_games(column, ascend=True, start_row=1, end_row=10):
90     """
91     Get specific number of rows from games table ordered by a specific column(s).
92
93     Args:
94         column (_type_): Column to sort by.
95         ascend (bool, optional): Sort ascending or descending. Defaults to True.
96         start_row (int, optional): First row returned. Defaults to 1.
97         end_row (int, optional): Last row returned. Defaults to 10.
98
99     Raises:
100         ValueError: If ascend argument or column argument are invalid types.
101
102     Returns:
103         list[dict]: List of ordered game entries represented as dictionaries.
104     """
105     if not isinstance(ascend, bool) or not isinstance(column, str):
106         raise ValueError('database_helpers.get_ordered_games) Invalid input arguments!')
107
108     connection = sqlite3.connect(database_path, detect_types=sqlite3.
PARSE_DECLTYPES)

```

```

109     connection.row_factory = sqlite3.Row
110     cursor = connection.cursor()
111
112     # Match ascend bool to correct SQL keyword
113     if ascend:
114         ascend_arg = 'ASC'
115     else:
116         ascend_arg = 'DESC'
117
118     # Partition by winner, then order by time and number_of_ply
119     if column == 'winner':
120         cursor.execute(f'''
121             SELECT * FROM
122                 (SELECT ROW_NUMBER() OVER (
123                     PARTITION BY winner
124                     ORDER BY time {ascend_arg}, number_of_ply {ascend_arg}
125                 ) AS row_num, * FROM games)
126             WHERE row_num >= ? AND row_num <= ?
127             ''', (start_row, end_row))
128     else:
129         # Order by time or number_of_ply only
130         cursor.execute(f'''
131             SELECT * FROM
132                 (SELECT ROW_NUMBER() OVER (
133                     ORDER BY {column} {ascend_arg}
134                 ) AS row_num, * FROM games)
135             WHERE row_num >= ? AND row_num <= ?
136             ''', (start_row, end_row))
137
138     games = cursor.fetchall()
139
140     connection.close()
141
142     return [dict(game) for game in games]
143
144 def get_number_of_games():
145     """
146     Returns:
147         int: Number of rows in the games.
148     """
149     connection = sqlite3.connect(database_path)
150     cursor = connection.cursor()
151
152     cursor.execute("""
153         SELECT COUNT(ROWID) FROM games
154     """)
155
156     result = cursor.fetchall()[0][0]
157
158     connection.close()
159
160     return result
161
162 # delete_all_games()

```

3.9 Shaders

3.9.1 Shader Manager

The `ShaderManager` class is responsible for handling all shader passes, handling the Pygame display, and combining both and drawing the result to the window screen. The class also inherits from the `SMPProtocol` class, an interface class containing all required `ShaderManager` methods and attributes to aid with syntax highlighting in the fragment shader classes.

Fragment shaders such as `Bloom` are applied by default, and others such as `Ray` are applied during runtime through calling methods on `shaderManager`, and adding the appropriate fragment shader class to the internal shader pass list.

`shader.py`

```

1  from pathlib import Path
2  from array import array
3  import moderngl
4  from data.shaders.classes import shader_pass_lookup
5  from data.shaders.protocol import SMPProtocol
6  from data.constants import ShaderType
7
8  shader_path = (Path(__file__).parent / '../shaders/').resolve()
9
10 SHADER_PRIORITY = [
11     ShaderType.CRT,
12     ShaderType.SHAKE,
13     ShaderType.BLOOM,
14     ShaderType.CHROMATIC_ABBREVIATION,
15     ShaderType.RAYS,
16     ShaderType.GRAYSCALE,
17     ShaderType.BASE,
18 ]
19
20 pygame_quad_array = array('f', [
21     -1.0, 1.0, 0.0, 0.0,
22     1.0, 1.0, 0.0, 0.0,
23     -1.0, -1.0, 0.0, 1.0,
24     1.0, -1.0, 1.0, 1.0,
25 ])
26
27 opengl_quad_array = array('f', [
28     -1.0, -1.0, 0.0, 0.0,
29     1.0, -1.0, 1.0, 0.0,
30     -1.0, 1.0, 0.0, 1.0,
31     1.0, 1.0, 1.0, 1.0,
32 ])
33
34 class ShaderManager(SMPProtocol):
35     def __init__(self, ctx: moderngl.Context, screen_size):
36         self._ctx = ctx
37         self._ctx.gc_mode = 'auto'
38
39         self._screen_size = screen_size
40         self._opengl_buffer = self._ctx.buffer(data=opengl_quad_array)
41         self._pygame_buffer = self._ctx.buffer(data=pygame_quad_array)
42         self._shader_list = [ShaderType.BASE]
43
44         self._vert_shaders = {}
45         self._frag_shaders = {}
46         self._programs = {}
47         self._vaos = {}

```

```

48         self._textures = {}
49         self._shader_passes = {}
50         self.framebuffers = {}
51
52         self.load_shader(ShaderType.BASE)
53         self.load_shader(ShaderType._CALIBRATE)
54         self.create_framebuffer(ShaderType._CALIBRATE)
55
56     def load_shader(self, shader_type, **kwargs):
57         """
58             Loads a given shader by creating a VAO reading the corresponding .frag
59             file.
60
61             Args:
62                 shader_type (ShaderType): The type of shader to load.
63                 **kwargs: Additional arguments passed when initialising the fragment
64             shader class.
65
66             self._shader_passes[shader_type] = shader_pass_lookup[shader_type](self,
67             **kwargs)
68             self.create_vao(shader_type)
69
70     def clear_shaders(self):
71         """
72             Clears the shader list, leaving only the base shader.
73
74             self._shader_list = [ShaderType.BASE]
75
76     def create_vao(self, shader_type):
77         """
78             Creates a vertex array object (VAO) for the given shader type.
79
80             Args:
81                 shader_type (ShaderType): The type of shader.
82
83             frag_name = shader_type[1:] if shader_type[0] == '_' else shader_type
84             vert_path = Path(shader_path / 'vertex/base.vert').resolve()
85             frag_path = Path(shader_path / f'fragments/{frag_name}.frag').resolve()
86
87             self._vert_shaders[shader_type] = vert_path.read_text()
88             self._frag_shaders[shader_type] = frag_path.read_text()
89
90             program = self._ctx.program(vertex_shader=self._vert_shaders[shader_type],
91             fragment_shader=self._frag_shaders[shader_type])
92             self._programs[shader_type] = program
93
94             if shader_type == ShaderType._CALIBRATE:
95                 self._vaos[shader_type] = self._ctx.vertex_array(self._programs[
96                     shader_type], [(self._pygame_buffer, '2f 2f', 'vert', 'texCoords')])
97             else:
98                 self._vaos[shader_type] = self._ctx.vertex_array(self._programs[
99                     shader_type], [(self._opengl_buffer, '2f 2f', 'vert', 'texCoords')]))
100
101     def create_framebuffer(self, shader_type, size=None, filter=moderngl.NEAREST):
102         """
103             Creates a framebuffer for the given shader type.
104
105             Args:
106                 shader_type (ShaderType): The type of shader.
107                 size (tuple[int, int], optional): The size of the framebuffer.
108                     Defaults to screen size.
109                 filter (moderngl.Filter, optional): The texture filter. Defaults to

```

```

    NEAREST.
103     """
104     texture_size = size or self._screen_size
105     texture = self._ctx.texture(size=texture_size, components=4)
106     texture.filter = (filter, filter)
107
108     self._textures[shader_type] = texture
109     self.framebuffers[shader_type] = self._ctx.framebuffer(color_attachments=[
110         self._textures[shader_type]])
111
112     def render_to_fbo(self, shader_type, texture, output_fbo=None, program_type=
113         None, use_image=True, **kwargs):
114         """
115             Applies the shaders and renders the resultant texture to a framebuffer
116             object (FBO).
117
118             Args:
119                 shader_type (ShaderType): The type of shader.
120                 texture (moderngl.Texture): The texture to render.
121                 output_fbo (moderngl.Framebuffer, optional): The output framebuffer.
122                     Defaults to None.
123                 program_type (ShaderType, optional): The program type. Defaults to
124                     None.
125                 use_image (bool, optional): Whether to use the image uniform. Defaults
126                     to True.
127                 **kwargs: Additional uniforms for the fragment shader.
128
129             fbo = output_fbo or self.framebuffers[shader_type]
130             program = self._programs[program_type] if program_type else self._programs
131             [shader_type]
132             vao = self._vaos[program_type] if program_type else self._vaos[shader_type]
133
134             fbo.use()
135             texture.use(0)
136
137             if use_image:
138                 program['image'] = 0
139                 for uniform, value in kwargs.items():
140                     program[uniform] = value
141
142             vao.render(mode=moderngl.TRIANGLE_STRIP)
143
144     def apply_shader(self, shader_type, **kwargs):
145         """
146             Applies a shader of the given type and adds it to the list.
147
148             Args:
149                 shader_type (ShaderType): The type of shader to apply.
150
151             Raises:
152                 ValueError: If the shader is already being applied.
153
154             if shader_type in self._shader_list:
155                 return
156
157             self.load_shader(shader_type, **kwargs)
158             self._shader_list.append(shader_type)
159
160             # Sort shader list based on the order in SHADER_PRIORITY, so that more
161             # important shaders are applied first
162             self._shader_list.sort(key=lambda shader: -SHADER_PRIORITY.index(shader))
163
164
165

```

```

156     def remove_shader(self, shader_type):
157         """
158             Removes a shader of the given type from the list.
159
160         Args:
161             shader_type (ShaderType): The type of shader to remove.
162         """
163         if shader_type in self._shader_list:
164             self._shader_list.remove(shader_type)
165
166     def render_output(self):
167         """
168             Renders the final output to the screen.
169         """
170         # Render to the screen framebuffer
171         self._ctx.screen.use()
172
173         # Take the texture of the last framebuffer to be rendered to, and render
174         # that to the screen framebuffer
175         output_shader_type = self._shader_list[-1]
176         self.get_fbo_texture(output_shader_type).use(0)
177         self._programs[output_shader_type]['image'] = 0
178
179         self._vaos[output_shader_type].render(mode=moderngl.TRIANGLE_STRIP)
180
181     def get_fbo_texture(self, shader_type):
182         """
183             Gets the texture from the specified shader type's FBO.
184
185         Args:
186             shader_type (ShaderType): The type of shader.
187
188         Returns:
189             moderngl.Texture: The texture from the FBO.
190
191         return self.framebuffers[shader_type].color_attachments[0]
192
193     def calibrate_pygame_surface(self, pygame_surface):
194         """
195             Converts the Pygame window surface into an OpenGL texture.
196
197         Args:
198             pygame_surface (pygame.Surface): The finished Pygame surface.
199
200         Returns:
201             moderngl.Texture: The calibrated texture.
202
203         texture = self._ctx.texture(pygame_surface.size, 4)
204         texture.filter = (moderngl.NEAREST, moderngl.NEAREST)
205         texture.swizzle = 'BGRA'
206         # Take the Pygame surface's pixel array and draw it to the new texture
207         texture.write(pygame_surface.get_view('1'))
208
209         # ShaderType._CALIBRATE has a VAO containing the pygame_quad_array
210         # coordinates, as Pygame uses different texture coordinates than ModernGL
211         # textures
212         self.render_to_fbo(ShaderType._CALIBRATE, texture)
213         return self.get_fbo_texture(ShaderType._CALIBRATE)
214
215     def draw(self, surface, arguments):
216         """
217             Draws the Pygame surface with shaders applied to the screen.

```

```

215
216     Args:
217         surface (pygame.Surface): The final Pygame surface.
218         arguments (dict): A dict of { ShaderType: Args } items, containing
219             keyword arguments for every fragment shader.
220             """
221         self._ctx.viewport = (0, 0, *self._screen_size)
222         texture = self.calibrate_pygame_surface(surface)
223
224         for shader_type in self._shader_list:
225             self._shader_passes[shader_type].apply(texture, **arguments.get(
226                 shader_type, {}))
227             texture = self.get_fbo_texture(shader_type)
228
229         self.render_output()
230
231     def __del__(self):
232         """
233             Cleans up ModernGL resources when the ShaderManager object is deleted.
234             """
235         self.cleanup()
236
237     def cleanup(self):
238         """
239             Cleans up resources used by the ModernGL.
240             Probably unnecessary as the 'auto' garbage collection mode is used.
241             """
242         self._pygame_buffer.release()
243         self._opengl_buffer.release()
244         for program in self._programs:
245             self._programs[program].release()
246         for texture in self._textures:
247             self._textures[texture].release()
248         for vao in self._vaos:
249             self._vaos[vao].release()
250         for framebuffer in self.framebuffers:
251             self.framebuffers[framebuffer].release()
252
253     def handle_resize(self, new_screen_size):
254         """
255             Handles resizing of the screen.
256
257             Args:
258                 new_screen_size (tuple[int, int]): The new screen size.
259             """
260         self._screen_size = new_screen_size
261
262         # Recreate all framebuffers to prevent scaling issues
263         for shader_type in self.framebuffers:
264             filter = self._textures[shader_type].filter[0]
265             self.create_framebuffer(shader_type, size=self._screen_size, filter=
266             filter)

```

3.9.2 Bloom

The `Bloom` shader effect is a common shader effect giving the illusion of a bright light. It consists of blurred fringes of light extending from the borders of bright areas. This effect can be achieved through obtaining all bright areas of the image, applying a Gaussian blur, and blending the blur additively onto the original image.

My `ShaderManager` class works with this multi-pass shader approach by reading the texture from the last shader's framebuffer for each pass.

Extracting bright colours

The `highlight_brightness` fragment shader extracts all colours that are bright enough to exert the bloom effect.

`highlight_brightness.frag`

```

1 # version 330 core
2
3 in vec2 uvs;
4 out vec4 f_colour;
5
6 uniform sampler2D image;
7 uniform float threshold;
8 uniform float intensity;
9
10 void main() {
11     vec4 pixel = texture(image, uvs);
12     // Dot product used to calculate brightness of a pixel from its RGB values
13     // Values taken from https://en.wikipedia.org/wiki/Relative\_luminance
14     float brightness = dot(pixel.rgb, vec3(0.2126, 0.7152, 0.0722));
15     float isBright = step(threshold, brightness);
16
17     f_colour = vec4(vec3(pixel.rgb * intensity) * isBright, 1.0);
18 }
```

Blur

The `Blur` class implements a two-pass Gaussian blur. This is preferably over a one-pass blur, as the complexity is $O(2n)$, sampling n pixels twice, as opposed to $O(n^2)$. I have implemented this using the ping-pong technique, with the first pass for blurring the image horizontally, and the second pass for blurring vertically, and the resultant textures being passed repeatedly between two framebuffers.

`blur.py`

```

1 from data.shaders.protocol import SMProtocol
2 from data.constants import ShaderType
3
4 BLUR_ITERATIONS = 4
5
6 class _Blur:
7     def __init__(self, shader_manager: SMProtocol):
8         self._shader_manager = shader_manager
9
10        shader_manager.create_framebuffer(ShaderType._BLUR)
11
12        shader_manager.create_framebuffer("blurPing")
13        shader_manager.create_framebuffer("blurPong")
14
15    def apply(self, texture):
16        """
17            Applies Gaussian blur to a given texture.
18
19            Args:
20                texture (moderngl.Texture): Texture to blur.
21            """
22        self._shader_manager.get_fbo_texture("blurPong").write(texture.read())
```

```

23
24     for _ in range(BLUR_ITERATIONS):
25         # Apply horizontal blur
26         self._shader_manager.render_to_fbo(
27             ShaderType._BLUR,
28             texture=self._shader_manager.get_fbo_texture("blurPong"),
29             output_fbo=self._shader_manager.framebuffers["blurPing"],
30             passes=5,
31             horizontal=True
32         )
33         # Apply vertical blur
34         self._shader_manager.render_to_fbo(
35             ShaderType._BLUR,
36             texture=self._shader_manager.get_fbo_texture("blurPing"), # Use
37             horizontal blur result as input texture
38             output_fbo=self._shader_manager.framebuffers["blurPong"],
39             passes=5,
40             horizontal=False
41         )
42         self._shader_manager.render_to_fbo(ShaderType._BLUR, self._shader_manager.
43             get_fbo_texture("blurPong"))

```

blur.frag

```

1 // Modified from https://learnopengl.com/Advanced-Lighting/Bloom
2 #version 330 core
3
4 in vec2 uvs;
5 out vec4 f_colour;
6
7 uniform sampler2D image;
8 uniform bool horizontal;
9 uniform int passes;
10 uniform float weight[5] = float[] (0.227027, 0.1945946, 0.1216216, 0.054054,
11                                     0.016216);
12 void main() {
13     vec2 offset = 1.0 / textureSize(image, 0);
14     vec3 result = texture(image, uvs).rgb * weight[0];
15
16     if (horizontal) {
17         for (int i = 1 ; i < passes ; ++i) {
18             result += texture(image, uvs + vec2(offset.x * i, 0.0)).rgb * weight[i];
19         }
20     }
21     else {
22         for (int i = 1 ; i < passes ; ++i) {
23             result += texture(image, uvs + vec2(0.0, offset.y * i)).rgb * weight[i];
24         }
25         result += texture(image, uvs - vec2(0.0, offset.y * i)).rgb * weight[i];
26     }
27 }
28
29 f_colour = vec4(result, 1.0);
30 }

```

Combining

The `Bloom` class combines the two operations, taking the highlighted areas, blurs them, and adds the RGB values for the final result onto the original texture to simulate bloom.

`bloom.py`

```

1  from data.shaders.classes.highlight_brightness import _HighlightBrightness
2  from data.shaders.classes.highlight_colour import _HighlightColour
3  from data.shaders.protocol import SMProtocol
4  from data.shaders.classes.blur import _Blur
5  from data.constants import ShaderType
6
7  BLOOM_INTENSITY = 0.6
8
9  class Bloom:
10     def __init__(self, shader_manager: SMProtocol):
11         self._shader_manager = shader_manager
12
13         shader_manager.load_shader(ShaderType._BLUR)
14         shader_manager.load_shader(ShaderType._HIGHLIGHT_BRIGHTNESS)
15         shader_manager.load_shader(ShaderType._HIGHLIGHT_COLOUR)
16
17         shader_manager.create_framebuffer(ShaderType.BLOOM)
18         shader_manager.create_framebuffer(ShaderType._BLUR)
19         shader_manager.create_framebuffer(ShaderType._HIGHLIGHT_BRIGHTNESS)
20         shader_manager.create_framebuffer(ShaderType._HIGHLIGHT_COLOUR)
21
22     def apply(self, texture, highlight_surface=None, highlight_colours=[], surface_intensity=BLOOM_INTENSITY, brightness_intensity=BLOOM_INTENSITY, colour_intensity=BLOOM_INTENSITY):
23         """
24             Applies a bloom effect to a given texture.
25
26             Args:
27                 texture (moderngl.Texture): Texture to apply bloom to.
28                 highlight_surface (pygame.Surface, optional): Surface to use as the highlights. Defaults to None.
29                 highlight_colours (list[list[int, int, int]], optional): Colours to use as the highlights. Defaults to [].
30                 surface_intensity (_type_, optional): Intensity of bloom applied to the highlight surface. Defaults to BLOOM_INTENSITY.
31                 brightness_intensity (_type_, optional): Intensity of bloom applied to the highlight brightness. Defaults to BLOOM_INTENSITY.
32                 colour_intensity (_type_, optional): Intensity of bloom applied to the highlight colours. Defaults to BLOOM_INTENSITY.
33             """
34
35         if highlight_surface:
36             # Calibrate Pygame surface and apply blur
37             glare_texture = self._shader_manager.calibrate_pygame_surface(
38                 highlight_surface)
39             _Blur(self._shader_manager).apply(glare_texture)
40
41             self._shader_manager.get_fbo_texture(ShaderType._BLUR).use(1)
42             self._shader_manager.render_to_fbo(ShaderType.BLOOM, texture,
43                 blurredImage=1, intensity=surface_intensity)
44
45             # Set bloom-applied texture as the base texture
46             texture = self._shader_manager.get_fbo_texture(ShaderType.BLOOM)
47
48             # Extract bright colours (highlights) from the texture
49             _HighlightBrightness(self._shader_manager).apply(texture, intensity=
50                 brightness_intensity)

```

```

47     highlight_texture = self._shader_manager.get_fbo_texture(ShaderType.
48     _HIGHLIGHT_BRIGHTNESS)
49
50     # Use colour as highlights
51     for colour in highlight_colours:
52         _HighlightColour(self._shader_manager).apply(texture, old_highlight=
53             highlight_texture, colour=colour, intensity=colour.intensity)
54         highlight_texture = self._shader_manager.get_fbo_texture(ShaderType.
55     _HIGHLIGHT_COLOUR)
56
57     # Apply Gaussian blur to highlights
58     _Blur(self._shader_manager).apply(highlight_texture)
59
60     # Add the pixel values for the highlights onto the base texture
61     self._shader_manager.get_fbo_texture(ShaderType._BLUR).use(1)
62     self._shader_manager.render_to_fbo(ShaderType.BLOOM, texture, blurredImage
63     =1, intensity=BLOOM_INTENSITY)

```

3.9.3 Rays

The `Ray` shader is applied whenever the sphinx shoots a laser. It simulates a 2D light source, providing pixel perfect shadows, through the shadow mapping technique outlined in Section 2.2.5. The laser demo seen on the main menu screen is also achieved using the Ray shader, by clamping the angle at which it emits light to a narrower range.

Occlusion

The occlusion fragment shader processes all pixels with a given colour value as being occluding. `occlusion.frag`

```

1 # version 330 core
2
3 in vec2 uvs;
4 out vec4 f_colour;
5
6 uniform sampler2D image;
7 uniform vec3 checkColour;
8
9 void main() {
10     vec4 pixel = texture(image, uvs);
11
12     // If pixel is occluding colour, set pixel to white
13     if (pixel.rgb == checkColour) {
14         f_colour = vec4(1.0, 1.0, 1.0, 1.0);
15     // Else, set pixel to black
16     } else {
17         f_colour = vec4(vec3(0.0), 1.0);
18     }
19 }

```

Shadowmap

The shadowmap fragment shader takes the occluding texture and creates a 1D shadow map. `shadowmap.frag`

```

1 # version 330 core
2
3 #define PI 3.1415926536;

```

```

4
5  in vec2 uvs;
6  out vec4 f_colour;
7
8  uniform sampler2D image;
9  uniform float resolution;
10 uniform float THRESHOLD=0.99;
11
12 void main() {
13     float maxDistance = 1.0;
14
15     for (float y = 0.0 ; y < resolution ; y += 1.0) {
16         //rectangular to polar filter
17         float currDistance = y / resolution;
18
19         vec2 norm = vec2(uvs.x, currDistance) * 2.0 - 1.0; // Range from [0, 1] ->
19 [-1, 1]
20         float angle = (1.5 - norm.x) * PI; // Range from [-1, 1] -> [0.5PI, 2.5PI]
21         float radius = (1.0 + norm.y) * 0.5; // Range from [-1, 1] -> [0, 1]
22
23         //coord which we will sample from occlude map
24         vec2 coords = vec2(radius * -sin(angle), radius * -cos(angle)) / 2.0 +
24 0.5;
25
26         // Sample occlusion map
27         vec4 occluding = texture(image, coords);
28
29         // If pixel is not occluding (Red channel value below threshold), set
30         maxDistance to current distance
31         // If pixel is occluding, don't change distance
32         // maxDistance therefore is the distance from the center to the nearest
32         occluding pixel
33         maxDistance = max(maxDistance * step(occluding.r, THRESHOLD), min(
33 maxDistance, currDistance));
34     }
35
36     f_colour = vec4(vec3(maxDistance), 1.0);
36 }

```

Lightmap

The lightmap shader checks if a pixel is in shadow, blurs the result, and applies the radial light source.

lightmap.frag

```

1 # version 330 core
2
3 #define PI 3.14159265
4
5 in vec2 uvs;
6 out vec4 f_colour;
7
8 uniform float softShadow;
9 uniform float resolution;
10 uniform float falloff;
11 uniform vec3 lightColour;
12 uniform vec2 angleClamp;
13 uniform sampler2D occlusionMap;
14 uniform sampler2D image;
15
16 vec3 normLightColour = lightColour / 255;

```

```

17 vec2 radiansClamp = angleClamp * (PI / 180);
18
19 float sample(vec2 coord, float r) {
20     /*
21     Sample from the 1D distance map.
22
23     Returns:
24     float: 1.0 if sampled radius is greater than the passed radius, 0.0 if not.
25     */
26     return step(r, texture(image, coord).r);
27 }
28
29 void main() {
30     // Cartesian to polar transformation
31     // Range from [0, 1] -> [-1, 1]
32     vec2 norm = uvs.xy * 2.0 - 1.0;
33     float angle = atan(norm.y, norm.x);
34     float r = length(norm);
35
36     // The texture coordinates to sample our 1D lookup texture
37     // Always 0.0 on y-axis, as the texture is 1D
38     float x = (angle + PI) / (2.0 * PI); // Normalise angle to [0, 1]
39     vec2 tc = vec2(x, 0.0);
40
41     // Sample the 1D lookup texture to check if pixel is in light or in shadow
42     // Gives us hard shadows
43     // 1.0 -> in light, 0.0, -> in shadow
44     float inLight = sample(tc, r);
45     // Clamp angle so that only pixels within the range are in light
46     inLight = inLight * step(angle, radiansClamp.y) * step(radiansClamp.x, angle);
47
48     // Multiply the blur amount by the distance from the center
49     // So that the blurring increases as distance increases
50     float blur = (1.0 / resolution) * smoothstep(0.0, 0.1, r);
51
52     // Use gaussian blur to apply blur effecy
53     float sum = 0.0;
54
55     sum += sample(vec2(tc.x - blur * 4.0, tc.y), r) * 0.05;
56     sum += sample(vec2(tc.x - blur * 3.0, tc.y), r) * 0.09;
57     sum += sample(vec2(tc.x - blur * 2.0, tc.y), r) * 0.12;
58     sum += sample(vec2(tc.x - blur * 1.0, tc.y), r) * 0.15;
59
60     sum += inLight * 0.16;
61
62     sum += sample(vec2(tc.x + blur * 1.0, tc.y), r) * 0.15;
63     sum += sample(vec2(tc.x + blur * 2.0, tc.y), r) * 0.12;
64     sum += sample(vec2(tc.x + blur * 3.0, tc.y), r) * 0.09;
65     sum += sample(vec2(tc.x + blur * 4.0, tc.y), r) * 0.05;
66
67     // Mix with the softShadow uniform to toggle degree of softShadows
68     float finalLight = mix(inLight, sum, softShadow);
69
70     // Multiply the final light value with the distance, to give a radial falloff
71     // Use as the alpha value, with the light colour being the RGB values
72     f_colour = vec4(normLightColour, finalLight * smoothstep(1.0, falloff, r));
73 }

```

Class

The `Rays` class takes in a texture and array of light information, applies the aforementioned shaders, and blends the final result with the original texture.

`rays.py`

```

1  from data.shaders.classes.lightmap import _Lightmap
2  from data.shaders.classes.blend import _Blend
3  from data.shaders.protocol import SMProtocol
4  from data.shaders.classes.crop import _Crop
5  from data.constants import ShaderType
6
7  class Rays:
8      def __init__(self, shader_manager: SMProtocol, lights):
9          self._shader_manager = shader_manager
10         self._lights = lights
11
12         # Load all necessary shaders
13         shader_manager.load_shader(ShaderType._LIGHTMAP)
14         shader_manager.load_shader(ShaderType._BLEND)
15         shader_manager.load_shader(ShaderType._CROP)
16         shader_manager.create_framebuffer(ShaderType.RAYS)
17
18     def apply(self, texture, occlusion=None, softShadow=0.3):
19         """
20             Applies the light rays effect to a given texture.
21
22             Args:
23                 texture (moderngl.Texture): The texture to apply the effect to.
24                 occlusion (pygame.Surface, optional): A Pygame mask surface to use as
25                 the occlusion texture. Defaults to None.
26
27             final_texture = texture
28
29             # Iterate through array containing light information
30             for pos, radius, colour, *args in self._lights:
31                 # Topleft of light source square
32                 light_topleft = (pos[0] - (radius * texture.size[1] / texture.size[0]),
33                 pos[1] - radius)
34                 # Relative size of light compared to texture
35                 relative_size = (radius * 2 * texture.size[1] / texture.size[0],
36                 radius * 2)
37
38                 # Crop texture to light source diameter, and to position light source
39                 # at the center
40                 _Crop(self._shader_manager).apply(texture, relative_pos=light_topleft,
41                 relative_size=relative_size)
42                 cropped_texture = self._shader_manager.get_fbo_texture(ShaderType.
43                 _CROP)
44
45                 if occlusion:
46                     # Calibrate Pygame mask surface and crop it
47                     occlusion_texture = self._shader_manager.calibrate_pygame_surface(
48                     occlusion)
49                     _Crop(self._shader_manager).apply(occlusion_texture, relative_pos=
50                     light_topleft, relative_size=relative_size)
51                     occlusion_texture = self._shader_manager.get_fbo_texture(
52                     ShaderType._CROP)
53                 else:
54                     occlusion_texture = None
55
56             # Apply lightmap shader, shadowmap and occlusion are included within

```

```
the _Lightmap class
    _Lightmap(self._shader_manager).apply(cropped_texture, colour,
softShadow, occlusion_texture, *args)
    light_map = self._shader_manager.get_fbo_texture(ShaderType._LIGHTMAP)
50
51      # Blend the final result with the original texture
52      _Blend(self._shader_manager).apply(final_texture, light_map,
light_topleft)
    final_texture = self._shader_manager.get_fbo_texture(ShaderType._BLEND
)
54
55      self._shader_manager.render_to_fbo(ShaderType.RAYS, final_texture)
```

3.9.4 Stack

Chapter 4

Testing

4.1 Iterative Testing

I have been playtesting the program throughout the development process to find any bugs and fix them accordingly. However, a few issues have required additional measures.

4.1.1 Minimax

Since minimax is recursive algorithm, debugging it has proven a challenge. I have therefore configured the Python `logging` library to help collect information on the minimax tree for every function call.

`base.py`

```
1  def print_stats(self, score, move):
2      """
3          Prints statistics after traversing tree.
4
5          Args:
6              score (int): Final score obtained after traversal.
7              move (Move): Best move obtained after traversal.
8      """
9      if self._verbose is False:
10          return
11
12      self._stats['time_taken'] = round(1000 * (time.time() - self._stats['
13          time_taken']), 3)
14      self._stats['ms_per_node'] = round(self._stats['time_taken'] / self._stats[
15          'nodes'], 3)
16
17      # Prints stats across multiple lines
18      if self._verbose is True:
19          logger.info(f'\n\n'
20                      f'{self.__str__()} Search Results:\n'
21                      f'{printer.pformat(self._stats)}\n'
22                      f'Best score: {score}    Best move: {move}\n'
23          )
24
25      # Prints stats in a compacted format
26      elif self._verbose.lower() == 'compact':
27          logger.info(self._stats)
```

Listing 4.1: BaseCPU Method for logging minimax statistics

4.1.2 Migrations

To correct errors made to the `games` table, since recreating it would mean deleting all existing games, I have opted to use migrations to fix bugs by editing the table schema, as shown in Section 3.8.1.

4.2 Unit Tests

4.2.1 Board Evaluator

To test every aspect of the evaluation function, I have set up some unit tests with custom positions using my editor screen. These positions are designed to test every aspect of the evaluation, along with some obviously imbalanced positions to test the overall accuracy of the evaluation function. All positions are set up to give an advantage to the blue player.

Evaluating	FEN string	Score	Passed
Material	<code>sc9/10/10/4paPa4/5Pa4/10/10/9Sa b</code>	124	✓
Position	<code>sc9/4nanana3/10/10/10/4NaNaNa3/10/9Sa b</code>	66	✓
Mobility	See footnote ¹	196	✓
King Safety	<code>sc4fa3pa/10/10/10/10/10/10/5FaPa2Sa b</code>	3	✓
Combined	See footnote ²	437	✓

Table 4.1: Board evaluator test results

4.2.2 CPU

Similarly, to evaluate the strength of my CPU, I have setup some custom positions that I already know the best continuation of, and run each CPU engine on them to test if they can solve it.

Description	FEN string	Best Move	Passed
Mate in 1	<code>sc9/pafa8/Fa9/10/10/10/10/9Sa b</code>	Rotate J3 clockwise	✓
Mate in 1	<code>sc9/10/10/8faRb/8FaRb/10/9Sa b</code>	Move J3 to J2	✓
Mate in 3	<code>sc9/10/10/8Ra1/7FaRafa/8RaRa/9Ra/9Sa b</code>	Move J2 to I1... ³	✓
Mate in 3	<code>sc5fcnc2/4Pa4Pc/3pb6/2Pc2ra1pb2/10/pb9/7Pa2/2PdNaFa4Sa b</code>	Move E7 to F7... ⁴	✓
Escape Mate	<code>sc9/10/10/8faRb/8FaRb/10/9Sa b</code>	Move J3 to J2	✓
Win Material	<code>sc9/10/10/10/8faRb/8FaRb/10/9Sa b</code>	Move J3 to J2	✓

Table 4.2: Transposition Table CPU test results

¹`scpapa7/papapa7/papapa1Pa1Pa1Pa1/10/4Pa1Pa1Pa1/10/4Pa1Pa3/9Sa b`

²`scnc1fcncpbpb3/pa9/pb1pc1rbpa3Pd/1Pc2Pd4Pc/2Pd1RaRb4/10/7Pa2/2PdNaFaNa3Sa b`

³2. Move J4 to J5 3. Move J3 to I2

⁴2. Rotate anticlockwise H8 3. Move F7 to G7

4.2.3 Shadow Mapping

To test the shadow mapping algorithm, I have set up some occluding objects together with a light source. Since visuals are subjective, me and my client have deemed the following results to be adequate.

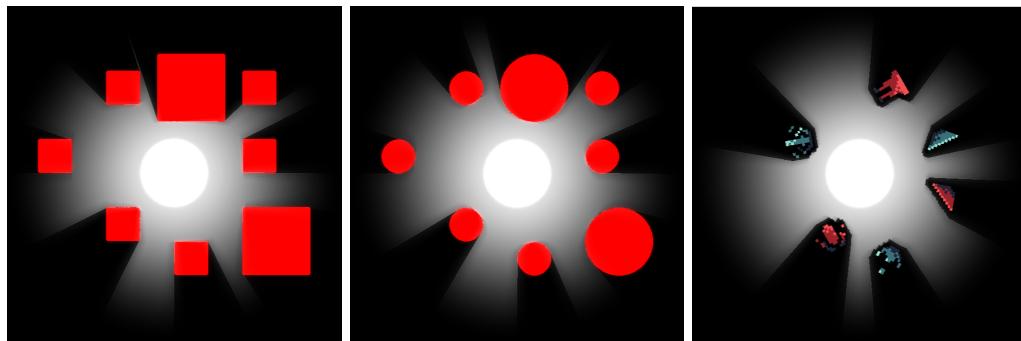


Figure 4.1: Shadow mapping algorithm test (softShadow=0.5, radius=0.5)

4.3 Final Tests

4.3.1 Objective 1

All laser chess game logic should be properly implemented.

No.	Input	Output	Passed
1	Laser fires on piece	Piece reflects laser	✓
2	Select piece and press rotate clockwise button	Piece rotates clockwise	✓
3	Select piece and adjacent empty square	Piece moves to adjacent square	✓
4	Blue player makes a move	Next move is made by red player	✓
5	Make move	Laser reflects off pieces correctly	✓
6	Position piece with non-reflecting side facing laser	Piece is destroyed	✓
7	Move Pharaoh in front of player	Game displays game over screen	✓
8	Repeat same position three times	Game displays game over screen	✓

4.3.2 Objective 2

Save or load game options should be implemented.

No.	Input	Output	Passed
9	Click on copy FEN string button in editor or browser screen	Position formatted as FEN string copied to clipboard	✓
10	Enter browser screen	Program shows list of past games to be scrolled through	✓

No.	Input	Output	Passed
11	Click on previous or next move button in review screen	Board undoes or applies move	✓
12	Enter review screen	Program displays list of past moves, winner and move number	✓

4.3.3 Objective 3

Other board game requirements should be implemented.

No.	Input	Output	Passed
13	Click on draw button	Game ends and shows draw result	✓
14	Click on resign button	Game ends and shows win result for opposite player	✓
15	Enable timer	Timer appears on the left and decrements every second	✓
16	Pause the game	Timer stops decrementing	✓

4.3.4 Objective 4

Game settings and config should be customisable.

No.	Input	Output	Passed
17	Set primary board colour to blue	Alternating board squares appear blue	✓
18	Select CPU player	Every other move is played by the CPU	✓
19	Input timer duration in config screen	Inputted timer duration appears on the left of the game screen	✓
21	Press starting colour button to set starting colour to red	Starting move is played by red player	✓
21	Set up custom board layout in editor screen	Game starts with custom board position	✓

4.3.5 Objective 5

Game UI should improve player experience.

No.	Input	Output	Passed
27	Click the play button on the main menu screen	Program switches to the config screen	✓
28	Click main menu button	Program switches to the menu screen	✓
29	Click help button	Help overlay appears	✓
30	Resize program window	GUI Widgets resize continuously	✓

No.	Input	Output	Passed
31	Drag program window	Program continues running	✓

4.4 Videos

Chapter 5

Evaluation

5.1 Objectives

5.1.1 Objective 1

All laser chess game logic should be properly implemented. Refer to Figure 5.4.

Both the play and review screens display a 10x8 laser chess board. Players can move and rotate pieces on their respective turns, with the laser firing and destroying pieces automatically. The game ends when a player draws, resigns, has their pharaoh destroyed or reaches three-fold repetition.

Objective 1 is fulfilled, the game plays successfully. A possible improvement would be an option to play against local hosts. This was not a requested or planned feature, but would be very handy for a two-player game.

5.1.2 Objective 2

Save or load game options should be implemented. Refer to Figures 5.6 and 5.7.

In the browser screen, users can scroll through all previous games, with the option to delete or review them, or copy their FEN string. Games can be sorted, and pages of games can be scrolled through. The game positions are encoded using a custom FEN string format, and games are saved as rows in a local SQLite database table. In the review screen, users can scroll through all the moves of a previous game. The right side bar displays information such as the winner and move number, and the timer, pieces and move list updates accordingly.

Objective 2 is fulfilled. A possible improvement would be to add the option of loading up a position to resume playing straight from the review screen. This would be a convenient feature, but is not a priority, as users can currently copy the FEN string from the browser screen to the config screen and load the position there as an alternative option.

5.1.3 Objective 3

Other board game requirements should be implemented. Refer to Figure 5.4.

In addition to the core game mechanics, other ancillary aspects are added as well. The piece display correctly updates to show all destroyed pieces. Timers can be enabled and disabled, decrement correctly, and end the game when they run out. Buttons also exist for drawing and resigning the game. The move list and status message widgets also provide update accordingly and provide information on the stage of the game.

Objective 3 is fulfilled.

5.1.4 Objective 4

Game settings and config should be customisable. Refer to Figures 5.2 and 5.3 and 5.5.

In the settings screen, the user can change settings to toggle the volume, fullscreen, board colours, particles and shaders. All settings update correctly, and are saved to a local JSON file when the settings screen is exited. The game configurations are changed in the config screen. Here, users can change the game's starting colour, configure timer settings, change to the CPU player and specify the difficulty, select a board preset, or create a custom board layout through the editor screen. The editor screen comes with all the basic operations of placing pieces, rotating pieces, and erasing and dragging them.

Objective 4 is fulfilled.

5.1.5 Objective 5

Game UI should improve player experience. Refer to Figure 5.4.

When a player holds down on a piece, the piece can be moved through drag-and-drop. Indicators are also present to show adjacent squares that the piece can be moved to. Audio cues also improve the immersiveness of the game, as well as the laser visuals and particle effects.

Objective 5 is fulfilled. An ambitious plan for greater visuals when the game ends was planned, with a zooming camera and greyscale fade, but was not implemented due to time constraints.

5.1.6 Objective 6

GUI design should be functional and display concise information. Refer to Figure 5.1.

I have created most of the custom pixel art and icon graphics to improve the game's visual and attempt to make it more engaging. Most screens also contain both the main menu button and help button. Clicking the menu button switches to the main menu screen, and clicking the help button shows an overlay displaying the functionality of drawn widgets. Shaders are also used to improve the game's visuals, such as by giving the laser a light-emitting effect, but is also used to draw all the backgrounds. The program also resizes seamlessly.

Objective 6 is fulfilled. Some fragment shaders are computationally expensive, and may therefore affect the performance. I have attempted to resolve this by adding the option to disable shaders, however, a better solution would be to optimise the expensive shader code. Working on Windows, I am unable to bundle the program to MacOS or Linux. Although this was not a priority, having access other OS testing environments would've widened access to the game.

5.2 Client Feedback

The following interview was conducted after Mr Myslov received and played through the program.

Q: Did the final product meet your expectations?

A: Yes, it certainly did. The game plays perfectly, I could move, rotate all the pieces as expected, and the laser works well. All the features I requested for were there, and the visuals were also more than I expected and welcome.

Q: What improvements could be made to the program?

A: I found that it was difficult for my laptop to run the program without sacrificing some of the visuals. I also found your FEN string implementation confusing, as there was no guidance on what the characters mean. The text box could also be improved, as it was slightly tedious erasing all the characters manually.

Q: What other aspects would you like to have been added?

A: Being able to somehow easily obtain a digital file for a game would be useful, so I could share it with my students easily. Having a multi-player option instead of people surrounding one laptop would also be a great addition.

My client was satisfied with my final program. His perspective revealed some aspects of the program that I could've better considered and improved upon.

I should've improved upon the intuitiveness of the game by adding more tutorials, to teach new users about the rules or the game, and about my custom FEN string format. Although a tutorial screen is already available in the game screen, an interactive one would perhaps serve the purpose better.

To improve upon the text box and intuitiveness of the widgets, I could implement shortcuts for **Ctrl-A**, or a drag-to-select system.

My client also mentioned a multi-player option, this could be achieved within Python through a peer-to-peer system. This would require a rewrite of the MVC model and how moves are processed, but is a future addition well worth considering.

Regardless, given the limited time frame, I think we are both pleased with the final result.

5.3 Conclusion

The final product fulfilled all proposed objectives and more, and has been approved by my client.

Throughout 6 months of development, I felt that I improved on many aspects needed to be a proficient developer. Having the opportunity to create bespoke software for a client was insightful: I learnt about the importance of conducting research and interviews, of obtaining feedback, but also of good communication between client and provider. In terms of coding, working on a large project help improve file management, documentation, and keeping robust backups through Git. It also gave me the opportunity to learn GLSL for my shaders, and LaTeX for my documentation. Having a greater familiarity with Pygame, I also plan to rework my widget system as a library, to be shared for the benefit of all future Pygame users.

Overall, this project was a success.

5.4 Screenshots

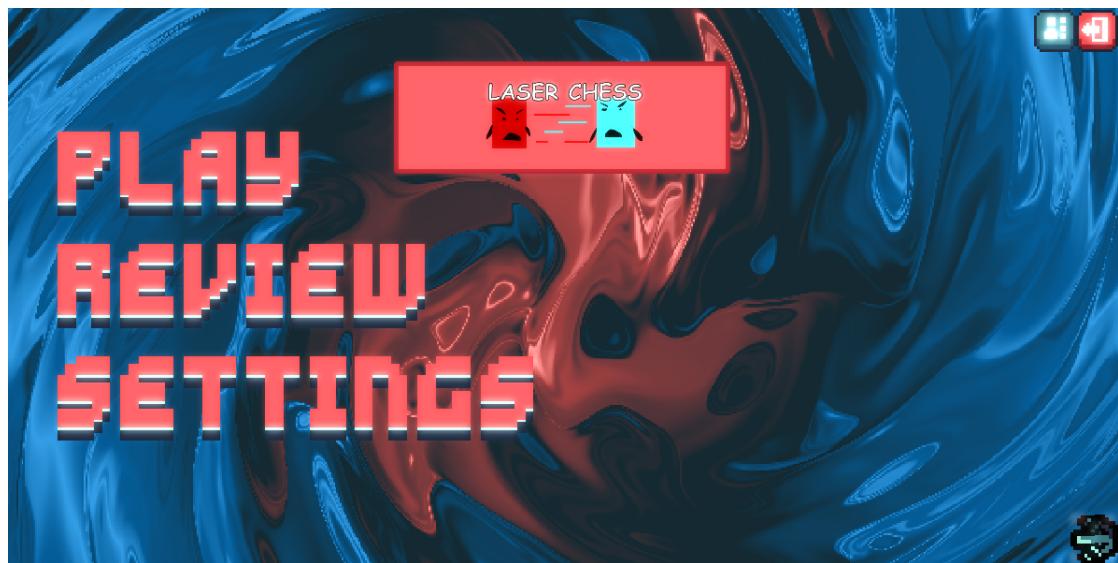


Figure 5.1: Main menu screen

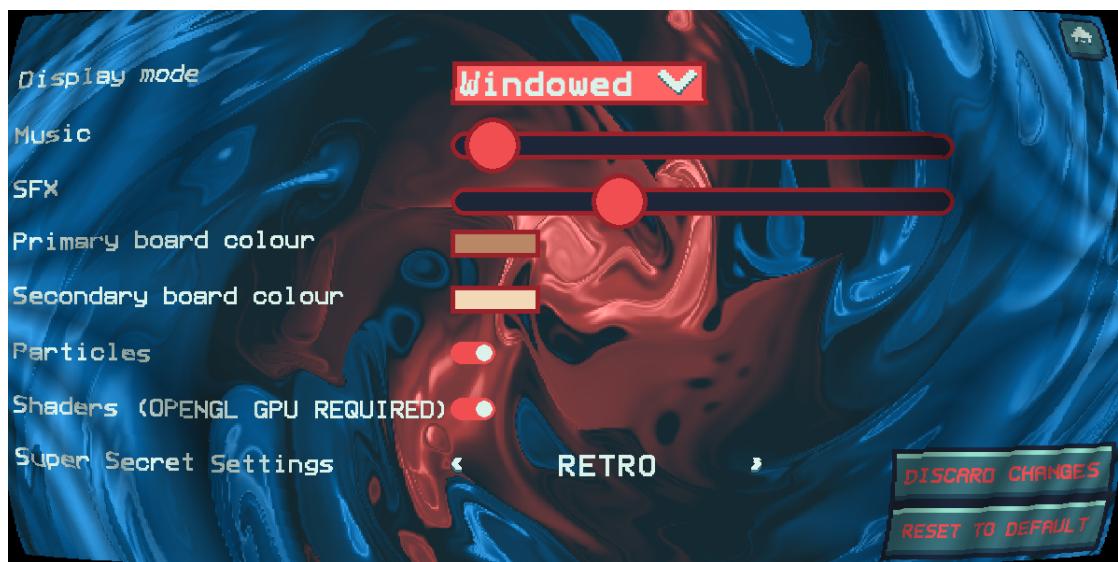


Figure 5.2: Settings screen

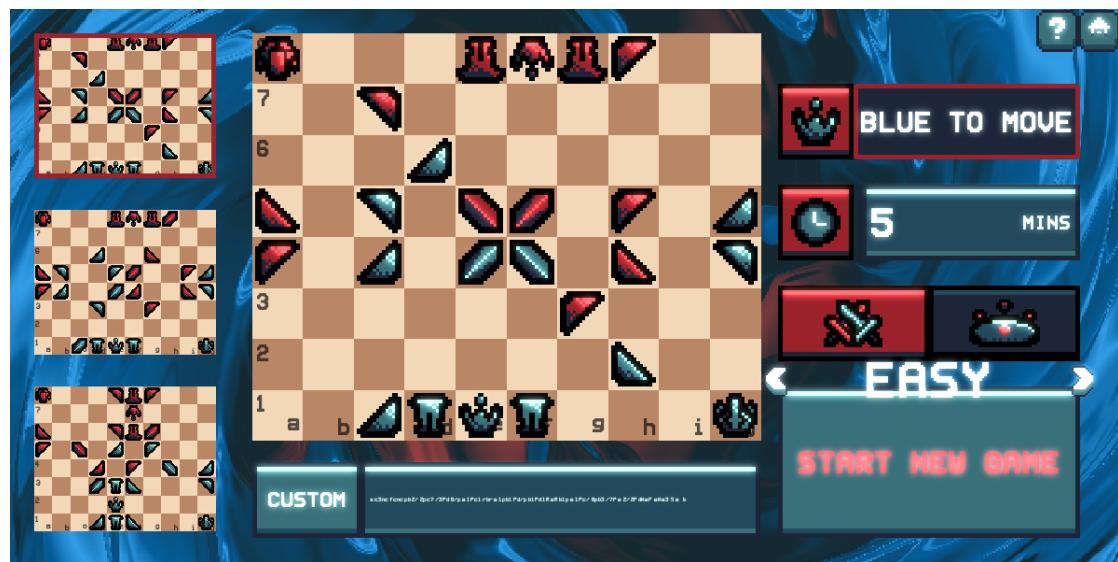


Figure 5.3: Config screen

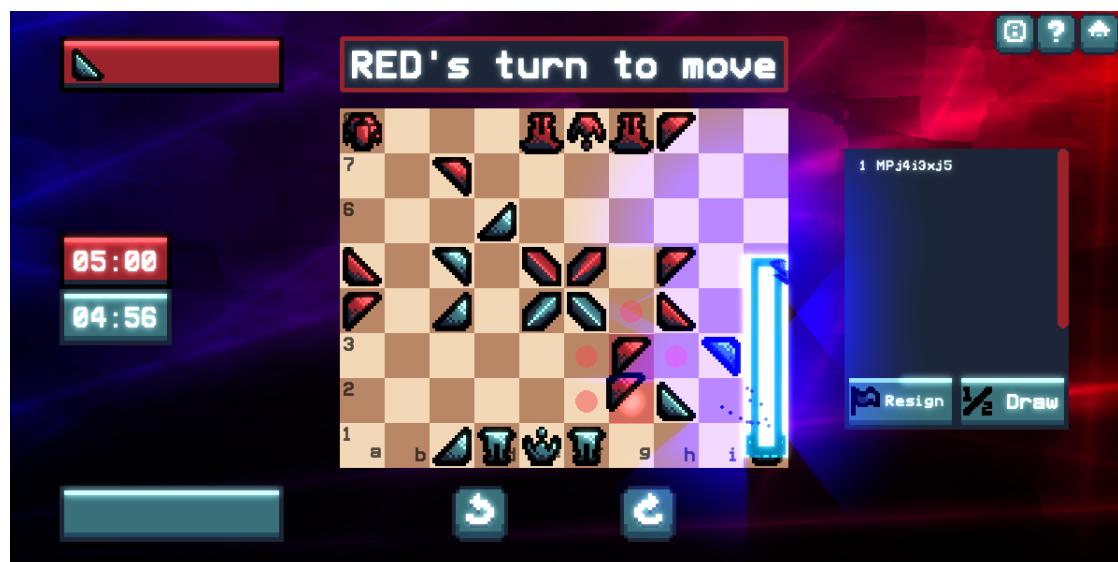


Figure 5.4: Game screen



Figure 5.5: Editor screen

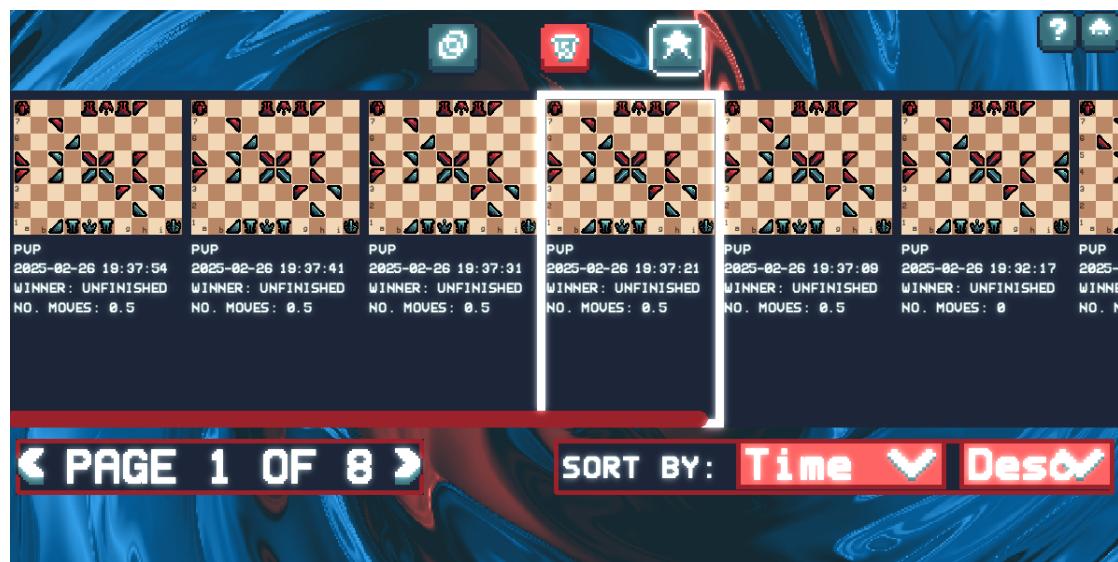


Figure 5.6: Browser screen



Figure 5.7: Review screen