

Chapter 1

Technical Solution

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1.1 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.

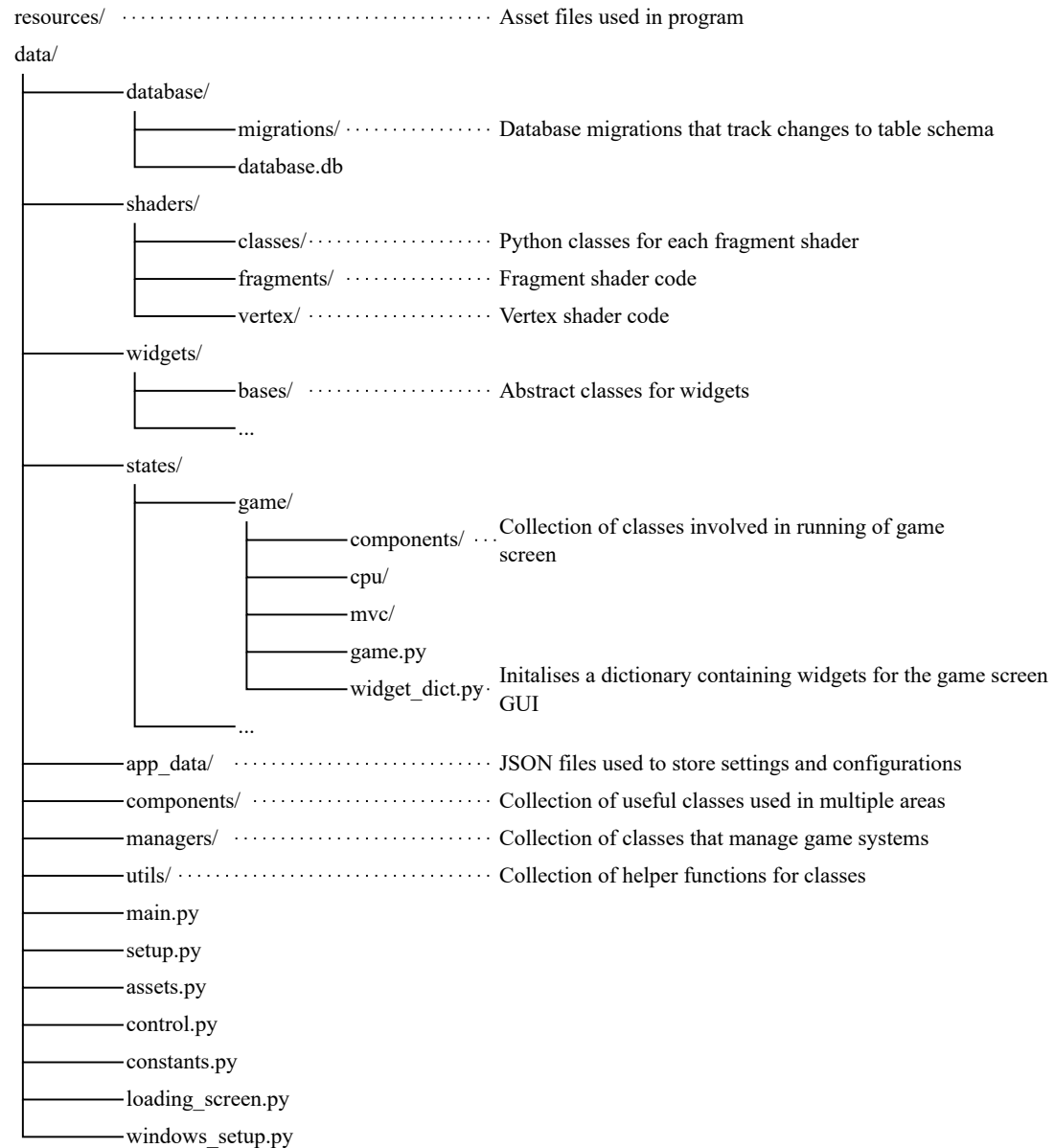


Figure 1.1: File tree diagram

1.2 Summary of Complexity

- Alpha-beta pruning and transposition table improvements for Minimax (1.6.2 and 1.6.3)
- Shadow mapping and coordinate transformations (1.9.3)
- Recursive Depth-First Search tree traversal (1.3.4 and 1.6.1)
- Circular doubly-linked list and stack (1.4.3 and 1.9.4)
- Multipass shaders and gaussian blur (1.9.2)
- Aggregate and Window SQL functions (1.8.2)
- OOP techniques (1.4.3 and 1.4.4)
- Multithreading (1.3.2 and 1.6.5)
- Bitboards (1.5.5)
- Zobrist hashing (1.6.6)
- (File handling and JSON parsing) (1.3.3)
- (Dictionary recursion) (1.3.4)
- (Dot product) (1.3.3 and 1.9.2)

1.3 Overview

1.3.1 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
7 if platform == 'win32':
8     import data.windows_setup as win_setup
9
10 from data.loading_screen import LoadingScreen
11
12 states = [None, None]
13
14 def load_states():
15     """
16     Initialises instances of all screens, executed on another thread with results
17     being stored to the main thread by modifying a mutable such as the states list
18     """
19     from data.control import Control
20     from data.states.game.game import Game
21     from data.states.menu.menu import Menu
```

```

20     from data.states.settings.settings import Settings
21     from data.states.config.config import Config
22     from data.states.browser.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()

```

1.3.2 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/
    logo.png').resolve()
12 sfx_path_1 = (Path(__file__).parent / '../resources/sfx/loading_screen/
    loading_screen_1.wav').resolve()
13 sfx_path_2 = (Path(__file__).parent / '../resources/sfx/loading_screen/
    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
60         return (center_pos[0], center_pos[1] + displacement - displacement *
61             easeOutBack(progress))
62
63     @property
64     def logo_opacity(self):
65         return min(255, (pygame.time.get_ticks() - start_ticks) / 5)
66
67     @property
68     def duration_not_over(self):
69         return (pygame.time.get_ticks() - start_ticks) < 1500
70
71     def event_loop(self):
72         """
73         Handles events for the loading screen, no user input is taken except to
74         quit the game.
75         """
76         for event in pygame.event.get():
77             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)

```

1.3.3 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]))
    else:
        pos_list.append((0, perimeter - perimeter_offset))
    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     """
6     Creates surface for sliders.
7
8     Args:
9         size (list[int, int]): Image size.
10        fill_colour (pygame.Color): Fill (inner) colour.
11        border_width (float): Border width.
12        border_colour (pygame.Color): Border colour.
13
14    Returns:
15        pygame.Surface: Slider image surface.
16    """
17    gradient_surface = pygame.Surface(size, pygame.SRCALPHA)
18    border_rect = pygame.Rect((0, 0, gradient_surface.width, gradient_surface.
19    height))
20
21    # Draws rectangle with a border radius half of image height, to draw an
22    # rectangle with semicircular cap (obround)
23    pygame.draw.rect(gradient_surface, fill_colour, border_rect, border_radius=int
24    (size[1] / 2))
25    pygame.draw.rect(gradient_surface, border_colour, border_rect, width=int(
26    border_width), border_radius=int(size[1] / 2))
27
28    return gradient_surface
29
30 def create_slider_gradient(size, border_width, border_colour):
31     """
32     Draws surface for colour slider, with a full colour gradient as fill colour.
33
34     Args:
35         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
49             radius of cap (half of image height)
50             distance_from_cutoff = min(abs(first_round_end - i), abs(i -
51             second_round_end))
52             draw_height = calculate_gradient_slice_height(distance_from_cutoff,
53             gradient_surface.height / 2)
54
55             # Get colour from distance from left side of slider
56             color = pygame.Color(0)
57             color.hsva = (int(360 * i / gradient_surface.width), 100, 100, 100)
58
59             draw_rect = pygame.Rect((0, 0, 1, draw_height - 2 * border_width))
60             draw_rect.center = (i, gradient_y_mid)
61
62             pygame.draw.rect(gradient_surface, color, draw_rect)
63
64     border_rect = pygame.Rect((0, 0, gradient_surface.width, gradient_surface.
65     height))
66     pygame.draw.rect(gradient_surface, border_colour, border_rect, width=int(
67     border_width), border_radius=int(size[1] / 2))
68
69     return gradient_surface
70
71 def calculate_gradient_slice_height(distance, radius):
72     """
73     Calculate height of vertical slice of semicircular slider cap.
74
75     Args:
76         distance (float): x-distance from center of circle.
77         radius (float): Radius of semicircle.
78
79     Returns:
80         float: Height of vertical slice.
81     """
82     return sqrt(radius ** 2 - distance ** 2) * 2 + 2
83
84 def create_slider_thumb(radius, colour, border_colour, border_width):
85     """
86     Creates surface with bordered circle.
87
88     Args:
89         radius (float): Radius of circle.
90         colour (pygame.Color): Fill colour.
91         border_colour (pygame.Color): Border colour.
92         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     surface = pygame.Surface(size, pygame.SRCALPHA)
163     pygame.draw.rect(surface, colours[0], (0, 0, *size))
164     pygame.draw.rect(surface, colours[2], (border_width, border_width, size[0] - 2
165     * border_width, size[1] - 2 * border_width))
166     pygame.draw.rect(surface, colours[3], (border_width, border_width, size[0] - 2
167     * border_width, border_width))
168     pygame.draw.rect(surface, colours[1], (border_width, size[1] - 2 *
169     border_width, size[0] - 2 * border_width, border_width))
170
171     return surface

```

1.3.4 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):
7     """
8     Recursive depth-first search to yield all items in a dictionary.
9
10    Args:
11        dictionary (dict): Dictionary to be iterated through.
12        parent_key (str, optional): Prefix added to every key. Defaults to None.
13
14    Yields:
15        dict | tuple[str, str]: Another dictionary or key, value pair.
16    """
17    for key, value in dictionary.items():
18        if parent_key:
19            new_key = parent_key + key.capitalize()
20        else:
21            new_key = key
22
23        if isinstance(value, dict):
24            yield from flatten_dictionary_generator(value, new_key).items()
25        else:
26            yield new_key, value
27

```

```

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('(ThemeManager.__getitem__)Requested theme item not
54             found:', arg)
55
56         return item
57
58 theme = ThemeManager()

```

1.4 GUI

1.4.1 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         laser_path = laser_result.laser_path.copy()
38         laser_types = [LaserType.END]
39         # List of angles in degree to rotate the laser image surface when drawn
40         laser_rotation = [laser_path[0][1]]
41         laser_lights = []
42
43         # Iterates through every square laser passes through
44         for i in range(1, len(laser_path)):
45             previous_direction = laser_path[i-1][1]
46             current_coords, current_direction = laser_path[i]
47
48             if current_direction == previous_direction:
49                 laser_types.append(LaserType.STRAIGHT)
50                 laser_rotation.append(current_direction)
51             elif current_direction == previous_direction.get_clockwise():
52                 laser_types.append(LaserType.CORNER)
53                 laser_rotation.append(current_direction)
54             elif current_direction == previous_direction.get_anticlockwise():
55                 laser_types.append(LaserType.CORNER)
56                 laser_rotation.append(current_direction.get_anticlockwise())
57
58         # Adds a shader ray effect on the first and last square of the laser
59         trajectory
60         if i in [1, len(laser_path) - 1]:
61             abs_position = coords_to_screen_pos(current_coords, self.
62             _board_position, self._square_size)
63             laser_lights.append([
64                 (abs_position[0] / window.size[0], abs_position[1] / window.
65                 size[1]),
66                 0.5,
67                 (0, 0, 255) if laser_colour == Colour.BLUE else (255, 0, 0),
68             ])
69
70         # Sets end laser draw type if laser hits a piece
71         if laser_result.hit_square_bitboard != EMPTY_BB:
72             laser_types[-1] = LaserType.END
73             laser_path[-1] = (laser_path[-1][0], laser_path[-2][1].get_opposite())
74             laser_rotation[-1] = laser_path[-2][1].get_opposite()
75
76         audio.play_sfx(SFX['piece_destroy'])
77
78         laser_path = [(coords, rotation, type) for (coords, dir), rotation, type
79         in zip(laser_path, laser_rotation, laser_types)]
80         self._laser_lists.append((laser_path, laser_colour))
81
82         window.clear_effect(ShaderType.RAYS)
83         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         # Scaled glow surfaces drawn on top with the RGB_ADD blend mode
126         if glow:
127             screen.fblits(glow_list, pygame.BLEND_RGB_ADD)
128
129         screen.blits(laser_list)
130
131     def draw(self, screen):
132         """
133         Draws all lasers on the screen.
134
135         Args:
136             screen (pygame.Surface): The screen to draw on.
137         """
138         for laser_list in self._laser_lists:
139             self.draw_laser(screen, laser_list)

```

```

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

```

1.4.2 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,
   get_angle_between_vectors, get_next_corner
4  from data.states.game.components.piece_sprite import PieceSprite
5
6  class ParticlesDraw:
7      def __init__(self, gravity=0.2, rotation=180, shrink=0.5, opacity=150):
8          self._particles = []
9          self._glow_particles = []
10
11          self._gravity = gravity
12          self._rotation = rotation
13          self._shrink = shrink
14          self._opacity = opacity
15
16      def fragment_image(self, image, number):
17          image_size = image.get_rect().size
18          """
19          1. Takes an image surface and samples random points on the perimeter.
20          2. Iterates through points, and depending on the nature of two consecutive
           points, finds a corner between them.
21          3. Draws a polygon with the points as the vertices to mask out the area
           not in the fragment.
22
23          Args:
24              image (pygame.Surface): Image to fragment.
25              number (int): The number of fragments to create.
26
27          Returns:
28              list[pygame.Surface]: List of image surfaces with fragment of original
           surface drawn on top.
29          """
30          center = image.get_rect().center
31          points_list = get_perimeter_sample(image_size, number)
32          fragment_list = []
33
34          points_list.append(points_list[0])
35
36          # Iterate through points_list, using the current point and the next one
37          for i in range(len(points_list) - 1):
38              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
on the same side
51             corners_to_draw = 4
52
53             elif abs(vertex_1[0] - vertex_2[0]) == image_size[0] or abs(vertex_1
[1] - vertex_2[1]) == image_size[1]: # Points on opposite sides
54                 corners_to_draw = 2
55
56             elif angle < 180: # Points on adjacent sides
57                 corners_to_draw = 3
58
59             else:
60                 corners_to_draw = 1
61
62             corners_list = []
63             for j in range(corners_to_draw):
64                 if len(corners_list) == 0:
65                     corners_list.append(get_next_corner(vertex_2, image_size))
66                 else:
67                     corners_list.append(get_next_corner(corners_list[-1],
image_size))
68
69             pygame.draw.polygon(cropped_image, (0, 0, 0, 0), (center, vertex_2, *
corners_list, vertex_1))
70
71             fragment_list.append(cropped_image)
72
73             return fragment_list
74
75 def add_captured_piece(self, piece, colour, rotation, position, size):
76     """
77     Adds a captured piece to fragment into particles.
78
79     Args:
80         piece (Piece): The piece type.
81         colour (Colour): The active colour of the piece.
82         rotation (int): The rotation of the piece.
83         position (tuple[int, int]): The position where particles originate
from.
84         size (tuple[int, int]): The size of the piece.
85     """
86     piece_sprite = PieceSprite(piece, colour, rotation)
87     piece_sprite.set_geometry((0, 0), size)
88     piece_sprite.set_image()
89
90     particles = self.fragment_image(piece_sprite.image, 5)
91
92     for particle in particles:
93         self.add_particle(particle, position)
94
95 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] - end_size[1]))
154
155             # Update rotation
156             rotation = (self._rotation if particle[3][0] <= 0 else -self.
157 _rotation) * particle[4]

```

```

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

```

1.4.3 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         .
30         relative_margin (float): The relative margin of the widget.
31         relative_border_width (float): The relative border width of the widget.
32         relative_border_radius (float): The relative border radius of the widget.
33
34         anchor_x (str): The horizontal anchor direction ('left', 'right', 'center
35         ').
36         anchor_y (str): The vertical anchor direction ('top', 'bottom', 'center').
37         fixed_position (tuple[int, int], optional): The fixed position of the
38         widget in pixels.
39         border_colour (pygame.Color): The border color of the widget.
40         text_colour (pygame.Color): The text color of the widget.
41         fill_colour (pygame.Color): The fill color of the widget.
42         font (pygame.freetype.Font): The font used for the widget.
43         """
44         super().__init__()
45
46         for required_kwarg in REQUIRED_KWARGS:
47             if required_kwarg not in kwargs:
48                 raise KeyError(f'(_Widget.__init__) Required keyword "{
49                 required_kwarg}" not in base kwargs')
50
51         self._surface = None # Set in WidgetGroup, as needs to be reassigned every
52         frame
53         self._raw_surface_size = DEFAULT_SURFACE_SIZE
54
55         self._parent = kwargs.get('parent')
56
57         self._relative_font_size = None # Set in subclass
58
59         self._relative_position = kwargs.get('relative_position')
60         self._relative_margin = theme['margin'] / self._raw_surface_size[1]
61         self._relative_border_width = theme['borderWidth'] / self.
62         _raw_surface_size[1]
63         self._relative_border_radius = theme['borderRadius'] / self.
64         _raw_surface_size[1]
65
66         self._border_colour = pygame.Color(theme['borderPrimary'])
67         self._text_colour = pygame.Color(theme['textPrimary'])
68         self._fill_colour = pygame.Color(theme['fillPrimary'])
69         self._font = DEFAULT_FONT
70
71         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.
surface_size[0]) / self.surface_size[1], (kwargs.get('relative_size')[1] *
self.surface_size[0] / self.surface_size[1]))
70             case 'both':
71                 self._relative_size = ((kwargs.get('relative_size')[0] * self.
surface_size[0]) / self.surface_size[1], kwargs.get('relative_size')[1])
72             case _:
73                 raise ValueError('(_Widget.__init__) Unknown scale mode:',
scale_mode)
74         else:
75             self._relative_size = (1, 1)
76
77         if 'margin' in kwargs:
78             self._relative_margin = kwargs.get('margin') / self._raw_surface_size
[1]
79
80             if (self._relative_margin * 2) > min(self._relative_size[0], self.
_relative_size[1]):
81                 raise ValueError('(_Widget.__init__) Margin larger than specified
size!')
82
83         if 'border_width' in kwargs:
84             self._relative_border_width = kwargs.get('border_width') / self.
_raw_surface_size[1]
85
86         if 'border_radius' in kwargs:
87             self._relative_border_radius = kwargs.get('border_radius') / self.
_raw_surface_size[1]
88
89         if 'border_colour' in kwargs:
90             self._border_colour = pygame.Color(kwargs.get('border_colour'))
91
92         if 'fill_colour' in kwargs:
93             self._fill_colour = pygame.Color(kwargs.get('fill_colour'))
94
95         if 'text_colour' in kwargs:
96             self._text_colour = pygame.Color(kwargs.get('text_colour'))
97
98         if 'font' in kwargs:
99             self._font = kwargs.get('font')
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         x, y = None, None
128         if self._fixed_position:
129             x, y = self._fixed_position
130         if x is None:
131             x = self._relative_position[0] * self.surface_size[0]
132         if y is None:
133             y = self._relative_position[1] * self.surface_size[1]
134
135         if self._anchor_x == 'left':
136             x = x
137         elif self._anchor_x == 'right':
138             x = self.surface_size[0] - x - self.size[0]
139         elif self._anchor_x == 'center':
140             x = (self.surface_size[0] / 2 - self.size[0] / 2) + x
141
142         if self._anchor_y == 'top':
143             y = y
144         elif self._anchor_y == 'bottom':
145             y = self.surface_size[1] - y - self.size[1]
146         elif self._anchor_y == 'center':
147             y = (self.surface_size[1] / 2 - self.size[1] / 2) + y
148
149         # Position widget relative to parent, if exists.
150         if self._parent:
151             return (x + self._parent.position[0], y + self._parent.position[1])
152         else:
153             return (x, y)
154
155     @property
156     def size(self):
157         return (self._relative_size[0] * self.surface_size[0], self._relative_size
158               [1] * self.surface_size[1])
159
160     @property
161     def margin(self):
162         return self._relative_margin * self._raw_surface_size[1]
163
164     @property
165     def border_width(self):
166         return self._relative_border_width * self._raw_surface_size[1]
167
168     @property
169     def border_radius(self):
170         return self._relative_border_radius * self._raw_surface_size[1]
171
172     @property
173     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         self._raw_surface_size = new_surface_size
215
216     def process_event(self, event):
217         """
218         Abstract method to handle events.
219
220         Args:
221             event (pygame.Event): The event to process.
222         """
223         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        Args:
45        key: The key to set as the current item.
46        Raises:
47        ValueError: If no nodes within the circular linked list contains the
48        key as its data.
49        """
50        if self._keys_list.data_in_list(key) is False:
51            raise ValueError('(_Circular.set_to_key) Key not found:', key)
52
53        for _ in range(len(self._items_dict)):
54            if self.current_key == key:
55                self.set_image()
56                self.set_geometry()
57                return
58
59        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         self._head = None
17
18         if list_to_convert:
19             for item in list_to_convert:
20                 self.insert_at_end(item)
21
22     def __str__(self):
23         """
24         Returns a string representation of the circular linked list.
25
26         Returns:
27             str: Linked list formatted as string.
28         """
29         if self._head is None:
30             return '| empty |'
31
32         characters = '| -> '
33         current_node = self._head
34         while True:
35             characters += str(current_node.data) + ' -> '
36             current_node = current_node.next
37
38             if current_node == self._head:
39                 characters += '|'
40                 return characters
41
42     def insert_at_beginning(self, data):
43         """
44         Inserts a node at the beginning of the circular linked list.
45
46         Args:
47             data: The data to insert.
48         """
49         new_node = Node(data)
50
51         if self._head is None:
52             self._head = new_node
53             new_node.next = self._head
54             new_node.previous = self._head
55         else:
56             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
97         if index == 0 or self._head is None:
98             self.insert_at_beginning(data)
99         else:
100             new_node = Node(data)
101             current_node = self._head
102             count = 0
103
104             while count < index - 1 and current_node.next != self._head:
105                 current_node = current_node.next
106                 count += 1
107
108             if count == (index - 1):
109                 new_node.next = current_node.next
110                 new_node.previous = current_node
111                 current_node.next = new_node
112             else:
113                 raise ValueError('Index out of range! (CircularLinkedList.
114 insert_at_index)')
115
116     def delete(self, data):
117         """

```

```

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

```

1.4.4 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,
   BrowserEventType, EditorEventType
2
3 required_args = {
4     GameEventType.BOARD_CLICK: ['coords'],
5     GameEventType.ROTATE_PIECE: ['rotation_direction'],
6     GameEventType.SET_LASER: ['laser_result'],
7     GameEventType.UPDATE_PIECES: ['move_notation'],
8     GameEventType.TIMER_END: ['active_colour'],
9     GameEventType.PIECE_DROP: ['coords', 'piece', 'colour', 'rotation', '
   remove_overlay'],
10    SettingsEventType.COLOUR_SLIDER_SLIDE: ['colour'],
11    SettingsEventType.PRIMARY_COLOUR_PICKER_CLICK: ['colour'],
12    SettingsEventType.SECONDARY_COLOUR_PICKER_CLICK: ['colour'],
13    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.OPENGGL_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         if event_type in required_args:
54             for required_arg in required_args[event_type]:
55                 if required_arg not in kwargs:
56                     raise ValueError(f"Argument '{required_arg}' required for {
57                     event_type.name} event (GameEvent.create_event)")
58
59             for kwarg in kwargs:
60                 if kwarg not in required_args[event_type]:
61                     raise ValueError(f"Argument '{kwarg}' not included in
62                     required_args dictionary for event '{event_type}'! (GameEvent.create_event)")
63
64             return event_cls(event_type, **kwargs)
65
66         else:
67             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
        super classes
10         _Pressable.__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
        self._center is True.
30
31         Returns:
32             list[int, int]: Position of widget.
33         """
34         position = super().position
35
36         if self._center:
37             self._size_diff = (self.size[0] - self.rect.width, self.size[1] - self
        .rect.height)
38             return (position[0] + self._size_diff[0] / 2, position[1] + self.
        _size_diff[1] / 2)
39         else:
40             return position
41
42     def set_image(self):
43         """
44         Sets current icon to image.
45         """
46         self.current_item.set_image()
47         self.image = self.current_item.image
48
49     def set_geometry(self):
50         """
51         Sets size and position of widget.
52         """
53         super().set_geometry()
54         self.current_item.set_geometry()
55         self.current_item.rect.topleft = self.rect.topleft
56
57     def set_surface_size(self, new_surface_size):
58         """
59         Overrides base method to resize every widget state icon, not just the
        current one.
60
61         Args:
62             new_surface_size (list[int, int]): New surface size.
63         """
64         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 instantiated 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)
35
36     @property

```

```

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.
border_width)
93         self._thumb.set_position(self.relative_to_global_position((self.
thumb_position[0], self.thumb_position[1])))
94
95         thumb_surface = self._thumb.get_surface()
96         self.image.blit(thumb_surface, self.thumb_position)
97
98     def process_event(self, event):
99         """
100         Processes Pygame events.
101
102         Args:
103             event (pygame.Event): Event to process.
104
105         Returns:
106             pygame.Color: Current colour slider is displaying.
107         """
108         if event.type not in [pygame.MOUSEMOTION, pygame.MOUSEBUTTONDOWN, pygame.
MOUSEBUTTONUP]:
109             return
110
111         # Gets widget state before and after event is processed by slider thumb
112         before_state = self._thumb.state
113         self._thumb.process_event(event)
114         after_state = self._thumb.state
115
116         # If widget state changes (e.g. hovered -> pressed), redraw widget
117         if before_state != after_state:
118             self.set_image()
119
120         if event.type == pygame.MOUSEMOTION:
121             if self._thumb.state == WidgetState.PRESS:
122                 # Recalculates slider colour based on mouse position change
123                 selected_percent = self.calculate_gradient_percent(event.pos)
124                 self._last_mouse_x = event.pos[0]
125
126                 if selected_percent is not None:
127                     self._selected_percent = selected_percent
128
129                 return self.selected_colour
130
131         if event.type == pygame.MOUSEBUTTONUP:
132             # When user stops scrolling, return new slider colour
133             self._last_mouse_x = None
134             return self.selected_colour
135
136         if event.type == pygame.MOUSEBUTTONDOWN or before_state != after_state:
137             # Redraws widget when slider thumb is hovered or pressed
138             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         # Multiple inheritance used here, adding the functionality of pressing,
20         # and custom box colours, to the text widget
21         _Box.__init__(self, box_colours=INPUT_COLOURS)
22         _Pressable.__init__(
23             self,
24             event=None,
25             hover_func=lambda: self.set_state_colour(WidgetState.HOVER),
26             down_func=lambda: self.set_state_colour(WidgetState.PRESS),
27             up_func=lambda: self.set_state_colour(WidgetState.BASE),
28             sfx=None
29         )
30         Text.__init__(self, text="", center=False, box_colours=INPUT_COLOURS[
31             WidgetState.BASE], **kwargs)
32
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
    is shown
67     def is_placeholder(self, is_true):
68         self._is_placeholder = is_true
69
70         if is_true:
71             self._text_colour = self._placeholder_colour
72         else:
73             self._text_colour = self._text_colour_copy
74
75     @property
76     def cursor_size(self):
77         cursor_height = (self.size[1] - self.border_width * 2) * 0.75
78         return (cursor_height * 0.1, cursor_height)
79
80     @property
81     def cursor_position(self):
82         current_width = (self.margin / 2)
83         for index, metrics in enumerate(self._font.get_metrics(self._text, size=
    self.font_size)):
84             if index == self._cursor_index:
85                 return (current_width - self.cursor_size[0], (self.size[1] - self.
    cursor_size[1]) / 2)
86
87             glyph_width = metrics[4]
88             current_width += glyph_width
89         return (current_width - self.cursor_size[0], (self.size[1] - self.
    cursor_size[1]) / 2)
90
91     @property
92     def text(self):
93         if self.is_placeholder:
94             return ''
95
96         return self._text
97
98     def relative_x_to_cursor_index(self, relative_x):
99         """
100         Calculates cursor index using mouse position relative to the widget
    position.
101
102         Args:
103             relative_x (int): Horizontal distance of the mouse from the left side
    of the widget.
104
105         Returns:
106             int: Cursor index.
107         """
108         current_width = 0
109
110         for index, metrics in enumerate(self._font.get_metrics(self._text, size=
    self.font_size)):
111             glyph_width = metrics[4]
112
113             if current_width >= relative_x:
114                 return index
115
116             current_width += glyph_width
117

```

```

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         self.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     previous_state = self.get_widget_state()
188     super().process_event(event)
189     current_state = self.get_widget_state()
190
191     match event.type:
192         case pygame.MOUSEMOTION:
193             if self._cursor_index is None:
194                 return
195
196             # If mouse is hovering over widget, turn mouse cursor into an I-
197 beam
198             if self.rect.collidepoint(event.pos):
199                 if cursor.get_mode() != CursorMode.IBEAM:
200                     cursor.set_mode(CursorMode.IBEAM)
201             else:
202                 if cursor.get_mode() == CursorMode.IBEAM:
203                     cursor.set_mode(CursorMode.ARROW)
204
205             return
206
207         case pygame.MOUSEBUTTONDOWN:
208             # When user selects widget
209             if previous_state == WidgetState.PRESS:
210                 self.focus_input(event.pos)
211             # When user unselects widget
212             if current_state == WidgetState.BASE and self._cursor_index is not
213 None:
214                 self.unfocus_input()
215                 return CustomEvent(**vars(self._event), text=self.text)
216
217         case pygame.KEYDOWN:
218             if self._cursor_index is None:
219                 return
220
221             # Handling Ctrl-C and Ctrl-V shortcuts
222             if event.mod & (pygame.KMOD_CTRL):
223                 if event.key == pygame.K_c:
224                     logger.info('COPIED')
225
226                 elif event.key == pygame.K_v:
227                     pasted_text = pyperclip.paste()
228                     pasted_text = ''.join(char for char in pasted_text if 32
229 <= ord(char) <= 127)
230                     self._text = self._text[:self._cursor_index] + pasted_text
231                     + self._text[self._cursor_index:]
232                     self._cursor_index += len(pasted_text)
233
234                     self.resize_text()
235                     self.set_image()
236                     self.set_geometry()
237
238             return
239
240     match event.key:

```



```

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

```

```

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

```

1.5 Game

1.5.1 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 CPUThread
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             'ZOBTRIS_KEYS': []

```

```

36     }
37
38     self._cpu = ABMinimaxCPU(self.states['CPU_DEPTH'], self.cpu_callback,
verbose=False)
39     self._cpu_thread = CPUThread(self._cpu)
40     self._cpu_thread.start()
41     self._cpu_move = None
42
43     logger.info(f'Initialising CPU depth of {self.states['CPU_DEPTH']}')
44
45     def register_listener(self, listener, parent_class):
46         """
47         Registers listener method of another MVC class.
48
49         Args:
50             listener (callable): Listener callback function.
51             parent_class (str): Class name.
52         """
53         self._listeners[parent_class].append(listener)
54
55     def alert_listeners(self, event):
56         """
57         Alerts all registered classes of an event by calling their listener
function.
58
59         Args:
60             event (GameEventType): Event to pass as argument.
61
62         Raises:
63             Exception: If an unrecognised event tries to be passed onto listeners.
64         """
65         for parent_class, listeners in self._listeners.items():
66             match event.type:
67                 case GameEventType.UPDATE_PIECES:
68                     if parent_class in 'game':
69                         for listener in listeners: listener(event)
70
71                 case GameEventType.SET_LASER:
72                     if parent_class == 'game':
73                         for listener in listeners: listener(event)
74
75                 case GameEventType.PAUSE_CLICK:
76                     if parent_class in ['pause', 'game']:
77                         for listener in listeners:
78                             listener(event)
79
80                 case _:
81                     raise Exception('Unhandled event type (GameModel.
alert_listeners)')
82
83     def set_winner(self, colour=None):
84         """
85         Sets winner.
86
87         Args:
88             colour (Colour, optional): Describes winnner colour, or draw. Defaults
to None.
89         """
90         self.states['WINNER'] = colour
91
92     def toggle_paused(self):
93         """

```

```

94         Toggles pause screen, and alerts pause view.
95         """
96         self.states['PAUSED'] = not self.states['PAUSED']
97         game_event = CustomEvent.create_event(GameEventType.PAUSE_CLICK)
98         self.alert_listeners(game_event)
99
100     def get_terminal_move(self):
101         """
102         Debugging method for inputting a move from the terminal.
103
104         Returns:
105             Move: Parsed move.
106         """
107         while True:
108             try:
109                 move_type = ip_helpers.parse_move_type(input('Input move type (m/r
110 ): '))
111                 src_square = ip_helpers.parse_notation(input("From: "))
112                 dest_square = ip_helpers.parse_notation(input("To: "))
113                 rotation = ip_helpers.parse_rotation(input("Enter rotation (a/b/c/
114 d): "))
115                 return Move.instance_from_notation(move_type, src_square,
116 dest_square, rotation)
117             except ValueError as error:
118                 logger.warning('Input error (Board.get_move): ' + str(error))
119
120     def make_move(self, move):
121         """
122         Takes a Move object and applies it to the board.
123
124         Args:
125             move (Move): Move to apply.
126         """
127         colour = self._board.bitboards.get_colour_on(move.src)
128         piece = self._board.bitboards.get_piece_on(move.src, colour)
129         # Apply move and get results of laser trajectory
130         laser_result = self._board.apply_move(move, add_hash=True)
131
132         self.alert_listeners(CustomEvent.create_event(GameEventType.SET_LASER ,
133 laser_result=laser_result))
134
135         # Sets new active colour and checks for a win
136         self.states['ACTIVE_COLOUR'] = self._board.get_active_colour()
137         self.set_winner(self._board.check_win())
138
139         move_notation = move.to_notation(colour, piece, laser_result.
140 hit_square_bitboard)
141
142         self.alert_listeners(CustomEvent.create_event(GameEventType.UPDATE_PIECES ,
143 move_notation=move_notation))
144
145         # Adds move to move history list for review screen
146         self.states['MOVES'].append({
147             'time': {
148                 Colour.BLUE: GAME_WIDGETS['blue_timer'].get_time(),
149                 Colour.RED: GAME_WIDGETS['red_timer'].get_time()
150             },
151             'move': move_notation,
152             'laserResult': laser_result
153         })
154
155     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.
204
205         Returns:
206             int: Bitboard representing all empty surrounding squares.
207         """
208         if (bitboard & self._board.get_all_active_pieces()) != EMPTY_BB:
209             return self._board.get_valid_squares(bitboard)
210
211         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

```

1.5.2 View

game_view.py

```

1  import pygame
2  from data.constants import GameEventType, Colour, StatusText, Miscellaneous,
   ShaderType
3  from data.states.game.components.overlay_draw import OverlayDraw
4  from data.states.game.components.capture_draw import CaptureDraw
5  from data.states.game.components.piece_group import PieceGroup
6  from data.states.game.components.laser_draw import LaserDraw
7  from data.states.game.components.father import DragAndDrop
8  from data.utils.bitboard_helpers import bitboard_to_coords
9  from data.utils.board_helpers import screen_pos_to_coords
10 from data.states.game.widget_dict import GAME_WIDGETS
11 from data.components.custom_event import CustomEvent
12 from data.components.widget_group import WidgetGroup
13 from data.components.cursor import Cursor
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 = {
24             GameEventType.UPDATE_PIECES: self.handle_update_pieces,
25             GameEventType.SET_LASER: self.handle_set_laser,
26             GameEventType.PAUSE_CLICK: self.handle_pause,
27         }
28
29         # Register model event handling with process_model_event()

```

```

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

```

```

89         GAME_WIDGETS['status_text'].set_text(f"Game is a draw! Boring
...")
90     else:
91         GAME_WIDGETS['status_text'].set_text(f"{self._model.states['
WINNER'].name} won!")
92     case StatusText.DRAW:
93         GAME_WIDGETS['status_text'].set_text(f"Game is a draw! Boring...")
94
95 def handle_resize(self):
96     """
97     Handles resizing of the window.
98     """
99     self._overlay_draw.handle_resize(self.board_position, self.board_size)
100    self._capture_draw.handle_resize(self.board_position, self.board_size)
101    self._piece_group.handle_resize(self.board_position, self.board_size)
102    self._laser_draw.handle_resize(self.board_position, self.board_size)
103    self._laser_draw.handle_resize(self.board_position, self.board_size)
104    self._widget_group.handle_resize(window.size)
105
106    if self._laser_draw.firing:
107        self.update_laser_mask()
108
109 def handle_update_pieces(self, event=None):
110     """
111     Callback function to update pieces after move.
112
113     Args:
114         event (GameEventType, optional): If updating pieces after player move,
event
contains move information. Defaults to None.
115         toggle_timers (bool, optional): Toggle timers on and off for new
active colour. Defaults to True.
116     """
117     piece_list = self._model.get_piece_list()
118     self._piece_group.initialise_pieces(piece_list, self.board_position, self.
board_size)
119
120     if event:
121         GAME_WIDGETS['move_list'].append_to_move_list(event.move_notation)
122         GAME_WIDGETS['scroll_area'].set_image()
123         audio.play_sfx(SFX['piece_move'])
124
125     if self._model.states['ACTIVE_COLOUR'] == Colour.BLUE:
126         self.set_status_text(StatusText.PLAYER_MOVE)
127     elif self._model.states['CPU_ENABLED'] is False:
128         self.set_status_text(StatusText.PLAYER_MOVE)
129     else:
130         self.set_status_text(StatusText.CPU_MOVE)
131
132     if self._model.states['WINNER'] is not None:
133         self.toggle_timer(self._model.states['ACTIVE_COLOUR'], False)
134         self.toggle_timer(self._model.states['ACTIVE_COLOUR'].
get_flipped_colour(), False)
135
136         self.set_status_text(StatusText.WIN)
137
138         audio.play_sfx(SFX['sphinx_destroy_1'])
139         audio.play_sfx(SFX['sphinx_destroy_2'])
140         audio.play_sfx(SFX['sphinx_destroy_3'])
141
142 def handle_set_laser(self, event):
143     """
144     Callback function to draw laser after move.

```



```

145
146     Args:
147         event (GameEventType): Contains laser trajectory information.
148     """
149     laser_result = event.laser_result
150
151     # If laser has hit a piece
152     if laser_result.hit_square_bitboard:
153         coords_to_remove = bitboard_to_coords(laser_result.hit_square_bitboard
154 )
155         self._piece_group.remove_piece(coords_to_remove)
156
157         if laser_result.piece_colour == Colour.BLUE:
158             GAME_WIDGETS['red_piece_display'].add_piece(laser_result.piece_hit
159 )
160
161         elif laser_result.piece_colour == Colour.RED:
162             GAME_WIDGETS['blue_piece_display'].add_piece(laser_result.
163 piece_hit)
164
165     # Draw piece capture GFX
166     self._capture_draw.add_capture(
167         laser_result.piece_hit,
168         laser_result.piece_colour,
169         laser_result.piece_rotation,
170         coords_to_remove,
171         laser_result.laser_path[0][0],
172         self._model.states['ACTIVE_COLOUR']
173     )
174
175     self._laser_draw.add_laser(laser_result, self._model.states['ACTIVE_COLOUR
176 '])
177     self.update_laser_mask()
178
179 def handle_pause(self, event=None):
180     """
181     Callback function for pausing timer.
182
183     Args:
184         event (None): Event argument not used.
185     """
186     is_active = not(self._model.states['PAUSED'])
187     self.toggle_timer(self._model.states['ACTIVE_COLOUR'], is_active)
188
189 def initialise_timers(self):
190     """
191     Initialises both timers with the correct amount of time and starts the
192     timer for the active colour.
193     """
194     if self._model.states['TIME_ENABLED']:
195         GAME_WIDGETS['blue_timer'].set_time(self._model.states['TIME'] * 60 *
196 1000)
197         GAME_WIDGETS['red_timer'].set_time(self._model.states['TIME'] * 60 *
198 1000)
199     else:
200         GAME_WIDGETS['blue_timer'].kill()
201         GAME_WIDGETS['red_timer'].kill()
202
203     self.toggle_timer(self._model.states['ACTIVE_COLOUR'], True)
204
205 def toggle_timer(self, colour, is_active):
206     """
207     Stops or resumes timer.

```

```

200
201     Args:
202         colour (Colour): Timer to toggle.
203         is_active (bool): Whether to pause or resume timer.
204     """
205     if colour == Colour.BLUE:
206         GAME_WIDGETS['blue_timer'].set_active(is_active)
207     elif colour == Colour.RED:
208         GAME_WIDGETS['red_timer'].set_active(is_active)
209
210     def update_laser_mask(self):
211         """
212         Uses pygame.mask to create a mask for the pieces.
213         Used for occluding the ray shader.
214         """
215         temp_surface = pygame.Surface(window.size, pygame.SRCALPHA)
216         self._piece_group.draw(temp_surface)
217         mask = pygame.mask.from_surface(temp_surface, threshold=127)
218         mask_surface = mask.to_surface(unsetcolor=(0, 0, 0, 255), setcolor=(255,
219 0, 0, 255))
220
221         window.set_apply_arguments(ShaderType.RAYS, occlusion=mask_surface)
222
223     def draw(self):
224         """
225         Draws GUI and pieces onto the screen.
226         """
227         self._widget_group.update()
228         self._capture_draw.update()
229
230         self._widget_group.draw()
231         self._overlay_draw.draw(window.screen)
232
233         if self._hide_pieces is False:
234             self._piece_group.draw(window.screen)
235
236         self._laser_draw.draw(window.screen)
237         self._drag_and_drop.draw(window.screen)
238         self._capture_draw.draw(window.screen)
239
240     def process_model_event(self, event):
241         """
242         Registered listener function for handling GameModel events.
243         Each event is mapped to a callback function, and the appropriate one is run
244         .
245
246     Args:
247         event (GameEventType): Game event to process.
248
249     Raises:
250         KeyError: If an unrecognised event type is passed as the argument.
251     """
252     try:
253         self._event_to_func_map.get(event.type)(event)
254     except:
255         raise KeyError('Event type not recognized in Game View (GameView.
256 process_model_event):', event.type)
257
258     def set_overlay_coords(self, available_coords_list, selected_coord):
259         """
260         Set board coordinates for potential moves overlay.

```

```

259         Args:
260             available_coords_list (list[tuple[int, int]], ...): Array of
coordinates
261             selected_coord (list[int, int]): Coordinates of selected piece.
262         """
263         self._selected_coords = selected_coord
264         self._overlay_draw.set_selected_coords(selected_coord)
265         self._overlay_draw.set_available_coords(available_coords_list)
266
267     def get_selected_coords(self):
268         return self._selected_coords
269
270     def set_dragged_piece(self, piece, colour, rotation):
271         """
272         Passes information of the dragged piece to the dragging drawing class.
273
274         Args:
275             piece (Piece): Piece type of dragged piece.
276             colour (Colour): Colour of dragged piece.
277             rotation (Rotation): Rotation of dragged piece.
278         """
279         self._drag_and_drop.set_dragged_piece(piece, colour, rotation)
280
281     def remove_dragged_piece(self):
282         """
283         Stops drawing dragged piece when user lets go of piece.
284         """
285         self._drag_and_drop.remove_dragged_piece()
286
287     def convert_mouse_pos(self, event):
288         """
289         Passes information of what mouse cursor is interacting with to a
GameController object.
290
291         Args:
292             event (pygame.Event): Mouse event to process.
293
294         Returns:
295             CustomEvent | None: Contains information what mouse is doing.
296         """
297         clicked_coords = screen_pos_to_coords(event.pos, self.board_position, self
.board_size)
298
299         if event.type == pygame.MOUSEBUTTONDOWN:
300             if clicked_coords:
301                 return CustomEvent.create_event(GameEventType.BOARD_CLICK, coords=
clicked_coords)
302
303             else:
304                 return None
305
306         elif event.type == pygame.MOUSEBUTTONUP:
307             if self._drag_and_drop.dragged_sprite:
308                 piece, colour, rotation = self._drag_and_drop.get_dragged_info()
309                 piece_dragged = self._drag_and_drop.remove_dragged_piece()
310                 return CustomEvent.create_event(GameEventType.PIECE_DROP, coords=
clicked_coords, piece=piece, colour=colour, rotation=rotation, remove_overlay=
piece_dragged)
311
312     def add_help_screen(self):
313         """
314         Draw help overlay when player clicks on the help button.

```

```

315         """
316         self._widget_group.add(GAME_WIDGETS['help'])
317         self._widget_group.handle_resize(window.size)
318
319     def add_tutorial_screen(self):
320         """
321         Draw tutorial overlay when player clicks on the tutorial button.
322         """
323         self._widget_group.add(GAME_WIDGETS['tutorial'])
324         self._widget_group.handle_resize(window.size)
325         self._hide_pieces = True
326
327     def remove_help_screen(self):
328         GAME_WIDGETS['help'].kill()
329
330     def remove_tutorial_screen(self):
331         GAME_WIDGETS['tutorial'].kill()
332         self._hide_pieces = False
333
334     def process_widget_event(self, event):
335         """
336         Passes Pygame event to WidgetGroup to allow individual widgets to process
337         events.
338
339         Args:
340             event (pygame.Event): Event to process.
341
342         Returns:
343             CustomEvent | None: A widget event.
344         """
345         return self._widget_group.process_event(event)

```

1.5.3 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_new_game):
11         self._model = model
12         self._view = view
13         self._win_view = win_view
14         self._pause_view = pause_view
15
16         self._to_menu = to_menu
17         self._to_new_game = to_new_game
18
19         self._view.initialise_timers()
20
21     def cleanup(self, next):
22         """
23         Handles game quit, either leaving to main menu or restarting a new game.
24
25         Args:

```

```

26         next (str): New state to switch to.
27     """
28     self._model.kill_thread()
29
30     if next == 'menu':
31         self._to_menu()
32     elif next == 'game':
33         self._to_new_game()
34
35 def make_move(self, move):
36     """
37     Handles player move.
38
39     Args:
40         move (Move): Move to make.
41     """
42     self._model.make_move(move)
43     self._view.set_overlay_coords([], None)
44
45     if self._model.states['CPU_ENABLED']:
46         self._model.make_cpu_move()
47
48 def handle_pause_event(self, event):
49     """
50     Processes events when game is paused.
51
52     Args:
53         event (GameEventType): Event to process.
54
55     Raises:
56         Exception: If event type is unrecognised.
57     """
58     game_event = self._pause_view.convert_mouse_pos(event)
59
60     if game_event is None:
61         return
62
63     match game_event.type:
64         case GameEventType.PAUSE_CLICK:
65             self._model.toggle_paused()
66
67         case GameEventType.MENU_CLICK:
68             self.cleanup('menu')
69
70         case _:
71             raise Exception('Unhandled event type (GameController.handle_event
72 )')
73
74 def handle_winner_event(self, event):
75     """
76     Processes events when game is over.
77
78     Args:
79         event (GameEventType): Event to process.
80
81     Raises:
82         Exception: If event type is unrecognised.
83     """
84     game_event = self._win_view.convert_mouse_pos(event)
85
86     if game_event is None:
87         return

```

```

87
88         match game_event.type:
89             case GameEventType.MENU_CLICK:
90                 self.cleanup('menu')
91                 return
92
93             case GameEventType.GAME_CLICK:
94                 self.cleanup('game')
95                 return
96
97             case _:
98                 raise Exception('Unhandled event type (GameController.handle_event
99             )')
100
101     def handle_game_widget_event(self, event):
102         """
103         Processes events for game GUI widgets.
104
105         Args:
106             event (GameEventType): Event to process.
107
108         Raises:
109             Exception: If event type is unrecognised.
110
111         Returns:
112             CustomEvent | None: A widget event.
113         """
114         widget_event = self._view.process_widget_event(event)
115
116         if widget_event is None:
117             return None
118
119         match widget_event.type:
120             case GameEventType.ROTATE_PIECE:
121                 src_coords = self._view.get_selected_coords()
122
123                 if src_coords is None:
124                     logger.info('None square selected')
125                     return
126
127                 move = Move.instance_from_coords(MoveType.ROTATE, src_coords,
128                 src_coords, rotation_direction=widget_event.rotation_direction)
129                 self.make_move(move)
130
131             case GameEventType.RESIGN_CLICK:
132                 self._model.set_winner(self._model.states['ACTIVE_COLOUR'].
133                 get_flipped_colour())
134                 self._view.set_status_text(StatusText.WIN)
135
136             case GameEventType.DRAW_CLICK:
137                 self._model.set_winner(Miscellaneous.DRAW)
138                 self._view.set_status_text(StatusText.DRAW)
139
140             case GameEventType.TIMER_END:
141                 if self._model.states['TIME_ENABLED']:
142                     self._model.set_winner(widget_event.active_colour.
143                     get_flipped_colour())
144
145             case GameEventType.MENU_CLICK:
146                 self.cleanup('menu')
147
148             case GameEventType.HELP_CLICK:

```

```

145         self._view.add_help_screen()
146
147         case GameEventType.TUTORIAL_CLICK:
148             self._view.add_tutorial_screen()
149
150         case _:
151             raise Exception('Unhandled event type (GameController.handle_event
)')
152
153     return widget_event.type
154
155 def check_cpu(self):
156     """
157     Checks if CPU calculations are finished every frame.
158     """
159     if self._model.states['CPU_ENABLED'] and self._model.states['AWAITING_CPU'
] is False:
160         self._model.check_cpu()
161
162 def handle_game_event(self, event):
163     """
164     Processes Pygame events for main game.
165
166     Args:
167         event (pygame.Event): If event type is unrecognised.
168
169     Raises:
170         Exception: If event type is unrecognised.
171     """
172     # Pass event for widgets to process
173     widget_event = self.handle_game_widget_event(event)
174
175     if event.type in [pygame.MOUSEBUTTONDOWN, pygame.MOUSEBUTTONUP, pygame.
KEYDOWN]:
176         if event.type != pygame.KEYDOWN:
177             game_event = self._view.convert_mouse_pos(event)
178         else:
179             game_event = None
180
181         if game_event is None:
182             if widget_event is None:
183                 if event.type in [pygame.MOUSEBUTTONUP, pygame.KEYDOWN]:
184                     # If user releases mouse click not on a widget
185                     self._view.remove_help_screen()
186                     self._view.remove_tutorial_screen()
187                 if event.type == pygame.MOUSEBUTTONUP:
188                     # If user releases mouse click on neither a widget or
board
189                     self._view.set_overlay_coords(None, None)
190
191             return
192
193         match game_event.type:
194             case GameEventType.BOARD_CLICK:
195                 if self._model.states['AWAITING_CPU']:
196                     return
197
198                 clicked_coords = game_event.coords
199                 clicked_bitboard = bb_helpers.coords_to_bitboard(
clicked_coords)
200                 selected_coords = self._view.get_selected_coords()
201

```

```

202         if selected_coords:
203             if clicked_coords == selected_coords:
204                 # If clicking on an already selected square, start
dragging piece on that square
205                 self._view.set_dragged_piece(*self._model.
get_piece_info(clicked_bitboard))
206                 return
207
208                 selected_bitboard = bb_helpers.coords_to_bitboard(
selected_coords)
209                 available_bitboard = self._model.get_available_moves(
selected_bitboard)
210
211                 if bb_helpers.is_occupied(clicked_bitboard,
available_bitboard):
212                     # If the newly clicked square is not the same as the
old one, and is an empty surrounding square, make a move
213                     move = Move.instance_from_coords(MoveType.MOVE,
selected_coords, clicked_coords)
214                     self.make_move(move)
215                 else:
216                     # If the newly clicked square is not the same as the
old one, but is an invalid square, unselect the currently selected square
217                     self._view.set_overlay_coords(None, None)
218
219                     # Select hovered square if it is same as active colour
220                     elif self._model.is_selectable(clicked_bitboard):
221                         available_bitboard = self._model.get_available_moves(
clicked_bitboard)
222                         self._view.set_overlay_coords(bb_helpers.
bitboard_to_coords_list(available_bitboard), clicked_coords)
223                         self._view.set_dragged_piece(*self._model.get_piece_info(
clicked_bitboard))
224
225             case GameEventType.PIECE_DROP:
226                 hovered_coords = game_event.coords
227
228                 # if piece is dropped onto the board
229                 if hovered_coords:
230                     hovered_bitboard = bb_helpers.coords_to_bitboard(
hovered_coords)
231                     selected_coords = self._view.get_selected_coords()
232                     selected_bitboard = bb_helpers.coords_to_bitboard(
selected_coords)
233                     available_bitboard = self._model.get_available_moves(
selected_bitboard)
234
235                     if bb_helpers.is_occupied(hovered_bitboard,
available_bitboard):
236                         # Make a move if mouse is hovered over an empty
surrounding square
237                         move = Move.instance_from_coords(MoveType.MOVE,
selected_coords, hovered_coords)
238                         self.make_move(move)
239
240                     if game_event.remove_overlay:
241                         self._view.set_overlay_coords(None, None)
242
243                     self._view.remove_dragged_piece()
244
245             case _:

```



```

246         raise Exception('Unhandled event type (GameController.
handle_event)', game_event.type)
247
248     def handle_event(self, event):
249         """
250         Passe a Pygame event to the correct handling function according to the
game state.
251
252         Args:
253             event (pygame.Event): Event to process.
254         """
255         if event.type in [pygame.MOUSEBUTTONDOWN, pygame.MOUSEBUTTONUP, pygame.
MOUSEMOTION, pygame.KEYDOWN]:
256             if self._model.states['PAUSED']:
257                 self.handle_pause_event(event)
258             elif self._model.states['WINNER'] is not None:
259                 self.handle_winner_event(event)
260             else:
261                 self.handle_game_event(event)
262
263         if event.type == pygame.KEYDOWN:
264             if event.key == pygame.K_ESCAPE:
265                 self._model.toggle_paused()
266             elif event.key == pygame.K_l:
267                 logger.info('\nSTOPPING CPU')
268                 self._model._cpu_thread.stop_cpu() #temp

```

1.5.4 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="sc3ncfcncpb2/2pc7/3Pd6/pa1Pc1rbra1pb1Pd/
pb1Pd1RaRb1pa1Pc/6pb3/7Pa2/2PdNaFaNa3Sa b"):
11         self.bitboards = BitboardCollection(fen_string)
12         self.hash_list = [self.bitboards.get_hash()]
13
14     def __str__(self):
15         """
16         Returns a string representation of the board.
17
18         Returns:
19             str: Board formatted as string.
20         """
21         characters = ''
22         pieces = defaultdict(int)
23
24         for rank in reversed(Rank):

```

```

25         for file in File:
26             mask = 1 << (rank * 10 + file)
27             blue_piece = self.bitboards.get_piece_on(mask, Colour.BLUE)
28             red_piece = self.bitboards.get_piece_on(mask, Colour.RED)
29
30             if blue_piece:
31                 pieces[blue_piece.value.upper()] += 1
32                 characters += f'{blue_piece.upper()} '
33             elif red_piece:
34                 pieces[red_piece.value] += 1
35                 characters += f'{red_piece} '
36             else:
37                 characters += '. '
38
39             characters += '\n\n'
40
41             characters += str(dict(pieces))
42             characters += f'\nCURRENT PLAYER TO MOVE: {self.bitboards.active_colour.
name}\n'
43             return characters
44
45     def get_piece_list(self):
46         """
47         Converts the board bitboards to a list of pieces.
48
49         Returns:
50             list: List of Pieces.
51         """
52         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 Pharoah 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.
active_colour)
101
102         if piece_symbol is None:
103             raise ValueError('Invalid move - no piece found on source square')
104         elif piece_symbol == Piece.SPHINX:
105             raise ValueError('Invalid move - sphinx piece is immovable')
106
107         if move.move_type == MoveType.MOVE:
108             possible_moves = self.get_valid_squares(move.src)
109             if bb_helpers.is_occupied(move.dest, possible_moves) is False:
110                 raise ValueError('Invalid move - destination square is occupied')
111
112             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.
active_colour)
119             piece_rotation = self.bitboards.get_rotation_on(move.src)
120
121             if move.rotation_direction == RotationDirection.CLOCKWISE:
122                 new_rotation = piece_rotation.get_clockwise()
123             elif move.rotation_direction == RotationDirection.ANTICLOCKWISE:
124                 new_rotation = piece_rotation.get_anticlockwise()
125
126             self.bitboards.update_rotation(move.src, move.src, new_rotation)
127
128         laser = None
129         if fire_laser:
130             laser = self.fire_laser(add_hash)
131
132         if add_hash:
133             self.hash_list.append(self.bitboards.get_hash())
134
135         self.bitboards.flip_colour()
136
137         return laser
138
139     def undo_move(self, move, laser_result):
140         """
141         Undoes a move on the board.
142
143         Args:
144             move (Move): The move to undo.

```

```

145         laser_result (Laser): The laser trajectory result.
146     """
147     self.bitboards.flip_colour()
148
149     if laser_result.hit_square_bitboard:
150         # Get info of destroyed piece, and add it to the board again
151         src = laser_result.hit_square_bitboard
152         piece = laser_result.piece_hit
153         colour = laser_result.piece_colour
154         rotation = laser_result.piece_rotation
155
156         self.bitboards.set_square(src, piece, colour)
157         self.bitboards.clear_rotation(src)
158         self.bitboards.set_rotation(src, rotation)
159
160         # Create new Move object that is the inverse of the passed move
161         if move.move_type == MoveType.MOVE:
162             reversed_move = Move.instance_from_bitboards(MoveType.MOVE, move.dest,
163 move.src)
164         elif move.move_type == MoveType.ROTATE:
165             reversed_move = Move.instance_from_bitboards(MoveType.ROTATE, move.src
166 , move.src, move.rotation_direction.get_opposite())
167
168         self.apply_move(reversed_move, fire_laser=False)
169         self.bitboards.flip_colour()
170
171     def remove_piece(self, square_bitboard):
172         """
173         Removes a piece from a given square.
174
175         Args:
176             square_bitboard (int): The bitboard representation of the square.
177         """
178         self.bitboards.clear_square(square_bitboard, Colour.BLUE)
179         self.bitboards.clear_square(square_bitboard, Colour.RED)
180         self.bitboards.clear_rotation(square_bitboard)
181
182     def get_valid_squares(self, src_bitboard, colour=None):
183         """
184         Gets valid squares for a piece to move to.
185
186         Args:
187             src_bitboard (int): The bitboard representation of the source square.
188             colour (Colour, optional): The active colour of the piece.
189
190         Returns:
191             int: The bitboard representation of valid squares.
192         """
193         target_top_left = (src_bitboard & A_FILE_MASK & EIGHT_RANK_MASK) << 9
194         target_top_middle = (src_bitboard & EIGHT_RANK_MASK) << 10
195         target_top_right = (src_bitboard & J_FILE_MASK & EIGHT_RANK_MASK) << 11
196         target_middle_right = (src_bitboard & J_FILE_MASK) << 1
197
198         target_bottom_right = (src_bitboard & J_FILE_MASK & ONE_RANK_MASK) >> 9
199         target_bottom_middle = (src_bitboard & ONE_RANK_MASK) >> 10
200         target_bottom_left = (src_bitboard & A_FILE_MASK & ONE_RANK_MASK) >> 11
201         target_middle_left = (src_bitboard & A_FILE_MASK) >> 1
202
203         possible_moves = target_top_left | target_top_middle | target_top_right |
204 target_middle_right | target_bottom_right | target_bottom_middle |
205 target_bottom_left | target_middle_left

```

```

203         if colour is not None:
204             valid_possible_moves = possible_moves & ~self.bitboards.
combined_colour_bitboards[colour]
205         else:
206             valid_possible_moves = possible_moves & ~self.bitboards.
combined_all_bitboard
207
208         return valid_possible_moves
209
210     def get_all_valid_squares(self, colour):
211         """
212         Gets all valid squares for a given colour.
213
214         Args:
215             colour (Colour): The colour of the pieces.
216
217         Returns:
218             int: The bitboard representation of all valid squares.
219         """
220         piece_bitboard = self.bitboards.combined_colour_bitboards[colour]
221         possible_moves = 0b0
222
223         for square in bb_helpers.occupied_squares(piece_bitboard):
224             possible_moves |= self.get_valid_squares(square)
225
226         return possible_moves
227
228     def get_all_active_pieces(self):
229         """
230         Gets all active pieces for the current player.
231
232         Returns:
233             int: The bitboard representation of all active pieces.
234         """
235         active_pieces = self.bitboards.combined_colour_bitboards[self.bitboards.
active_colour]
236         sphinx_bitboard = self.bitboards.get_piece_bitboard(Piece.SPHINX, self.
bitboards.active_colour)
237         return active_pieces ^ sphinx_bitboard
238
239     def fire_laser(self, remove_hash):
240         """
241         Fires the laser and removes hit pieces.
242
243         Args:
244             remove_hash (bool): Whether to clear the hash list if a piece is hit.
245
246         Returns:
247             Laser: The result of firing the laser.
248         """
249         laser = Laser(self.bitboards)
250
251         if laser.hit_square_bitboard:
252             self.remove_piece(laser.hit_square_bitboard)
253
254             if remove_hash:
255                 self.hash_list = [] # Remove all hashes for threefold repetition,
as the position is impossible to be repeated after a piece is removed
256         return laser
257
258     def generate_square_moves(self, src):
259         """

```

```

260         Generates all valid moves for a piece on a given square.
261
262     Args:
263         src (int): The bitboard representation of the source square.
264
265     Yields:
266         Move: A valid move for the piece.
267     """
268     for dest in bb_helpers.occupied_squares(self.get_valid_squares(src)):
269         yield Move(MoveType.MOVE, src, dest)
270
271 def generate_all_moves(self, colour):
272     """
273     Generates all valid moves for a given colour.
274
275     Args:
276         colour (Colour): The colour of the pieces.
277
278     Yields:
279         Move: A valid move for the active colour.
280     """
281     sphinx_bitboard = self.bitboards.get_piece_bitboard(Piece.SPHINX, colour)
282     # Remove source squares for Sphinx pieces, as they cannot be moved
283     sphinx_masked_bitboard = self.bitboards.combined_colour_bitboards[colour]
284     ~ sphinx_bitboard
285
286     for square in bb_helpers.occupied_squares(sphinx_masked_bitboard):
287         # Generate movement moves
288         yield from self.generate_square_moves(square)
289
290         # Generate rotational moves
291         for rotation_direction in RotationDirection:
292             yield Move(MoveType.ROTATE, square, rotation_direction=
rotation_direction)

```

1.5.5 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:
EMPTY_BB for char in Piece}]
12         self.combined_colour_bitboards = [EMPTY_BB, EMPTY_BB]
13         self.combined_all_bitboard = EMPTY_BB
14         self.rotation_bitboards = [EMPTY_BB, EMPTY_BB]
15         self.active_colour = Colour.BLUE
16         self._hasher = ZobristHasher()
17

```

```

18         try:
19             if fen_string:
20                 self.piece_bitboards, self.combined_colour_bitboards, self.
combined_all_bitboard, self.rotation_bitboards, self.active_colour =
parse_fen_string(fen_string)
21                 self.initialise_hash()
22         except ValueError as error:
23             logger.info('Please input a valid FEN string:', error)
24             raise error
25
26     def __str__(self):
27         """
28         Returns a string representation of the bitboards.
29
30         Returns:
31             str: Bitboards formatted with piece type and colour shown.
32         """
33         characters = ''
34         for rank in reversed(Rank):
35             for file in File:
36                 bitboard = 1 << (rank * 10 + file)
37
38                 colour = self.get_colour_on(bitboard)
39                 piece = self.get_piece_on(bitboard, Colour.BLUE) or self.
get_piece_on(bitboard, Colour.RED)
40
41                 if piece is not None:
42                     characters += f'{piece.upper()} ' if colour == Colour.BLUE
else piece} '
43                 else:
44                     characters += '. '
45
46             characters += '\n\n'
47
48         return characters
49
50     def get_rotation_string(self):
51         """
52         Returns a string representation of the board rotations.
53
54         Returns:
55             str: Board formatted with only rotations shown.
56         """
57         characters = ''
58         for rank in reversed(Rank):
59
60             for file in File:
61                 mask = 1 << (rank * 10 + file)
62                 rotation = self.get_rotation_on(mask)
63                 has_piece = bb_helpers.is_occupied(self.combined_all_bitboard,
mask)
64
65                 if has_piece:
66                     characters += f'{rotation.upper()} '
67                 else:
68                     characters += '. '
69
70             characters += '\n\n'
71
72         return characters
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()
99
100     if self.active_colour == Colour.RED:
101         self._hasher.apply_red_move_hash()
102
103 def update_move(self, src, dest):
104     """
105     Updates the bitboards for a move.
106
107     Args:
108         src (int): The bitboard representation of the source square.
109         dest (int): The bitboard representation of the destination square.
110     """
111     piece = self.get_piece_on(src, self.active_colour)
112
113     self.clear_square(src, Colour.BLUE)
114     self.clear_square(dest, Colour.BLUE)
115     self.clear_square(src, Colour.RED)
116     self.clear_square(dest, Colour.RED)
117
118     self.set_square(dest, piece, self.active_colour)
119
120 def update_rotation(self, src, dest, new_rotation):
121     """
122     Updates the rotation bitboards for a move.
123
124     Args:
125         src (int): The bitboard representation of the source square.
126         dest (int): The bitboard representation of the destination square.
127         new_rotation (Rotation): The new rotation.
128     """
129     self.clear_rotation(src)
130     self.set_rotation(dest, new_rotation)
131
132 def clear_rotation(self, bitboard):
133     """
134     Clears the rotation for a given square.
135
136     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(
rotation_1, bitboard)
140     self.rotation_bitboards[RotationIndex.SECONDBIT] = bb_helpers.clear_square
(rotation_2, bitboard)
141
142     self._hasher.apply_rotation_hash(bitboard, old_rotation)
143
144 def clear_square(self, bitboard, colour):
145     """
146     Clears a square piece and rotation for a given colour.
147
148     Args:
149         bitboard (int): The bitboard representation of the square.
150         colour (Colour): The colour to clear.
151     """
152     piece = self.get_piece_on(bitboard, colour)
153
154     if piece is None:
155         return
156
157     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(
piece_bitboard, bitboard)
162     self.combined_colour_bitboards[colour] = bb_helpers.clear_square(
colour_bitboard, bitboard)
163     self.combined_all_bitboard = bb_helpers.clear_square(all_bitboard,
bitboard)
164
165     self._hasher.apply_piece_hash(bitboard, piece, colour)
166
167 def set_rotation(self, bitboard, rotation):
168     """
169     Sets the rotation for a given square.
170
171     Args:
172         bitboard (int): The bitboard representation of the square.
173         rotation (Rotation): The rotation to set.
174     """
175     rotation_1, rotation_2 = self.rotation_bitboards
176     self._hasher.apply_rotation_hash(bitboard, rotation)
177
178     match rotation:
179         case Rotation.UP:
180             return
181         case Rotation.RIGHT:
182             self.rotation_bitboards[RotationIndex.FIRSTBIT] = bb_helpers.
set_square(rotation_1, bitboard)
183             return
184         case Rotation.DOWN:
185             self.rotation_bitboards[RotationIndex.SECONDBIT] = bb_helpers.
set_square(rotation_2, bitboard)
186             return
187         case Rotation.LEFT:
188             self.rotation_bitboards[RotationIndex.FIRSTBIT] = bb_helpers.
set_square(rotation_1, bitboard)

```

```

189         self.rotation_bitboards[RotationIndex.SECONDBIT] = bb_helpers.
set_square(rotation_2, bitboard)
190         return
191     case _:
192         raise ValueError('Invalid rotation input (bitboard.py):', rotation
)
193
194 def set_square(self, bitboard, piece, colour):
195     """
196     Sets a piece on a given square.
197
198     Args:
199         bitboard (int): The bitboard representation of the square.
200         piece (Piece): The piece to set.
201         colour (Colour): The colour of the piece.
202     """
203     piece_bitboard = self.get_piece_bitboard(piece, colour)
204     colour_bitboard = self.combined_colour_bitboards[colour]
205     all_bitboard = self.combined_all_bitboard
206
207     self.piece_bitboards[colour][piece] = bb_helpers.set_square(piece_bitboard
, bitboard)
208     self.combined_colour_bitboards[colour] = bb_helpers.set_square(
colour_bitboard, bitboard)
209     self.combined_all_bitboard = bb_helpers.set_square(all_bitboard, bitboard)
210
211     self._hasher.apply_piece_hash(bitboard, piece, colour)
212
213 def get_piece_bitboard(self, piece, colour):
214     """
215     Gets the bitboard for a piece type for a given colour.
216
217     Args:
218         piece (Piece): The piece bitboard to get.
219         colour (Colour): The colour of the piece.
220
221     Returns:
222         int: The bitboard representation for all squares occupied by that
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],
target_bitboard)):
238         return None
239
240     return next(
241         (piece for piece in Piece if
242          bb_helpers.is_occupied(self.get_piece_bitboard(piece, colour),
target_bitboard)),
243         None)

```

```

244
245 def get_rotation_on(self, target_bitboard):
246     """
247     Gets the rotation on a given square.
248
249     Args:
250         target_bitboard (int): The bitboard representation of the square.
251
252     Returns:
253         Rotation: The rotation on the square.
254     """
255     rotationBits = [bb_helpers.is_occupied(self.rotation_bitboards[
RotationIndex.SECONDBIT], target_bitboard), bb_helpers.is_occupied(self.
rotation_bitboards[RotationIndex.FIRSTBIT], target_bitboard)]
256
257     match rotationBits:
258         case [False, False]:
259             return Rotation.UP
260         case [False, True]:
261             return Rotation.RIGHT
262         case [True, False]:
263             return Rotation.DOWN
264         case [True, True]:
265             return Rotation.LEFT
266
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

```

1.6 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 to 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 return to `find_move` and passed and run with the callback function.

1.6.1 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        """

```

```

18     self.initialise_stats()
19     best_score, best_move = self.search(board, self._max_depth, stop_event)
20
21     if self._verbose:
22         self.print_stats(best_score, best_move)
23
24     self._callback(best_move)
25
26 def search(self, board, depth, stop_event):
27     """
28     Recursively DFS through minimax tree with evaluation score.
29
30     Args:
31         board (Board): The current board state.
32         depth (int): The current search depth.
33         stop_event (threading.Event): Event used to kill search from an
external class.
34     Returns:
35         tuple[int, Move]: The best score and the best move found.
36     """
37     if (base_case := super().search(board, depth, stop_event)):
38         return base_case
39
40     best_move = None
41
42     # 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 new_score > max_score:
52                 max_score = new_score
53                 best_move = move
54             elif new_score == max_score:
55                 # If evaluated scores are equal, pick a random move
56                 choice([best_move, move])
57
58             board.undo_move(move, laser_result)
59
60         return max_score, best_move
61
62     else:
63         min_score = Score.INFINITE
64
65         for move in board.generate_all_moves(Colour.RED):
66             laser_result = board.apply_move(move)
67             new_score = self.search(board, depth - 1, stop_event)[0]
68
69             if new_score < min_score:
70                 min_score = new_score
71                 best_move = move
72             elif new_score == min_score:
73                 choice([best_move, move])
74
75             board.undo_move(move, laser_result)
76
77         return min_score, best_move

```

1.6.2 Alpha-beta Pruning

alpha_beta.py

```
1 from data.constants import Score, Colour
2 from data.states.game.cpu.base import BaseCPU
3 from random import choice
4
5 class ABMinimaxCPU(BaseCPU):
6     def __init__(self, max_depth, callback, verbose=True):
7         super().__init__(callback, verbose)
8         self._max_depth = max_depth
9
10    def initialise_stats(self):
11        """
12        Initialises the number of prunes to the statistics dictionary to be logged
13        """
14        super().initialise_stats()
15        self._stats['beta_prunes'] = 0
16        self._stats['alpha_prunes'] = 0
17
18    def find_move(self, board, stop_event):
19        """
20        Finds the best move for the current board state.
21
22        Args:
23            board (Board): The current board state.
24            stop_event (threading.Event): Event used to kill search from an
25            external class.
26        """
27        self.initialise_stats()
28        best_score, best_move = self.search(board, self._max_depth, -Score.
29        INFINITE, Score.INFINITE, stop_event)
30
31        if self._verbose:
32            self.print_stats(best_score, best_move)
33
34        self._callback(best_move)
35
36    def search(self, board, depth, alpha, beta, stop_event):
37        """
38        Recursively DFS through minimax tree while pruning branches using the
39        alpha and beta bounds.
40
41        Args:
42            board (Board): The current board state.
43            depth (int): The current search depth.
44            alpha (int): The upper bound value.
45            beta (int): The lower bound value.
46            stop_event (threading.Event): Event used to kill search from an
47            external class.
48
49        Returns:
50            tuple[int, Move]: The best score and the best move found.
51        """
52        if (base_case := super().search(board, depth, stop_event)):
53            return base_case
54
55        best_move = None
56
57        # Blue is the maximising player
```

```

54         if board.get_active_colour() == Colour.BLUE:
55             max_score = -Score.INFINITE
56
57         for move in board.generate_all_moves(Colour.BLUE):
58             laser_result = board.apply_move(move)
59             new_score = self.search(board, depth - 1, alpha, beta, stop_event)
[0]
60
61             if new_score > max_score:
62                 max_score = new_score
63                 best_move = move
64
65             board.undo_move(move, laser_result)
66
67             alpha = max(alpha, max_score)
68
69             if beta <= alpha:
70                 self._stats['alpha_prunes'] += 1
71                 break
72
73             return max_score, best_move
74
75         else:
76             min_score = Score.INFINITE
77
78         for move in board.generate_all_moves(Colour.RED):
79             laser_result = board.apply_move(move)
80             new_score = self.search(board, depth - 1, alpha, beta, stop_event)
[0]
81
82             if new_score < min_score:
83                 min_score = new_score
84                 best_move = move
85
86             board.undo_move(move, laser_result)
87
88             beta = min(beta, min_score)
89             if beta <= alpha:
90                 self._stats['beta_prunes'] += 1
91                 break
92
93             return min_score, best_move

```

1.6.3 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.

`transposition_table.py`

```

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 search(self, board, depth, alpha, beta, stop_event):
10         """

```

```

11         Searches transposition table for a cached move before running a full
search if necessary.
12         Caches the searched result.
13
14     Args:
15         board (Board): The current board state.
16         depth (int): The current search depth.
17         alpha (int): The upper bound value.
18         beta (int): The lower bound value.
19         stop_event (threading.Event): Event used to kill search from an
external class.
20
21     Returns:
22         tuple[int, Move]: The best score and the best move found.
23     """
24     hash = board.to_hash()
25     score, move = self._table.get_entry(hash, depth, alpha, beta)
26
27     if score is not None:
28         self._stats['cache_hits'] += 1
29         self._stats['nodes'] += 1
30
31         return score, move
32     else:
33         # If board hash entry not found in cache, run a full search
34         score, move = super().search(board, depth, alpha, beta, stop_event)
35         self._table.insert_entry(score, move, hash, depth, alpha, beta)
36
37         return score, move
38
39 class TTMinimaxCPU(TranspositionTableMixin, ABMinimaxCPU):
40     def initialise_stats(self):
41         """
42         Initialises cache statistics to be logged.
43         """
44         super().initialise_stats()
45         self._stats['cache_hits'] = 0
46
47     def print_stats(self, score, move):
48         """
49         Logs the statistics for the search.
50
51         Args:
52             score (int): The best score found.
53             move (Move): The best move found.
54         """
55         # Calculate number of cached entries retrieved as a percentage of all
nodes
56         self._stats['cache_hits_percentage'] = round(self._stats['cache_hits'] /
self._stats['nodes'], 3)
57         self._stats['cache_entries'] = len(self._table._table)
58         super().print_stats(score, move)

```

1.6.4 Evaluator

evaluator.py

```

1 from data.utils.bitboard_helpers import pop_count, occupied_squares,
bitboard_to_index
2 from data.states.game.components.psqt import PSQT, FLIP
3 from data.managers.logs import initialise_logger

```



```

4 from data.constants import Colour, Piece, Score
5
6 logger = initialise_logger(__name__)
7
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_pieces(board, Colour.BLUE) +
26             self.evaluate_position(board, Colour.BLUE) +
27             self.evaluate_mobility(board, Colour.BLUE) +
28             self.evaluate_pharoah_safety(board, Colour.BLUE)
29         )
30
31         red_score = (
32             self.evaluate_pieces(board, Colour.RED) +
33             self.evaluate_position(board, Colour.RED) +
34             self.evaluate_mobility(board, Colour.RED) +
35             self.evaluate_pharoah_safety(board, Colour.RED)
36         )
37
38         if self._verbose:
39             logger.info('\nPosition:', self.evaluate_position(board, Colour.BLUE),
40                         self.evaluate_position(board, Colour.RED))
41             logger.info('Mobility:', self.evaluate_mobility(board, Colour.BLUE),
42                         self.evaluate_mobility(board, Colour.RED))
43             logger.info('Safety:', self.evaluate_pharoah_safety(board, Colour.BLUE),
44                         self.evaluate_pharoah_safety(board, Colour.RED))
45             logger.info('Overall score', blue_score - red_score)
46
47         if absolute and board.get_active_colour() == Colour.RED:
48             return red_score - blue_score
49         else:
50             return blue_score - red_score
51
52     def evaluate_pieces(self, board, colour):
53         """
54         Evaluates the material score for a given colour.
55
56         Args:
57             board (Board): The current board state.
58             colour (Colour): The colour to evaluate.
59
60         Returns:
61             int: Sum of all piece scores.
62         """
63         return (
64             Score.SPHINX * board.bitboards.get_piece_count(Piece.SPHINX, colour) +

```

```

61         Score.PYRAMID * board.bitboards.get_piece_count(Piece.PYRAMID, colour)
62     +
63         Score.ANUBIS * board.bitboards.get_piece_count(Piece.ANUBIS, colour) +
64         Score.SCARAB * board.bitboards.get_piece_count(Piece.SCARAB, colour)
65     )
66
67 def evaluate_position(self, board, colour):
68     """
69     Evaluates the positional score for a given colour.
70
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 = pop_count(board.get_all_valid_squares(colour))
107
108     return number_of_moves * Score.MOVE
109
110 def evaluate_pharaoh_safety(self, board, colour):
111     """
112     Evaluates the safety of the Pharaoh for a given colour.
113
114     Args:
115         board (Board): The current board state.
116         colour (Colour): The colour to evaluate.
117
118     Returns:
119         int: Score representing mobility of the Pharaoh.
120     """
121     pharaoh_bitboard = board.bitboards.get_piece_bitboard(Piece.PHAROAH,
122     colour)

```

```

121     pharoah_available_moves = pop_count(board.get_valid_squares(
pharoah_bitboard, colour))
122     return (8 - pharoah_available_moves) * Score.PHAROAH_SAFETY

```

1.6.5 Multithreading

A `CPUThread` 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 CPUThread(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'(CPUThread.run) Thread {threading.get_native_id}
    (}} idling...')

```

1.6.6 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

```

1.6.7 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=50000):
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         str: Key for the given hash.
25     """
26     # return hash_key % self._max_entries
27     return str(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.org/3/library/collections.html#ordereddict-objects
63         (k := next(iter(self._table)), self._table.pop(k))
64
65 def get_entry(self, hash_key, depth, alpha, beta):
66     """
67     Gets an entry from the transposition table.
68
69     Args:
70         hash_key (int): The Zobrist hash key.
71         depth (int): The depth of the search.
72         alpha (int): The alpha value for pruning.
73         beta (int): The beta value for pruning.
74
75     Returns:
76         tuple[int, Move] | tuple[None, None]: The evaluation score and the
77         best move found, if entry exists.
78     """
79     index = self.calculate_entry_index(hash_key)

```

```

78         if index not in self._table:
79             return None, None
80
81         entry = self._table[index]
82
83         if entry.hash_key == hash_key and entry.depth >= depth:
84             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

```

1.7 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.

1.7.1 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.
BACKGROUND_WAVES)
53         window.set_apply_arguments(ShaderType.BLOOM, occlusion_colours=[(pygame.
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
92         REVIEW_WIDGETS['winner_text'].set_text(f'WINNER: {get_winner_string(self.
_game_info["winner"])}')
93         REVIEW_WIDGETS['blue_piece_display'].reset_piece_list()
94         REVIEW_WIDGETS['red_piece_display'].reset_piece_list()
95
96         if self._game_info['time_enabled']:
97             REVIEW_WIDGETS['timer_disabled_text'].kill()
98         else:
99             REVIEW_WIDGETS['blue_timer'].kill()
100             REVIEW_WIDGETS['red_timer'].kill()
101
102     def refresh_widgets(self):
103         """
104         Refreshes the widgets after every move.
105         """
106         REVIEW_WIDGETS['move_number_text'].set_text(f'MOVE NO: {(len(self._moves))
/ 2:.1f} / {(len(self._moves) + len(self._popped_moves)) / 2:.1f}')
107         REVIEW_WIDGETS['move_colour_text'].set_text(f'{self.calculate_colour().
name} TO MOVE')
108
109         if self._game_info['time_enabled']:
110             if len(self._moves) == 0:
111                 REVIEW_WIDGETS['blue_timer'].set_time(float(self._game_info['time'
]) * 60 * 1000)
112                 REVIEW_WIDGETS['red_timer'].set_time(float(self._game_info['time'
]) * 60 * 1000)
113             else:
114                 REVIEW_WIDGETS['blue_timer'].set_time(float(self._moves[-1]['
blue_time']) * 60 * 1000)
115                 REVIEW_WIDGETS['red_timer'].set_time(float(self._moves[-1]['
red_time']) * 60 * 1000)
116
117         REVIEW_WIDGETS['scroll_area'].set_image()
118
119     def refresh_pieces(self):
120         """
121         Refreshes the pieces on the board.
122         """
123         self._piece_group.initialise_pieces(self._board.get_piece_list(), self.
board_position, self.board_size)
124
125     def simulate_all_moves(self):
126         """
127         Simulates all moves at the start of every game to obtain laser results and
fill up piece display and move list widgets.
128         """
129         for index, move_dict in enumerate(self._moves):
130             laser_result = self._board.apply_move(move_dict['move'], fire_laser=
True)
131             self._moves[index]['laser_result'] = laser_result
132
133             if laser_result.hit_square_bitboard:
134                 if laser_result.piece_colour == Colour.BLUE:
135                     REVIEW_WIDGETS['red_piece_display'].add_piece(laser_result.
piece_hit)
136                 elif laser_result.piece_colour == Colour.RED:
137                     REVIEW_WIDGETS['blue_piece_display'].add_piece(laser_result.
piece_hit)
138

```

```

139         REVIEW_WIDGETS['move_list'].append_to_move_list(move_dict['
unparsed_move'])
140
141     def calculate_colour(self):
142         """
143         Calculates the current active colour to move.
144
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.

```

```

195     """
196     temp_surface = pygame.Surface(window.size, pygame.SRCALPHA)
197     self._piece_group.draw(temp_surface)
198     mask = pygame.mask.from_surface(temp_surface, threshold=127)
199     mask_surface = mask.to_surface(unsetcolor=(0, 0, 0, 255), setcolor=(255,
200 0, 0, 255))
201
202     window.set_apply_arguments(ShaderType.RAYS, occlusion=mask_surface)
203
204 def get_event(self, event):
205     """
206     Processes Pygame events.
207
208     Args:
209         event (pygame.event.Event): The event to handle.
210     """
211     if event.type in [pygame.MOUSEBUTTONDOWN, pygame.KEYDOWN]:
212         REVIEW_WIDGETS['help'].kill()
213
214     widget_event = self._widget_group.process_event(event)
215
216     if widget_event is None:
217         return
218
219     match widget_event.type:
220         case None:
221             return
222
223         case ReviewEventType.MENU_CLICK:
224             self.next = 'menu'
225             self.done = True
226
227         case ReviewEventType.PREVIOUS_CLICK:
228             if len(self._moves) == 0:
229                 return
230
231             # Pop last applied move off first stack
232             move = self._moves.pop()
233             # Pushed onto second stack
234             self._popped_moves.append(move)
235
236             # Undo last applied move
237             self._board.undo_move(move['move'], laser_result=move['
238 laser_result'])
239             self.handle_move(move, add_piece=False)
240             REVIEW_WIDGETS['move_list'].pop_from_move_list()
241
242             self.refresh_pieces()
243             self.refresh_widgets()
244             self.update_laser_mask()
245
246         case ReviewEventType.NEXT_CLICK:
247             if len(self._popped_moves) == 0:
248                 return
249
250             # Peek at second stack to get last undone move
251             move = self._popped_moves[-1]
252
253             # Reapply last undone move
254             self._board.apply_move(move['move'])
255             self.handle_move(move, add_piece=True)
256             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)

```

1.8 Database

This section outlines my database implementation using Python sqlite3.

1.8.1 DDL

As mentioned in Section ??, 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()

```

1.8.2 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     cursor = connection.cursor()
17
18     # Datetime added for created_dt column
19     game_entry = (*game_entry, datetime.now())
20
21     cursor.execute('''
22         INSERT INTO games (cpu_enabled, cpu_depth, winner, time_enabled, time,
23         number_of_ply, moves, start_fen_string, final_fen_string, created_dt)
24         VALUES (?, ?, ?, ?, ?, ?, ?, ?, ?, ?)
25     ''', game_entry)
26
27     connection.commit()
28     connection.close()
29
30 def get_all_games():
31     """
32     Get all rows in games table.
33
34     Returns:
35         list[dict]: List of game entries represented as dictionaries.
36     """
37     connection = sqlite3.connect(database_path, detect_types=sqlite3.
38     PARSE_DECLTYPES)
39     connection.row_factory = sqlite3.Row
40     cursor = connection.cursor()
41
42     cursor.execute('''
43         SELECT * FROM games
44     ''')

```

```

42     games = cursor.fetchall()
43
44     connection.close()
45
46     return [dict(game) for game in games]
47
48 def delete_all_games():
49     """
50     Delete all rows in games table.
51     """
52     connection = sqlite3.connect(database_path)
53     cursor = connection.cursor()
54
55     cursor.execute('''
56         DELETE FROM games
57     ''')
58
59     connection.commit()
60     connection.close()
61
62 def delete_game(id):
63     """
64     Deletes specific row in games table using id attribute.
65
66     Args:
67         id (int): Primary key for row.
68     """
69     connection = sqlite3.connect(database_path)
70     cursor = connection.cursor()
71
72     cursor.execute('''
73         DELETE FROM games WHERE id = ?
74     ''', (id,))
75
76     connection.commit()
77     connection.close()
78
79 def get_ordered_games(column, ascend=True, start_row=1, end_row=10):
80     """
81     Get specific number of rows from games table ordered by a specific column(s).
82
83     Args:
84         column (_type_): Column to sort by.
85         ascend (bool, optional): Sort ascending or descending. Defaults to True.
86         start_row (int, optional): First row returned. Defaults to 1.
87         end_row (int, optional): Last row returned. Defaults to 10.
88
89     Raises:
90         ValueError: If ascend argument or column argument are invalid types.
91
92     Returns:
93         list[dict]: List of ordered game entries represented as dictionaries.
94     """
95     if not isinstance(ascend, bool) or not isinstance(column, str):
96         raise ValueError('(database_helpers.get_ordered_games) Invalid input arguments!')
97
98     connection = sqlite3.connect(database_path, detect_types=sqlite3.PARSE_DECLTYPES)
99     connection.row_factory = sqlite3.Row
100     cursor = connection.cursor()
101

```

```

102     # Match ascend bool to correct SQL keyword
103     if ascend:
104         ascend_arg = 'ASC'
105     else:
106         ascend_arg = 'DESC'
107
108     # Partition by winner, then order by time and number_of_ply
109     if column == 'winner':
110         cursor.execute(f'''
111             SELECT * FROM
112                 (SELECT ROW_NUMBER() OVER (
113                     PARTITION BY winner
114                     ORDER BY time {ascend_arg}, number_of_ply {ascend_arg}
115                 ) AS row_num, * FROM games)
116             WHERE row_num >= ? AND row_num <= ?
117         ''', (start_row, end_row))
118     else:
119         # Order by time or number_of_ply only
120         cursor.execute(f'''
121             SELECT * FROM
122                 (SELECT ROW_NUMBER() OVER (
123                     ORDER BY {column} {ascend_arg}
124                 ) AS row_num, * FROM games)
125             WHERE row_num >= ? AND row_num <= ?
126         ''', (start_row, end_row))
127
128     games = cursor.fetchall()
129
130     connection.close()
131
132     return [dict(game) for game in games]
133
134 def get_number_of_games():
135     """
136     Returns:
137         int: Number of rows in the games.
138     """
139     connection = sqlite3.connect(database_path)
140     cursor = connection.cursor()
141
142     cursor.execute("""
143         SELECT COUNT(ROWID) FROM games
144     """)
145
146     result = cursor.fetchall()[0][0]
147
148     connection.close()
149
150     return result
151
152 # delete_all_games()

```

1.9 Shaders

1.9.1 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, 1.0, 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
    file.
59
60     Args:
61         shader_type (ShaderType): The type of shader to load.
62         **kwargs: Additional arguments passed when initialising the fragment
    shader class.
63     """
64     self._shader_passes[shader_type] = shader_pass_lookup[shader_type](self,
    **kwargs)
65     self.create_vao(shader_type)
66
67 def clear_shaders(self):
68     """
69     Clears the shader list, leaving only the base shader.
70     """
71     self._shader_list = [ShaderType.BASE]
72
73 def create_vao(self, shader_type):
74     """
75     Creates a vertex array object (VAO) for the given shader type.
76
77     Args:
78         shader_type (ShaderType): The type of shader.
79     """
80     frag_name = shader_type[1:] if shader_type[0] == '_' else shader_type
81     vert_path = Path(shader_path / 'vertex/base.vert').resolve()
82     frag_path = Path(shader_path / f'fragments/{frag_name}.frag').resolve()
83
84     self._vert_shaders[shader_type] = vert_path.read_text()
85     self._frag_shaders[shader_type] = frag_path.read_text()
86
87     program = self._ctx.program(vertex_shader=self._vert_shaders[shader_type],
    fragment_shader=self._frag_shaders[shader_type])
88     self._programs[shader_type] = program
89
90     if shader_type == ShaderType._CALIBRATE:
91         self._vaos[shader_type] = self._ctx.vertex_array(self._programs[
    shader_type], [(self._pygame_buffer, '2f 2f', 'vert', 'texCoords')])
92     else:
93         self._vaos[shader_type] = self._ctx.vertex_array(self._programs[
    shader_type], [(self._opengl_buffer, '2f 2f', 'vert', 'texCoords')])
94
95 def create_framebuffer(self, shader_type, size=None, filter=moderngl.NEAREST):
96     """
97     Creates a framebuffer for the given shader type.
98
99     Args:
100         shader_type (ShaderType): The type of shader.
101         size (tuple[int, int], optional): The size of the framebuffer.
    Defaults to screen size.
102         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=[

```

```

self._textures[shader_type]])
110
111 def render_to_fbo(self, shader_type, texture, output_fbo=None, program_type=
None, use_image=True, **kwargs):
112     """
113     Applies the shaders and renders the resultant texture to a framebuffer
object (FBO).
114
115     Args:
116         shader_type (ShaderType): The type of shader.
117         texture (moderngl.Texture): The texture to render.
118         output_fbo (moderngl.Framebuffer, optional): The output framebuffer.
Defaults to None.
119         program_type (ShaderType, optional): The program type. Defaults to
None.
120         use_image (bool, optional): Whether to use the image uniform. Defaults
to True.
121         **kwargs: Additional uniforms for the fragment shader.
122     """
123     fbo = output_fbo or self.framebuffers[shader_type]
124     program = self._programs[program_type] if program_type else self._programs
[shader_type]
125     vao = self._vaos[program_type] if program_type else self._vaos[shader_type]
126
127     fbo.use()
128     texture.use(0)
129
130     if use_image:
131         program['image'] = 0
132     for uniform, value in kwargs.items():
133         program[uniform] = value
134
135     vao.render(mode=moderngl.TRIANGLE_STRIP)
136
137 def apply_shader(self, shader_type, **kwargs):
138     """
139     Applies a shader of the given type and adds it to the list.
140
141     Args:
142         shader_type (ShaderType): The type of shader to apply.
143
144     Raises:
145         ValueError: If the shader is already being applied.
146     """
147     if shader_type in self._shader_list:
148         return
149
150     self.load_shader(shader_type, **kwargs)
151     self._shader_list.append(shader_type)
152
153     # Sort shader list based on the order in SHADER_PRIORITY, so that more
important shaders are applied first
154     self._shader_list.sort(key=lambda shader: -SHADER_PRIORITY.index(shader))
155
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.
218
219         Args:
220             surface (pygame.Surface): The final Pygame surface.
221             arguments (dict): A dict of { ShaderType: Args } items, containing
222             keyword arguments for every fragment shader.
223         """
224         self._ctx.viewport = (0, 0, *self._screen_size)
225         texture = self.calibrate_pygame_surface(surface)

```

```

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

```

1.9.2 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
horizontal blur result as input texture
37         output_fbo=self._shader_manager.framebuffers["blurPong"],
38         passes=5,
39         horizontal=False
40     )
41
42     self._shader_manager.render_to_fbo(ShaderType._BLUR, self._shader_manager.
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,
0.016216);
11
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             result += texture(image, uvs - vec2(offset.x * i, 0.0)).rgb * weight[i
21 ];
22         }
23     }
24     else {
25         for (int i = 1 ; i < passes ; ++i) {
26             result += texture(image, uvs + vec2(0.0, offset.y * i)).rgb * weight[i
27 ];
28             result += texture(image, uvs - vec2(0.0, offset.y * i)).rgb * weight[i
29 ];
30         }
31     }
32
33     f_colour = vec4(result, 1.0);
34 }

```

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 SMPProtocol
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: SMPProtocol):
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=[],
23             surface_intensity=BLOOM_INTENSITY, brightness_intensity=BLOOM_INTENSITY,
24             colour_intensity=BLOOM_INTENSITY):
25         """
26         Applies a bloom effect to a given texture.
27
28         Args:
29             texture (moderngl.Texture): Texture to apply bloom to.
30             highlight_surface (pygame.Surface, optional): Surface to use as the
31             highlights. Defaults to None.
32             highlight_colours (list[list[int, int, int], ...], optional): Colours
33             to use as the highlights. Defaults to [].
34             surface_intensity (_type_, optional): Intensity of bloom applied to
35             the highlight surface. Defaults to BLOOM_INTENSITY.
36             brightness_intensity (_type_, optional): Intensity of bloom applied to
37             the highlight brightness. Defaults to BLOOM_INTENSITY.
38             colour_intensity (_type_, optional): Intensity of bloom applied to the
39             highlight colours. Defaults to BLOOM_INTENSITY.
40         """
41         if highlight_surface:
42             # Calibrate Pygame surface and apply blur
43             glare_texture = self._shader_manager.calibrate_pygame_surface(
44                 highlight_surface)
45             _Blur(self._shader_manager).apply(glare_texture)
46
47             self._shader_manager.get_fbo_texture(ShaderType._BLUR).use(1)
48             self._shader_manager.render_to_fbo(ShaderType.BLOOM, texture,
49                 blurredImage=1, intensity=surface_intensity)
50
51             # Set bloom-applied texture as the base texture
52             texture = self._shader_manager.get_fbo_texture(ShaderType.BLOOM)
53
54             # Extract bright colours (highlights) from the texture
55             _HighlightBrightness(self._shader_manager).apply(texture, intensity=
56                 brightness_intensity)
57             highlight_texture = self._shader_manager.get_fbo_texture(ShaderType.
58                 _HIGHLIGHT_BRIGHTNESS)
59
60             # Use colour as highlights
61             for colour in highlight_colours:
62                 _HighlightColour(self._shader_manager).apply(texture, old_highlight=

```



```

highlight_texture, colour=colour, intensity=colour_intensity)
52     highlight_texture = self._shader_manager.get_fbo_texture(ShaderType.
        _HIGHLIGHT_COLOUR)
53
54     # Apply Gaussian blur to highlights
55     _Blur(self._shader_manager).apply(highlight_texture)
56
57     # Add the pixel values for the highlights onto the base texture
58     self._shader_manager.get_fbo_texture(ShaderType._BLUR).use(1)
59     self._shader_manager.render_to_fbo(ShaderType.BLOOM, texture, blurredImage
        =1, intensity=BLOOM_INTENSITY)

```

1.9.3 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 ?? . 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] ->
20         [-1, 1]
21         float angle = (1.5 - norm.x) * PI; // Range from [-1, 1] -> [0.5PI, 2.5PI]
22         float radius = (1.0 + norm.y) * 0.5; // Range from [-1, 1] -> [0, 1]
23
24         //coord which we will sample from occlude map
25         vec2 coords = vec2(radius * -sin(angle), radius * -cos(angle)) / 2.0 +
26         0.5;
27
28         // Sample occlusion map
29         vec4 occluding = texture(image, coords);
30
31         // If pixel is not occluding (Red channel value below threshold), set
32         maxDistance to current distance
33         // If pixel is occluding, don't change distance
34         // maxDistance therefore is the distance from the center to the nearest
35         occluding pixel
36         maxDistance = max(maxDistance * step(occluding.r, THRESHOLD), min(
37         maxDistance, currDistance));
38     }
39
40     f_colour = vec4(vec3(maxDistance), 1.0);
41 }

```

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=0.1;
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 effect
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 SMPProtocol

```

```

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):
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
the occlusion texture. Defaults to None.
25        """
26        final_texture = texture
27
28        # Iterate through array containing light information
29        for pos, radius, colour, *args in self._lights:
30            # Topleft of final light source
31            light_topleft = (pos[0] - (radius * texture.size[1] / texture.size[0])
, pos[1] - radius)
32            # Relative size of light compared to texture
33            relative_size = (radius * 2 * texture.size[1] / texture.size[0],
radius * 2)
34
35            # Crop texture to light source diameter, and to position light source
at the center
36            _Crop(self._shader_manager).apply(texture, relative_pos=light_topleft,
relative_size=relative_size)
37            cropped_texture = self._shader_manager.get_fbo_texture(ShaderType.
_CROP)
38
39            if occlusion:
40                # Calibrate Pygame mask surface and crop it
41                occlusion_texture = self._shader_manager.calibrate_pygame_surface(
occlusion)
42                _Crop(self._shader_manager).apply(occlusion_texture, relative_pos=
light_topleft, relative_size=relative_size)
43                occlusion_texture = self._shader_manager.get_fbo_texture(
ShaderType._CROP)
44            else:
45                occlusion_texture = None
46
47            # Apply lightmap shader, shadowmap and occlusion are included within
the _Lightmap class
48            _Lightmap(self._shader_manager).apply(cropped_texture, colour,
occlusion_texture, *args)
49            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)
53            final_texture = self._shader_manager.get_fbo_texture(ShaderType._BLEND

```

```
        )
54
55        self._shader_manager.render_to_fbo(ShaderType.RAYS, final_texture)
```

1.9.4 Stack