Contents

Related Work

In the field of games AI have been a focal point in creating interesting and engaging gaming experiences. This differs from the computer science view of AI in which the goal is to make intelligent systems. In this project providing in engaging game is far more important than the intelligence of the player. This chapter will describe the work related to games; what people find interesting and fun in games. As well as, research into different methods for constructing AI and some of the technical aspects of games related to the one used in the project.

m, n, k Games

An m, n, k Game is one in which players take turns placing coloured stones on an M by N board, the winner is the first to get k stones in a row. Popular examples of m, n, k games include Connect 4 and Tic Tac Toe, a typical tic tac toe game would be a 3, 3, 3 game. Games up to 7, 7, 5 and 8, 8, 5 have been solved, player two can force a draw in both instances (Wei-Yuan Hsu, 2019). The stealing strategy argument shows that m, n, k game in which player two can have a strategy which ensures they win. As these games have finite size the game is convergent, all games finish after some number of moves, the max number of moves available being m x n. They are also zero-sum games as there is only three possible end state a win, loss or draw. Moreover, these games have perfect information and are stochastic, this makes them great candidates for tree searching techniques such as monte carlo, or depth first search.

AI in Modern Games

Typically, in modern games AI are divided into three categories; Easy, Medium and Hard. The issue with this approach is that it either provides an AI which is too easy for the player, or one which is too difficult which can quickly become frustrating for the player (Chanel, 2008). To combat this issue game developers have turned to techniques known collectively as Dynamic Game Difficulty Balancing (DGDB). This is a process which measures a player’s ability in some form, whether it is accuracy in a First-Person Shooter or number of pieces won or lost in a board game. The data collected is then used to modify parameters in an attempt to keep players entertained. There are many ways this can be implemented, one is to passively help the player by giving them more resources, such as health packs and ammo, in an FPS setting (Hunicke, 2004). Though this system was found to be effective it did result in situations which were not intended. A solution to this is to use the data collected to modify the behaviour of Non-Playable Characters (NPCs). To take this a step farther, the 2014 game "Shadow of Mordor" featured what it called the "Nemesis System". This was a system that tracked hostile NPCs and their encounters with the player which the NPC would comment on in their next meeting with the player. This coupled with the NPCs personality gave the player a more in-depth experience with the game as interactions were more dynamic and let the player create stories independent of the main plot line of the game (Donlan, 2014).

Adaptive Behaviour

As discussed previously, having AI which differ drastically from the player in terms of skill level results in games that are not fun to play. Therefore, it is important to have AI which can satisfy players from both sides of the spectrum. Moreover, dynamic difficulty AI in particular has been shown to increase the players enjoyment of games, specifically in a Real Time Strategy game (Mirna Paula Silva, 2015). There are some requirements of dynamic AI which must be met before they would be suitable for use in a game, however. In the case of machine learning dynamically scripted agents it is important that they are quick in their computations, effective throughout the whole game (even while learning), robust to the randomness that is inherent in most games and finally they must be efficient in their learning as games can be short and similar situations will seldom happen in a single game (Spronck, 2006). Besides machine learning there are other methods that can be used to scale the difficulty of an AI opponent to a more appropriate level for the human player. For example "High-Fitness Penalising" is a system which gives higher rewards to mediocre moves instead of on how well the AI system is doing (Spronck, et al., 2004). Games are reported as being more fun when the difference between wins and losses are minimal and draws are uncommon (Tan, et al., 2011). It was shown that this can be formalised into the equation:

$$\mathrm{W} = \mathrm{L} = \frac{n - D}{2}$$

Where W, L and D represent the number of wins, losses and draws respectfully and n is the number of games played. The idea of artificial stupidity is also mentioned in Tan et al’s work. This is an AI system which makes plausible mistakes intentionally to help make the game more entertaining (Lidén, 2004).

Lidén talks about AI in the context of an FPS however. These include:

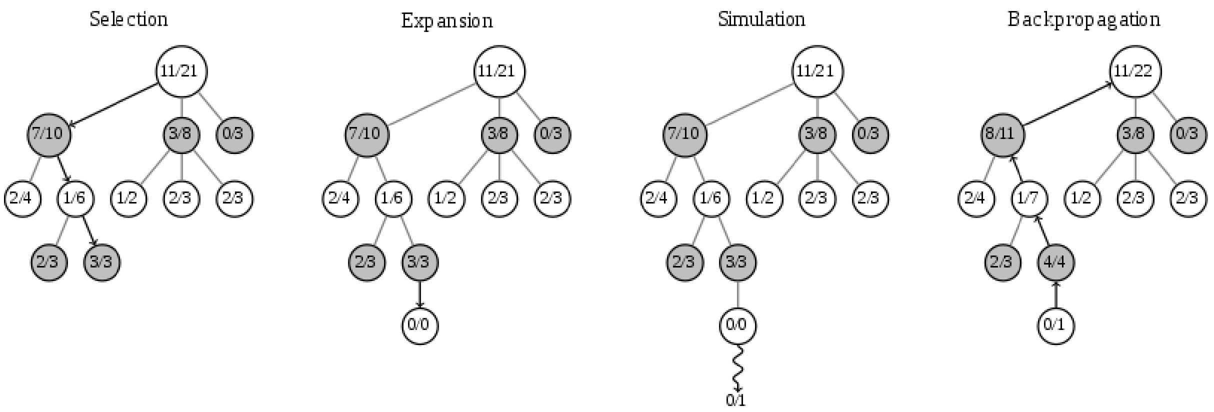
- Have Horrible Aim: As the AI can play optimally it is important that it intentionally misses so the player has a chance.
- Move before firing: Give the player a chance to react to the AI actions.

Moreover, it is mentioned that an AI opponent should feed into the players emotions to enhance the gaming experience most notably in the “Pull back at the last minute” scenario. Though Lidén does discuss in the previously mentioned section that the AI should let the player win the game, this goes against what Tan et al. say as excessive wins would maximise their equation and would suggest an unfun game. However, in this project the Minefield AI was built to accomplish the goal of raising the tension in the game even if it does not play very well.

Monte Carlo

Games can be modelled as trees where each node in the tree represents the game state and each connection represents the action taken to move between one game state to another. To decide which move is better than some other move one method is to simply count how often that move results in a win for the player compared to the others. The move which results in a win most often must be the best. The issue is for some games, such as chess or go, the game tree can become quite large quite quickly. As the game of Ultimate Tic Tac Toe (UTTT), the chosen game for this project, has an estimated 1.8 x 10^78 game states (Bredyn McCombs, 2018) it would be infeasible to perform an exhaustive search of the game tree and “Brute Force” a win. Monte Carlo Tree Search (MCTS) aims to make decisions based on the estimated chances of winning the game based on that move. The way it does this is by building up the tree asymmetrically, focusing on more promising sub trees and ignoring less promising ones, and more importantly by doing this it performs better than more classical algorithms in large trees. The algorithm for MCTS follows four basic steps.

- Selection: Starting from the root node, reclusively select the child node which looks most promising (in this project the UCT value will be used to calculate this) until a leaf node is reached.
- Expansion: If the leaf node is not a terminal state of the game, generate all child nodes from the leaf and select one of them. Child nodes are any valid move from the leaf node.
- Simulation: Complete a random playthrough of the game from the selected child node.
- Back Propagation: Use the result of the simulation to update the nodes on the path between the child node and the root.



The UCT formula is a variation on the UCB1 (Upped Confidence Bound) that is used in bandit problems. The formula has been shown to have performance advantages over its competitors in some artificial game domains (Kocsis & Szepesvári, 2006).

$$\mathrm{UCT} = \bar{x}_i + \mathrm{C}\sqrt{\frac{\ln N}{n_i}}$$

Where $\bar{x}_i$ is the reward for node i, C is some constant, typically it is $\sqrt{2}$ in a pure monte carlo implementation, N is the number of visits the parent node of i and n_i is the number of visits to the node i. This formula balances out the exploitation of a node, the first term, against the exploration of a node. This ensures that nodes are visited at least once and low scoring nodes still get visited, only less frequently.

Problem Description and Specification

Game playing has been one of the major areas of research since the inception of AI. The first example of game playing AI was developed by Eugene Grant, Herbert Koppel and Howard Bailer and it played Nim (Grant & Lardner, 1952). Since then game developers and computer scientists have built systems that play games with the intentions of creating unbeatable systems, not fun systems.

The Problem

When playing games against an AI opponent there is one major issue the human player faces, the opponent does not match their skill level. This means that the AI can be too easy which results in a boring game, or too hard which results in frustration. AI which are too difficult are more common as computer scientists and game developers aim to make the most impressive AI. In most cases game allow the player to pick from some pre-determined difficulty setting, which is meant to provide a way for players to select which difficulty gives them the most enjoyment. However, these settings are difficult to scale and can end up with "artificial difficulty", a system in which the game is not actually harder, the AI behaviour and overall experience is mostly the same. What changes is the amount of health enemies have, the amount of resources the player gets, the amount of damage the player can do etc. are changed (Suddaby, 2013).

The Good Dad

For a game against an AI to be enjoyable it must avoid the pitfalls of artificial difficulty and adapt some sort of "real" difficulty to the players ability. The play style desired is analogous to the way a father might play a game with their son, challenging but rewarding and fun. The aim of this project is to develop an AI system that will play as described, by dynamically adjusting its difficulty to the perceived ability of the player. This will require that the developer of the Good dad system to be able to accurately quantify the ability of the player and use that data to adjust the AIs play style.

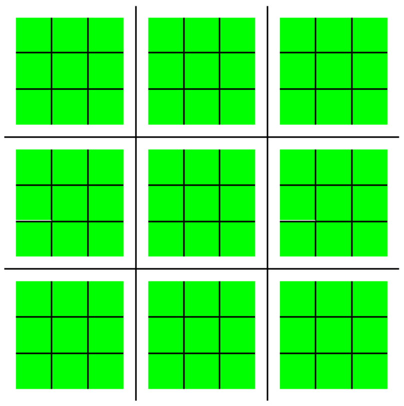
The Game

The game chosen for this project has some requirements that it must satisfy. Those requirements are: it must be fully observable, all information about the game state is available to both players, it must be sequential, the current move will affect every following move and lastly it must be static and the game state must not change while the player is thinking about their move. These requirements are in place to allow the human player to have access to the same information that the AI does.

Specification

In this section the selection of the game is discussed, as well as the approach for creating the AI.

Ultimate Tic Tac Toe

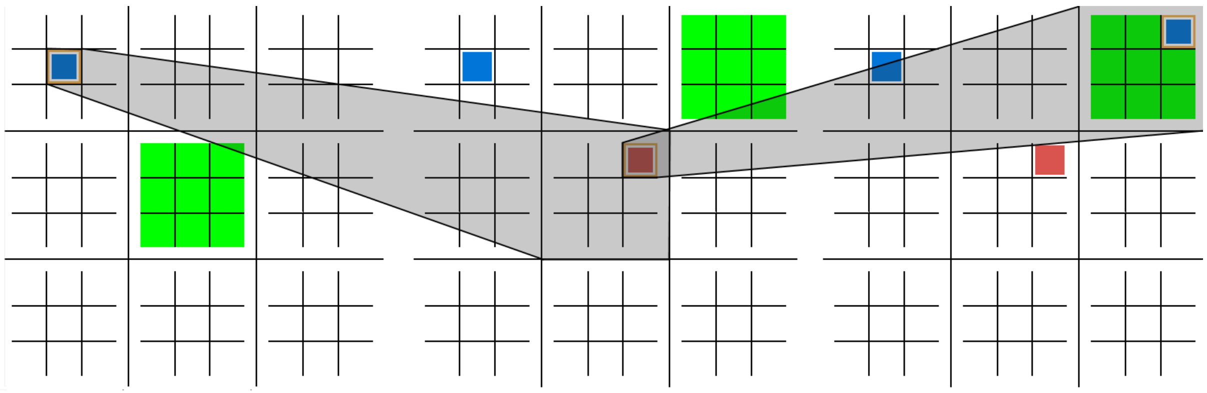


The game chosen for this project was Ultimate Tic Tac Toe, a twist on the classic pen and paper game. The game is fairly new with the earliest post on it being dated 2013 (Orlin, 2013). The game features a regular tic tac toe board, except in each space where a tile should be there is another nested tic tac toe board. The choice of UTTT was made as the familiarity of tic tac toe would give players an idea of how it is played, but the added strategic complexity of the nested boards would make it much more interesting and novel.

Rules

- In the opening move player one can choose any tile to make a move on
- Players then take turns making moves on tiles
- Whichever position in a sub board a player makes a move in dictates which sub board the next player must make a move in
- A player wins a sub board when they place three of their tiles in a row in that sub board

- If a player is sent to a board that has been won by either player, they can make a move on any available tile on the board
- There are no available moves in a board that has been won or drawn
- A sub board is drawn if all tiles have had moves made on them
- When a player wins three sub boards in a row, that player is the winner and the game is over



The positioning in the game adds a depth of complexity that users may not have experienced playing tic tac toe or any of its variations.

The AI

To carry out experiments there will need to be a minimum of three AIs. This is necessary to create a spectrum of difficulty that a user can interact with. An easy AI, this will be an AI which selects its moves randomly, a hard AI, this will be an AI which will seek to maximise the reward gained from each move, and the Good dad AI, this will adapt the moves made to reflect the skill of the player. There will also be a fourth type of AI included in this project inspired by Artificial Stupidity (Lidén, 2004), the “Minefield” AI which will aims to play on the users’ emotions to produce a entertaining game.

The Good dad AI

There were two different approaches used in designing the Good dad AI. The first and more simplistic was to build an AI which would select moves that were closest to the average reward that the opponent had. The second used a statistical analysis on the ranking of the opponents move to more accurately reflect the skill of the opponent.

System Design

The system was designed to allow many users to interact with the application while at the same time, while allowing future development work to take modify the behaviour of the application relatively easily. Test driven development was used throughout the creation of the application as it allows more robust and maintainable code to be developed.

Methodology

An Agile development cycle was implemented for the implementation of the application. The Agile development cycle follows a four-step cycle in which feedback about previous development is fed into the next development cycle (see figure 1), so the product better reflects the wants and needs of the client. The cycle that was used in the development of this system is on the simpler side as the project does not have the industrial scope that is normally paired with this type of development. However, the advantage of the Agile development cycle is that, unlike waterfall, it allows for requirements to be updated during the entire development process. Frameworks are normally used in conjunction with Agile to help developers maintain the work load and make sure all tasks are completed. The tool that was used in this project is Azure Devops. Azure devops maintained the work board, this contained all work completed and work to be completed, known as the backlogs, and allowed me to quickly and easily check what was next to be done. The use of these tools is not necessary in agile but by having them a development team can better manage their weekly work load and better assign resources to the tasks that need it. The Build step could be farther broken down into another cyclical development cycle, that being Test Drive Development (TDD). The TDD cycle is a simple one but is designed to make code flexible and robust. It is intended for paired programming but as the process creates a system with high test coverage and gives the developer much higher confidence in the code it was used for this project. Along with its other benefits TDD allows code to be

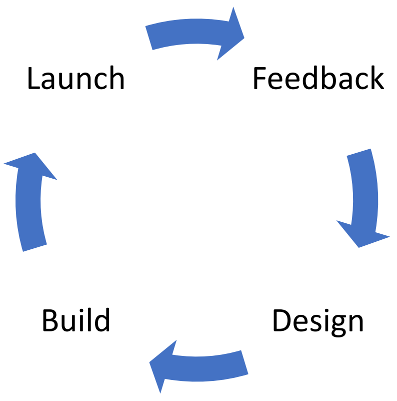


Figure 0-1 Agile Development Cycle

documented while it is developed. This project contains two hundred and forty tests, each one describing a small piece of functionality and each piece of functionality working as the product will not be published if tests do not pass

System Architecture

The system will be a web app containing an Angular front end and an Asp.Net Core back end. The choice of a web app was made as this would allow more people to access the application easier as well as have the user experiments take place in the application. The server follows a Layered Architecture with three layers; the controller layer, business layer and the data access layer. The layered architecture allows for each layer to be easily changed without disturbing any other layer. It also clearly separates different layers of abstraction such as retrieving data from a database from interacting with the game logic. The system could easily be changed to support different types of databases for example it currently interacts with a SQL database but changes could be made to the data access layer to interact with a no-SQL database or some other form of storage. The first two layers also behave as the controller and the model in a Model-View-Controller (MVC) architecture. The View is the HTML front end again the MVC architecture allows for parts of the system to be easily changed as long as all concrete classes satisfy the interfaces in the system, this principle is known as "Programming to and Interface" (Head First design). Lastly the front end uses an Event Driven architecture to communicate between components. This was chosen as being a web application connected to the server through the internet responses from API calls would take an unspecified amount of time to return, as such events are used to signal these returns to any component that is interested in the result. Moreover, as the front end needed to interact with the player, eg clicking on the screen (an interaction which is easily modelled with events), an event driven architecture was a good solution to all these problems.

Design Patterns

A Project of this size must employ established design patterns that allow code to be flexible to change and easily extendable. As such this project features several different design patterns for behaviour and creation.

Observer

The observer is a common design pattern normally used to communicate updates in a model, returns from asynchronous calls or user events. The pattern was used exclusively in the front end and allows components to maintain a loose coupling on each other while still communicating updates to some part of the system. The participants in a typical Observer pattern are:

- The Subject: The class which is being observed, it provides some mechanism for adding and removing observers
- The Observer: The interface which is called when an event is fired, typically it only has the "Update" method defined
- The concrete Subject: The object which updates observers of change
- The Concrete Observer: Implements the Observer interface.

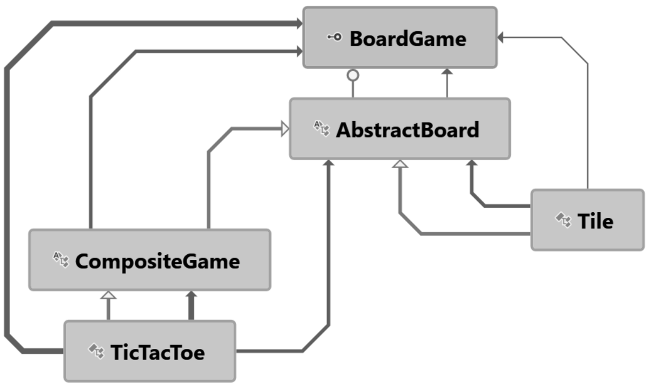
As Angular was used as the framework the implementation of the Observer is slightly changed in that classes do not implement an Observer interface, instead the subject class has an "Event Emitter" field which can be subscribed to. In effect this is analogues to adding the subscribed object to the subject objects' observer list, which would be done in a typical observer pattern. On subscription an anonymous function is passed to the subjects' event emitter which is called when an event is emitted. This implementation of the Observer pattern accomplishes the same goal as the more traditional pattern, but it does not require observer classes to implement an interface, while still maintaining loose coupling between the observer and the subject.

Composite

The composite pattern is a design pattern that allows tree structures to be easily modelled and allow clients treat parts of the hierarchy uniformly. This pattern was used to model the game of UTTT, as it is a tic tac toe game made of up tic tac toe games this pattern lends itself well to the problem. The pattern only has three participants normally, these are:

- The Component: Declares the interface for objects in the composite pattern

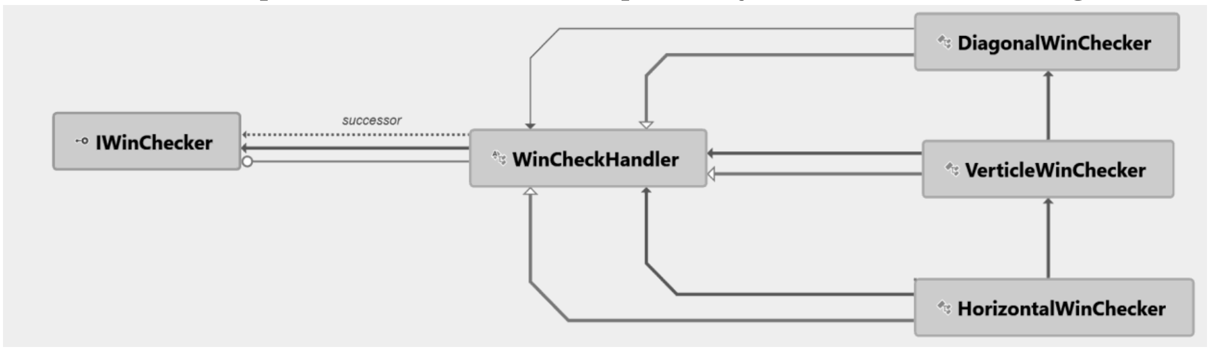
- The Leaf: Represents a leaf object in the tree structure (in the case of UTTT this would be a tile)
- The Composite: Stores child components and defines the behaviour for components which have children



In this example of the composite design pattern the Leaf class is the tile and the composite class is the TicTacToe class. The component that obscures this implementation from the client is the BoardGame interface which does not reference itself.

Chain of Responsibility

This design pattern is flexible and was used for two different reasons in this project, that being for behavioural changes and as a creational pattern. Chain of Responsibility allows a problem to be broken down into component parts and each one linked independently. This allows code to avoid long strings of "if else" blocks which can quickly get cumbersome and unmaintainable. The pattern consists of three classes; the chain interface, which defines a singular method used by the client to interact with the chain, the abstract chain class which defines an if statement and a mechanism for linking parts of the chain and the concrete chain class, this class defines the behaviour for part of the chain. This pattern was used to decouple the system that checked if a game was



over from the game itself, while also allowing the win checking to be better tested. The chain components in that example were a VerticalWinChecker, HorizontalWinChecker and a DiagonalWinChecker, which checked for a win condition vertically, horizontally and diagonally respectively. This allowed the problem to be broken down into manageable pieces and avoid multiple if else blocks. As a creational patter it is used when objects arrive to the controllers over the internet. As objects arrive as JSON and functions cannot be transferred objects must be created based on the properties of the JSON that is received. Different players have different properties so a Chain of Responsibility is used to decide which player should be created and to create it. This allowed me to easily add new links to the chain whenever a new player was created with little change to other code.

Dependency Injection

The final pattern that was used in this project is dependency injection (DI). This is a creational pattern that allows the developer to define what is known as a container, in which mappings between interfaces and concrete classes are established. Then when writing code, the constructor is simply given a reference to the interface and at run time the correct concrete class is provided. This allows the developer to create very flexible code as no class has a reference to any other classes' constructor. Moreover, no class has access to any concrete class instead only the interface which was defined in the container. However, this pattern does not allow for instances of a class to be swapped during runtime and so is not always applicable.

Design and Implementation

In this section I will cover in greater detail the design of the application, the models used, and the implementations created for this project. I will go over the changes that the project went through and some testing will be touched on.

Model

The models are the object representation of the game at any one point, it details where players have made moves, what moves are next available and which player is to move.

Requirements

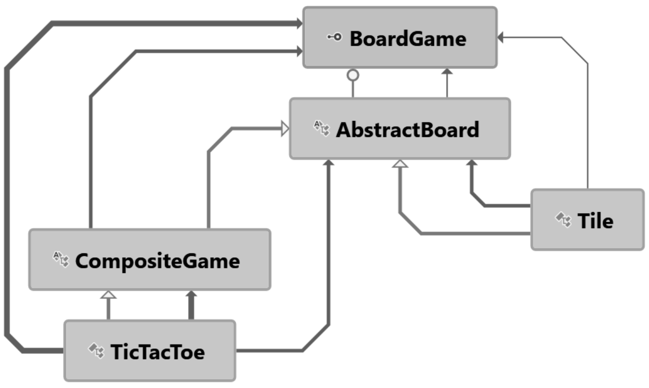
The requirements of the model were:

- Store the state of the game
    - The position of moves on the board
    - The types of players in the game
    - The current Player
    - The sub board the player must make their next move in
    - The sub boards that have been won

It must expose methods to the controller that allow moves to be made and to check if the game state is terminal, whether that is a win or a draw. As the View is completely separated from the server and objects are passed in through JSON methods are not transferred. Because of this it is not possible to expose any methods to the view and all interactions with the model must be done through the API.

Design

The design for the games model was decided early on in development and fit quite well with the behaviour that was needed. The UTTT board would be modelled as a two-dimensional list of objects each of which would have another two-dimensional list of tiles. This model lends itself to the composite design pattern that was used to perform calculations on the board. Moreover, it also made drawing the board on the screen simpler as Angular allows HTML components to be dynamically allocated in the DOM, which means that simply by defining the logic to decide if a tic tac toe board or a tile should be placed in one location would allow Angular to populate the DOM with all the necessary components. AI Players were not implemented on the client side, they ran on the server as to not have the performance of the clients machine impact their performance. To max`



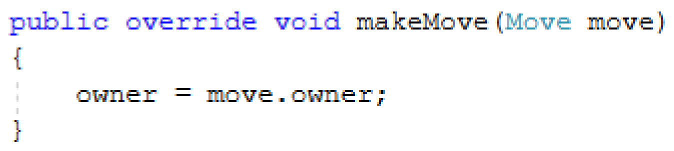
intain the information of which players where playing a game the players were enumerated and the enumerated value was sent along with the board to the server where the correct player could make its' move. The classes involved in the model are the TicTacToe class and the Tile class, both of which implement the BoardGame interface but the TicTacToe class also extends the CompositeGame class which is where it derives its' composite behaviour. The BoardGame interface defines only a handful of methods, the most important of which are the makeMove and the getAvailableMoves. Both these methods take advantage of the composite nature of the TicTacToe class to allow code to be more concise and maintainable. getAvailableMoves in particular takes advantage of the composite design pattern, by treating nested components identically no concession needs to be made for leaf components, the TicTacToe board simply calls to get available moves from which ever sub boards are defined as available and returns that list.

Implementation

The key methods in the model are the MakeMove and the TicTacToe class. MakeMove takes a Move object, which is also a Composite class, and because of the composite nature of the TicTacToe class, it can simply treat all child classes identically pass the

```
public override void makeMove(Move move)
{
    board[move.possition.X][move.possition.Y].makeMove(move.next);
    validateBoard();
    registerMove(move);
}
```

move along for processing. The validateBoard method is used to check the winner of the game as well as perform some simple checks after a move is made, registerMove allows the class to restrict what the next available sub board will be. The Tile class, which is the leaf of the composite pattern, must also implement the makeMove method and this is what allows the TicTacToe class to treat all sub boards identically.



```
public override void makeMove(Move move)
{
    owner = move.owner;
}
```

View

The view is a web app that displays and allows the user to interact with the model. It was made using Angular 5 framework which enables elements to be dynamically allocated to the DOM.

Requirements

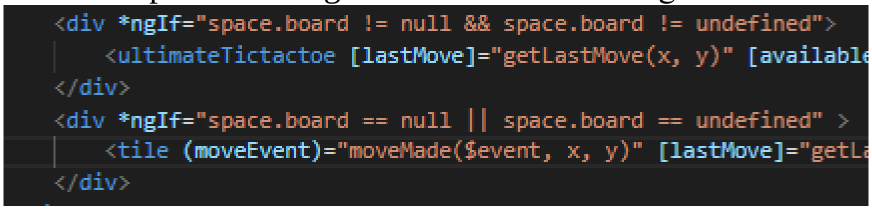
The fundamental objective of the view is to provide the user with a clear and intuitive representation of the underlaying data. The view does not provide the user with any functionality to manipulate the data however as this would break the single responsibility principle. The functionality the view does provide include:

- A Start screen with the functionality to:
    - Ability to selecting players in a game
    - Ability to select the number of games to play
- Login screen which provides functionality to
    - Ability to register as a new user
    - Ability to log in as an existing user
- Game screen with functionality to
    - Allow a player to play a move
    - Clearly display the moves available to the user
    - Display moves previously made
    - Allow the user to differentiate between the two players moves

- Allow the user to see who one each sub board at a glance

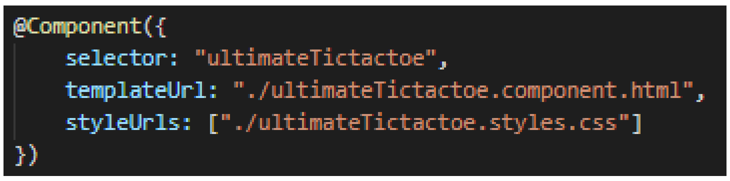
Design

The view was implemented with Angular Framework. It makes use of the Model-View-ViewModel (MVVM) design pattern. This means that the representation of the model in the view does not necessarily need to completely reflect the model, only the parts which are relevant. It also allows for separation between the logic and the HTML that displays the model to the viewer. Angular allows components to be dynamically be loaded to the dom, this was beneficial as it allowed components to be nested without knowledge of how deep the UTTT game is nested. The "*ngIf" decorator is part of the



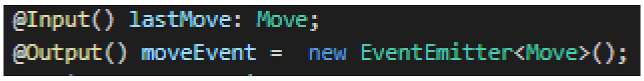
```
<div *ngIf="space.board != null && space.board != undefined">
    <ultimateTictactoe [lastMove]="getLastMove(x, y)" [available
</div>
<div *ngIf="space.board == null || space.board == undefined" >
    <tile (moveEvent)="moveMade($event, x, y)" [lastMove]="getLa
</div>
```

angular framework and is the mechanism by which angular dynamically selects components to render in the DOM. Both the "ultimateTictactoe" and the "tile" tags will be resolved to the HTML that is pointed to by the component with the selector decorator that matches the tag. The variables in the square brackets denote what angular define as



```
@Component({
    selector: "ultimateTictactoe",
    templateUrl: "./ultimateTictactoe.component.html",
    styleUrls: ["./ultimateTictactoe.styles.css"]
})
```

"Inputs". These are values that are passed from a parent component to a child component through the DOM. Additionally, the event in the round brackets is what is known as an "Output". This is the angular implementation of the observable, the function that is made equivalent to the output will be called whenever the emit is called on the event emitter that is tied to this output. The variable "$event" will be whatever variable is emitted. This is part of what makes the MVVM architecture powerful, as the logic that drives the UI can be completely refactored and remade without impacting the way the application looks, as long as the interfaces defined are respected.



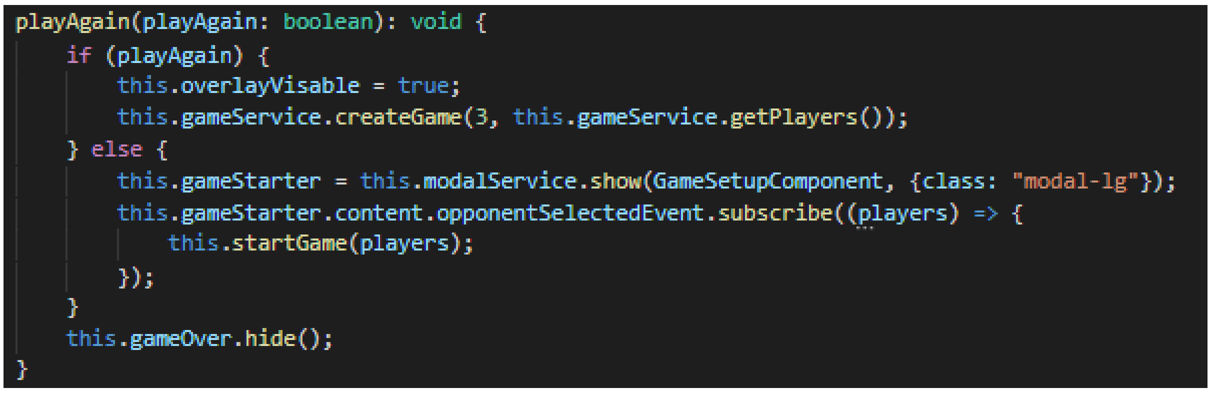
```
@Input() lastMove: Move;
@Output() moveEvent =  new EventEmitter<Move>();
```

Libraries

In the client a number of libraries were used to additional functionality and save time in development. Besides dependencies the main libraries used in this project were; Bootstrap, angular2-toaster and rxjs.

Bootstrap

Bootstrap provides an extensive css library which allows developers to quickly and



```
playAgain(playAgain: boolean): void {
    if (playAgain) {
        this.overlayVisable = true;
        this.gameService.createGame(3, this.gameService.getPlayers());
    } else {
        this.gameStarter = this.modalService.show(GameSetupComponent, {class: "modal-lg"});
        this.gameStarter.content.opponentSelectedEvent.subscribe((players) => {
            this.startGame(players);
        });
    }
    this.gameOver.hide();
}
```

easily create web pages that look clean and professional. The basic version of bootstrap however does not integrate well with angular, as it does not provide a way to interact with certain components such as modals. For this a wrapper library was used, “ngx-bootstrap”, which provides components which can be injected into code and provide extra functionality to the UI. The BsModalService is provided by ngx-bootstrap and is a wrapper for the bootstrap native modal class. This allows the developer to have greater control over how the UI behaves. As seen in (figure) the modal service allows bootstrap components to be interacted with in a concise and intuitive way. The show method simply displays the passed in component as a modal as well as applying the style defined by the user. Moreover, it allows developers to access to components encapsulated in the modal by way of the content variable.

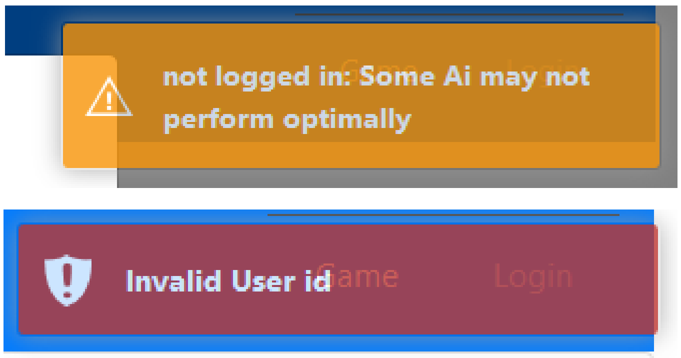
Ngx-toaster

This library provides services to display toasts. The library was selected over the ngx-bootstrap solution as there were version conflicts with the installed version of bootstrap and an attempt to resolve the conflicts proved to be cumbersome and time consuming. This library does not provide as clean a solution as ngx-bootstrap does as every component that wishes to display a toast must have a “toast-container” tag in its HTML. This in itself is not much of an issue in ways of separation of concerns, where it does become a problem is when errors occur in components that do not have views, such as services. In this case the component that uses that service must recognise the services use of toasts and provide a toast-container for it. This results in high coupling between components in the view.

Modals

Modals are a small component that pop up over the application, these are useful for giving the user a small piece of information or let the user input such as a confirmation box.

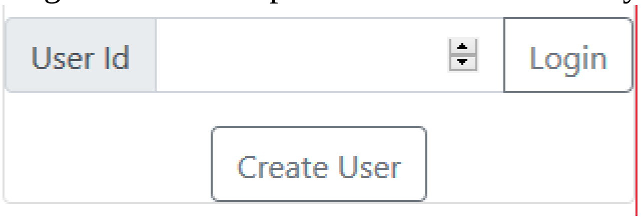
Toast



Toasts are small popups that contain a single piece of information. These do not interrupt the use of the application. These toasts can be different colours to communicate extra information to the user. The major difference between this and a modal is that toasts do not have any interactions with the user. They are used strictly to inform the user of some vital piece of information. The library used for toasts is “angular2-toaster”. This library encapsulates bootstraps native toast classes which allows them to be better integrated with angular, by allowing a toast service to be injected into components that will need to use it.

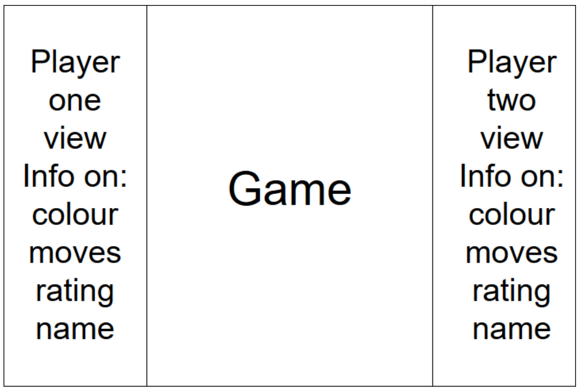
Login Screen Design

The loading screen is fairly simple in its design as it does not provide lot of functionality and should very easily afford logging in. It is a simple input with a login button appended and another button which allows users to create new accounts.



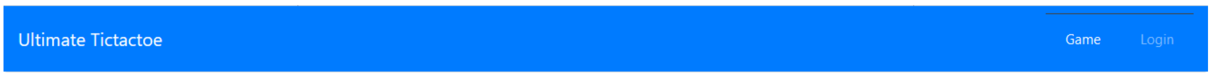
Game View Design

It was intended for the screen to be split into three sections when a game was in play. The outer most sections would be dedicated to each of the players, displaying information on what colour each player was, their name and other stats. Due to time constraints this design of the UI was never realised, and both end components were not implemented.


Player one view Info on: colour moves rating name
Game
Player two view Info on: colour moves rating name

Navigation

The navigation uses a simple nav bar places across the top of the screen. There are two pages contained in the app, the login page and the game page. It was intended for the login functionality to be encapsulated in a modal, however it was decided that a better separation of functions between this and other parts of the application made navigation easier.



Controllers

The controllers are split across the server and the client. They provide the user with a mechanism by which they can interact with and mutate the model.

Client

On the client side the controllers provide a way for the user to interact with the model through the view.

Requirements

The requirement on the client side are simple and surround the users ability to do two things, log in and play the game. For logging in the controller must:

- Communicate to the server the users actions
    - Login
        - Create new user
        - Login as existing user

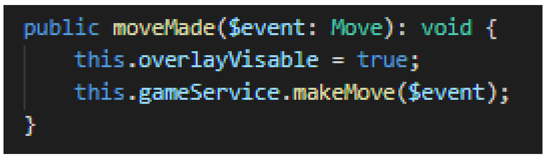
- Game play
    - Communicate with server which players to construct
    - Communicate with server which move to make

Design

The client side has only one controller. It is implemented as an Angular component as though it does not provide any view of its own it wraps the UTTT view and so must have HTML associated with it. It uses a system of modals and events to communicate with the view and underlying services. Moreover, it does not in anyway mutate the model it simply provides the mechanism for the user to communicate the actions they would like to take to the server, which in turn mutates the model.

Implementation

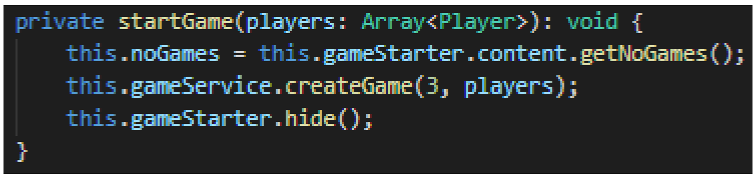
The client side controller consists of only two classes, the "GameComponent" class and the "UserComponent" class. The GameComponent class interacts with the UTTT Component, which provides the view for the game, and responds to click events that propagate out from the view. Observers for click events are registered in the HTML, when a click is registered on a tile it emits a move event up to the parent UTTT component. The UTTT component will then recursively emit move events to their parents until it reaches the GameComponent where it is then processed. Processing of moves simply involves sending the relevant



```
public moveMade($event: Move): void {
    this.overlayVisable = true;
    this.gameService.makeMove($event);
}
```

information to the GameService, which will then send it to the server in the correct format. Also, the GameComponent is responsible for communicating which players the user wishes to play. Again, to do this the component simply gets the relevant information from the view and passes it to the appropriate service to send it to the server. This separation of concerns between the controller and the server is vital for several reasons, for one the endpoints on the server may change, secondly the server may be replaced with some different system, possibly client side. These changes would be cumbersome if the GameComponent were to directly interface with the server. The other controller on the client side is the UserComponent, it is responsible for communicating login details and requests to the UserService, it does this in the same way that the GameComponent does.

Maintenance



```
private startGame(players: Array<Player>): void {
    this.noGames = this.gameStarter.content.getNoGames();
    this.gameService.createGame(3, players);
    this.gameStarter.hide();
}
```

In the first implementation of the game players were only given one option when setting up a game, this was who the opponent was going to be. As development progressed new needs arose, those being, two AI should be able to play each other, the human may not always want to play first, for experiments multiple games between the same opponents should be queued up. To accommodate these changes the GameSetupComponent, a component displayed by the GameComponent when the game window is first visited, was extended to allow players to select both players and a new input field was added to allow some number of games to be queued. That is why, in the above figure players is passed as an argument, as an array of players was always constructed by the GameSetupComponent, but the number of games is retrieved in the method call.

Server

In the server controllers behave slightly differently, they are responsible for retrieving web requests and calling services to do work on the information they receive.

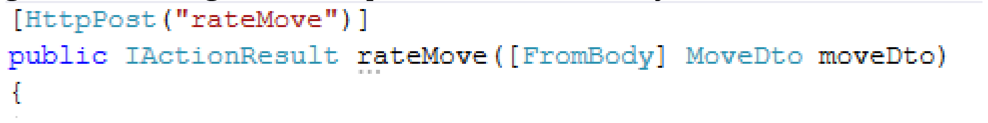
Requirements

The requirements for a server-side controller are minimal. They must:

- Expose an endpoint of the server
- Pass the appropriate information form the web to the service
- Return the request in the appropriate format

Design

To abstract some of the basic web interaction from more specialised controllers, all controllers extend a class called BaseController which in turn extends Controller. The Controller class is provided by the Asp.Net framework which provides methods for receiving and returning HTTP requests. There are only two classes which extend the

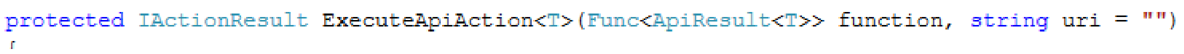


```
[HttpPost("rateMove")]
public IActionResult rateMove([FromBody] MoveDto moveDto)
{
```

BaseController these are, The GameController and the UserController. Both of these controllers expose various endpoints that allow a client to request actions be made to a model or some value be updated in a database. The Asp.Net framework also provides some decorators which are used to expose methods to the web. Furthermore, there are decorators which tell the framework that certain arguments to a method will be provided in the HTTP request.

Implementation

The BaseController has only one method, ExecuteApiAction, this method must be called by any controller that wishes to respond to a http request as it is responsible for

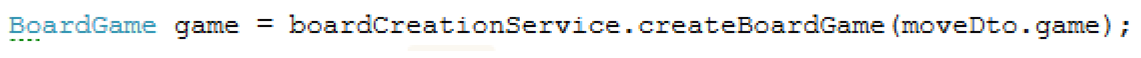


```
protected IActionResult ExecuteApiAction<T>(Func<ApiResult<T>> function, string uri = "")
```

returning the correct HTTP status code. The ExecuteApiAction method takes an anonymous function as an argument, this function will be called by the BaseController, if no error occur the result of the call will be wrapped in an IActionResult object, which is provided by Asp.Net core. If an error does occur, then the BaseController handles the exception and returns the correct HTTP error code. The decision of an anonymous function was made as it helps the BaseController be more generic. The ExecuteApiAction method can return an IActionResult of any type. It allows all inheriting classes to define any methods they wish as long as they return an ApiResult.

Maintenance

When a request arrives from the web it is in JSON. In the initial implementation of the GameController the object passed into the rateMove method had a variable called game, which is a representation of the board, and was typed as the interface BoardGame. This became an issue when the client was able to send requests to the server, as the interface is implemented by multiple classes so the JSON deserialiser provided by Asp.Net could not decide which class to use and through an exception. In an attempt to correct this issue, the JSON deserialiser was subclassed to add functionality that would determine the correct subclass to return. This also proved problematic as the new deserialisers could not have classes injected into them which were needed by the concrete classes of BoardGame. Another solution was implemented which saw the game variable's type being changed from a BoardGame to a JsonObject and a new class was implemented to properly construct the correct BoardGame from the JSON. This solution, though requiring more code, allowed the client to remain unchanged while also allowing classes to be injected into the new BoardGameConstructor class which allowed loose coupling between any service needed by a BoardGame and the constructor of the BoardGame.



```
BoardGame game = boardCreationService.createBoardGame(moveDto.game);
```

Services

Services exist on both the client and server side and both intend to make changes to the model. As discussed previously in this chapter client-side services do this by sending requests to the server, the server-side services have access to the actual implementation of the model though and so can call methods to mutate the model.

Client

On the client-side services exist through the duration of the tab that the app is open in, unlike other components. These services serve as the true version of the model that is passed from the server and all other components use a system of events to communicate with them

Requirements

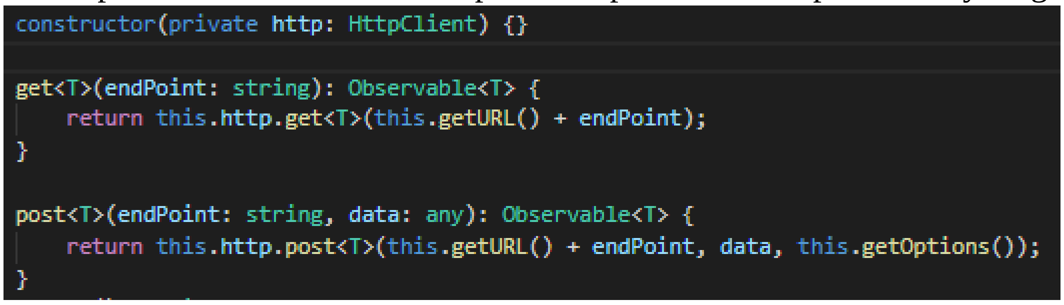
The requirements of clients side services are simple, they must:

- Maintain the model
- Provide methods to mutate the model
- Provide events for when the model is updated

The difference between this and a controller is this does not interact with any event from the view, it does not interpret click events or menu choices. Instead it provides the controllers with a way to communicate with the server, which in turn will mutate the model.

Design

To decouple the services of the client from the web a lower level of service was created called the ApiService. This service wraps the HttpClient that is provided by Angular.



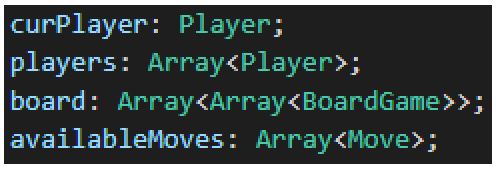
```
constructor(private http: HttpClient) {}

get<T>(endPoint: string): Observable<T> {
    return this.http.get<T>(this.getURL() + endPoint);
}

post<T>(endPoint: string, data: any): Observable<T> {
    return this.http.post<T>(this.getURL() + endPoint, data, this.getOptions());
}
```

Doing this isolates any change that Angular might implement on the HttpClient so only this class would need to be updated. Moreover, it allows reusability of this code as multiple services make HTTP requests. The classes which use this service are the

GameService and the UserService, both of which have the ApiService injected into them.

Implementation

The services on the client-side consist of two classes, the GameService and the UserService. As services in Angular exist for the duration of the application and are singletons by design they hold information that be requested for by controllers. The GameService holds all the information that the controllers would need to process user actions correctly, such as the state of the board, the available moves and the current player. The UserService is mostly the same except it stores information regarding the current logged in user. These classes are not meant to be overly large, as they are not meant to have much functionality in them. The UserService for example only has thirty nine lines of code, as it is mainly designed to forward information to the server's controllers.



```
curPlayer: Player;
players: Array<Player>;
board: Array<Array<BoardGame>>;
availableMoves: Array<Move>;
```

Server

The services on the server are where the vast majority of the games logic is processed. They exist in the business layer of the servers layered model along with the game models.

Requirements

The services are the where most of the code in this project exists. They provide the functionality that interacts with the model and the logic that formats the HTTP responses. These classes have the biggest requirement set of any in the project. They are:

- Let both players make moves
- Decide who the winner is
- Have the moves made by both AI and human players rated
- Have a mechanism for persisting the move data
- Flatten the response time for AI players

- Create the DTO that will be sent to the client
- Provide a mechanism for creating new users
- Provide a mechanism for retrieving existing users
- Provide a mechanism for updating existing users
- Provide a service for creating random numbers
- Provide a system for ranking moves
- Provide a mechanism for creating Model objects from the JSON received from the web

Design

The services all exist in a simple inheritance with only an interface and the concrete class. This is because Asp.Net frameworks dependency injection requires injected classes implement an interface and that interface is injected. The concrete class will be created by the runtime. Doing this decouples the implementation of the service from every class that uses it, as nowhere in the code that was developed is a new instance of a service created. This allows future developers to create new services which fulfil the promise of the interface. They can then change the mapping in the Asp.Net container which will then supply the new class. As mentioned previously the services exist in the business layer of the server, this means that they are used by the Api layer to mutate the models passed in from the web, while also having access the data access layer. Because of this these services are the largest classes in this project. There are multiple services in this project which exist only because TDD demands they do. Services such as the RandomService which wraps the Random class. This class is well tested, which would be substantially harder to do if every class which required random numbers simply had an instance of the random class.

Implementation

The main service class in the server are the GameService and the UserService, mirroring the client side services. These services though are far more substantial as they provide all the mechanisms needed to process the requests that come from the client. They are injected into the Controllers and are called to process all the requests that arrive from the web. The GameService interface only exposes two methods, processMove and rateMove. These methods are used by the controller to have the service process or rate a move that arrived from the web. The UserService is mostly the same providing methods for creating, updating and getting users.

Maintenance

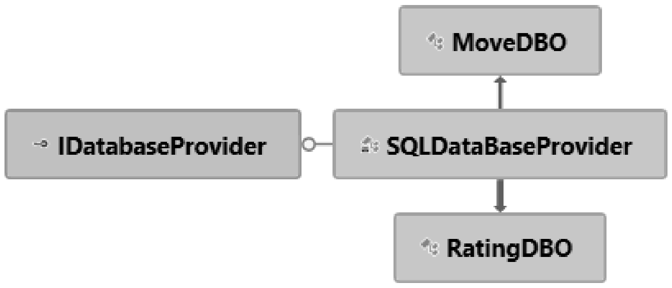
In the original implementation of the GameService the AI player was given the board which it then made its move on and returned. This system was found to be an issue for two reasons; AI players developed in the future could simply cheat and mutate the board however they wished as it was passed by reference, AI response times depended on how much processing they did before making a move, the RandomAI responded very quickly while the MCTSAI responded after a couple seconds and lastly the amount of time taken for an AI move was effectively doubled as to rate a move the MCTS algorithm was used, so AI which already performed this action would look to the user to take twice as long than AI which did not. To rectify this the MCTS algorithm was called before the AI were. They were then passed the board they were given and the tree built by the MCTS. This flattened the response time as the amount of time AI took to process the nodes they were given is minimal, while also only needing the MCTS algorithm to be ran once on the game. Furthermore, it meant that when rating AI moves the scores that the AI saw are identical to whatever will be stored. This means that the representation of the AI in the database accurately reflects how the AI intends to play.

Providers

Providers are class which exist exclusively in the server as their primary objective it so provide the application with access to a datastore. The provider lives in the data access layer of the server and abstracts the type of data store used by the system.

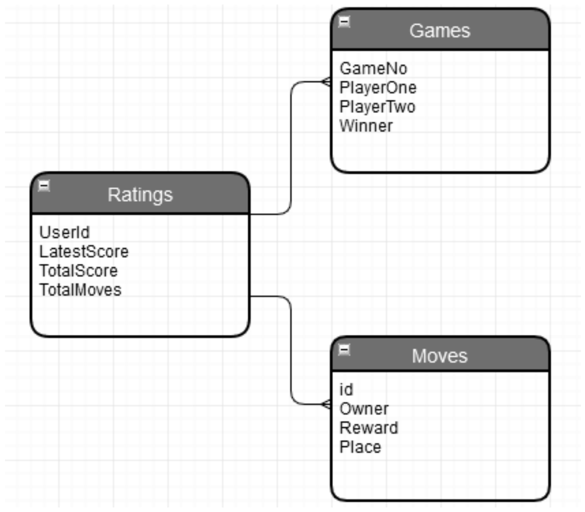
Design

The provider consists of only one class and one interface. This is because the data access layer, though vitally important to the operation of the application is not overly complex. The interface is used to abstract the implementation away from the business layer, so at any time in the future a new provider can be implemented which accesses some other form of data storage (No-SQL or Blob). As well as the provider there are a couple classes which serve to encapsulate related data these are known as DataBase Objects (DBOs). The DBOs allow the provider to pass data to the upper layers of the server without exposing the implementation of the storage.



Implementation

The SQLDataBaseProvider is the sole class that interacts with the database. It does this by instantiating connections with the azure database and performing queries on the desired tables to get the data requested for by the upper layers. The IDatabaseProvider does expose the Move and Rating DBOs it does this to allow the implementation to hide the rows it receives from the database while still communicating the data received. As a security feature the connection string required by the database required by the database to query tables is not stored in the implementation. Instead the string is stored in a JSON file which is read during the run time to get the connection string. The advantage of this is that the string can be update when the app is pushed to production, so the connection string is never exposed on the git server or locally. The DBOs are data objects, which is normally a code smell, they were designed like this to avoid multiple calls to the database, which is a slow operation. As data objects the DBOs do not have any methods defined, only public fields. The database is made up of three tables; the ratings table which holds the UserIds for all users and some rating information, the Games table, which holds information on games played, and the moves table, which holds a record of moves made by users.



Validation and Verification

To verify and validate the server and the client similar methods and techniques were used however the tools differed. The Microsoft testing library and Jasmine were both used extensively to develop the two hundred and forty tests which were vital in ensuring the correctness of the product while also allowing for quick bug identification and correction. There are one hundred and eighty tests on the server as it encapsulates most of the functionality and sixty on the client. UI testing is possible, with tools like Selenium, however, this was deemed as too time consuming as tweaks to the UI would cause tests to fail resulting in failed builds.

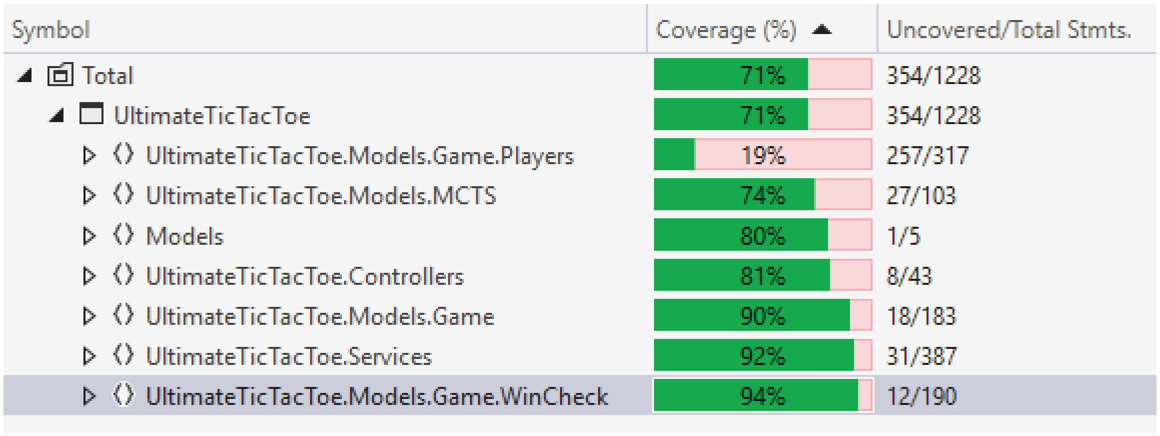
Testing Strategy

"Perfection is Achieved Not When There Is Nothing More to Add, But When There Is Nothing Left to Take Away" Antoine de Saint-Exupery

In this project Test Driven Development (TDD) was heavily leveraged to ensure a well-tested and maintainable product was produced. The TDD cycle follows a four-step process that allows the developer to be confident that the code does as it is described.

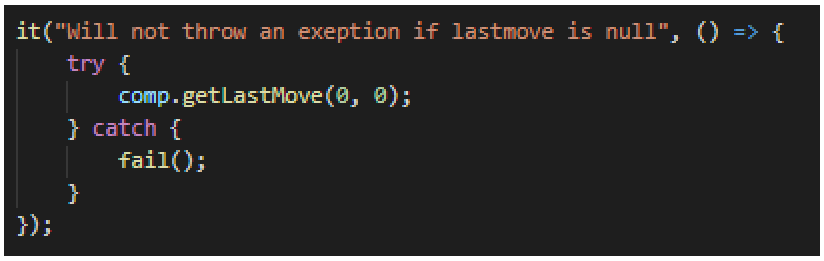
- Write a failing test
- Write code to pass the test
- Run all tests
- Refactor

The reason a test should be written before the code is fairly simple, a test that has never failed cannot be trusted. After code has been written to satisfy the test all tests in the project are run. This is to ensure that this piece of functionality did not affect the behaviour of any other component. And lastly refactoring is simply to allow the code to make sense. It also helps reinforce some core coding principles that were believed be of great importance, for example, it requires only code that satisfies tests to be written and so enforces the "You aren't gonna need it" principle. As development progressed however, and time became less abundant, the TDD structure as not followed as closely, as a result code coverage sits at 71% in the server, mostly due to untested code in couple of the AI classes. Excluding the AI brings coverage up to a respectful 89%. Moreover, in this project tests where seen as documentation. This is preferred over traditional



Symbol	Coverage (%)	Uncovered/Total Stmts.
Total	71%	354/1228
UltimateTicTacToe	71%	354/1228
UltimateTicTacToe.Models.Game.Players	19%	257/317
UltimateTicTacToe.Models.MCTS	74%	27/103
Models	80%	1/5
UltimateTicTacToe.Controllers	81%	8/43
UltimateTicTacToe.Models.Game	90%	18/183
UltimateTicTacToe.Services	92%	31/387
UltimateTicTacToe.Models.Game.WinCheck	94%	12/190

documentation as it they are infallible. The test must pass before the code will be committed to master and so they can be seen as the true behaviour of classes in the project. However, as also demonstrated in this project parts of the system are untested, and so lack documentation. There was every intention to test the code that had been written hastily but as it was complete and there was more work to do these tests were never written. Tests can still be written after the class has been otherwise completed, in instances of bug where all tests are correct, but some piece of functionality still does not behave as expected a test may be written with the input that caused the error. This will allow the developer to see where the code fails and correct it more easily.



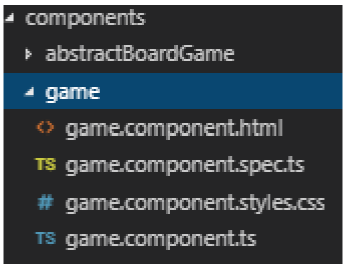
```
it("Will not throw an exeption if lastmove is null", () => {
    try {
        comp.getLastMove(0, 0);
    } catch {
        fail();
    }
});
```

Mocking

Mocking is a well-established testing practice that allows developers to isolate the code they are testing by “mocking” other pieces of functionality that is not under test. In this project two mocking libraries were used, jasmine for the client and Moq for the server. Both provide functionality that allows the developers to isolate testing code as well as test that interfaces were called with the correct arguments, the correct number of times etc. Mocking is a powerful tool when used in combination with DI as it abstracts away how components are created. Using a well-tested DI framework, like the ones used in this project, mocking can allow for classes to be completely isolated from their dependencies so unit tests can focus on one descrete piece of functionality in the class.

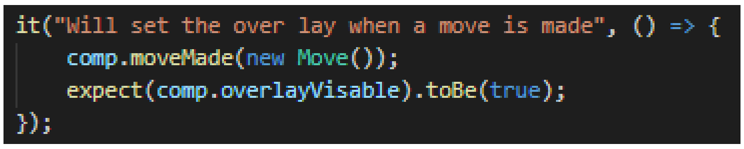
Moreover, mocking influenced how some of the project was designed, for example, the MCTSService has a NodeConstructorService injected into it, this was done to allow the creation of nodes to be thoroughly tested, which would have been more difficult had that functionality been hidden inside the MCTSService.

Jasmine



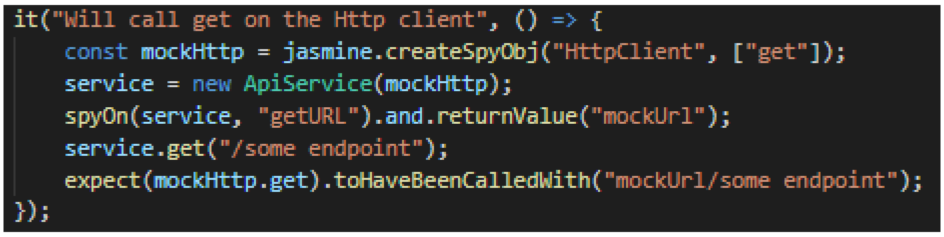
```
◢ components
  ▸ abstractBoardGame
  ◢ game
    <> game.component.html
    TS game.component.spec.ts
    #  game.component.styles.css
    TS game.component.ts
```

Jasmine provides two roles. It is a testing framework that allows javascript and typescript tests to be run in the browser, and it is a mocking framework. The structure of tests in the client is simple, every component exists in its own folder along with a test class (spec.ts). This allows future developers to quickly and easily find components, along with all their tests and check if everything works as described. Jasmine dictates a "It will" style in naming tests as the method used in the test is simply called "It" which then takes a string argument as the name of the test and an anonymous function which is the test. As demonstrated below the tests are



```
it("Will set the over lay when a move is made", () => {
    comp.moveMade(new Move());
    expect(comp.overlayVisable).toBe(true);
});
```

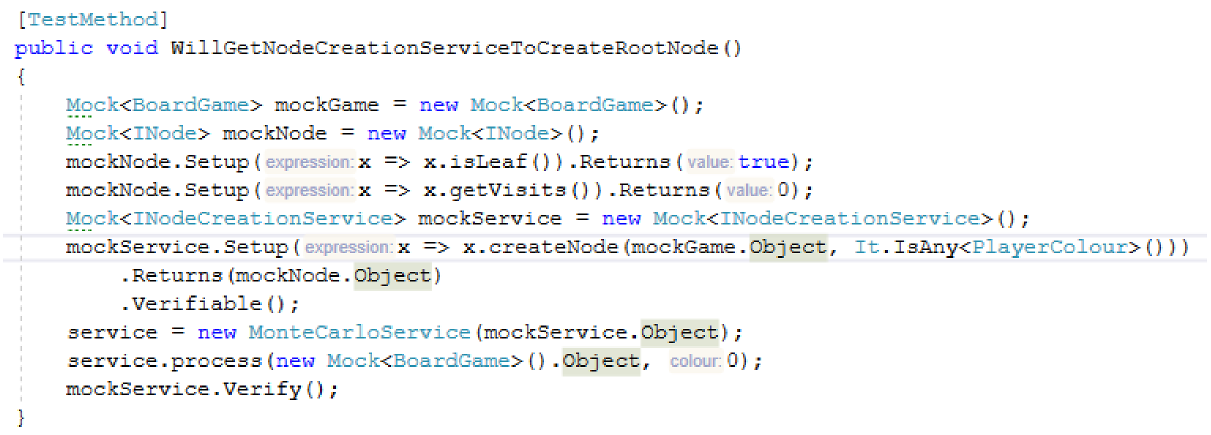
intended to be concise. They describe exactly one piece of functionality each, this is demonstrated by the fact that each test has only one "expect" call. This is important is it ensures that if a test ever fails future developers will know exactly which piece of functionality has not behaved as expected. As a mocking framework jasmine does two things, it can create mock objects and it can mock out calls to methods in the class under test.



```
it("Will call get on the Http client", () => {
    const mockHttp = jasmine.createSpyObj("HttpClient", ["get"]);
    service = new ApiService(mockHttp);
    spyOn(service, "getURL").and.returnValue("mockUrl");
    service.get("/some endpoint");
    expect(mockHttp.get).toHaveBeenCalledWith("mockUrl/some endpoint");
});
```

Microsoft Unit Testing

On the server Microsoft Unit Testing was used along with Moq. Moq is a mocking library that provides functionality that allows mocking of other interfaces, unlike jasmine it can not mock methods in the class under test. Though this is not a major issue as only public methods should be tested as they are the only methods other classes should be interacting with. Mocking works in much the same way as in Jasmine, however, this does mean that some design decisions were made to accommodate this. As discussed previously an example of this can be seen in the NodeCreationService used by the MCTSService. Looking at the tests it is easy to see why this decision was made, even if the code to construct a node is not complex it would have been much harder to test had it have been in the MCTSService. In the figure below it can be seen that the test demands only that the correct game (mockGame.Object) is passed to the node creation service, there will be another test for the player colour.



```
[TestMethod]
public void WillGetNodeCreationServiceToCreateRootNode()
{
    Mock<BoardGame> mockGame = new Mock<BoardGame>();
    Mock<INode> mockNode = new Mock<INode>();
    mockNode.Setup(expression: x => x.isLeaf()).Returns(value: true);
    mockNode.Setup(expression: x => x.getVisits()).Returns(value: 0);
    Mock<INodeCreationService> mockService = new Mock<INodeCreationService>();
    mockService.Setup(expression: x => x.createNode(mockGame.Object, It.IsAny<PlayerColour>()))
        .Returns(mockNode.Object)
        .Verifiable();
    service = new MonteCarloService(mockService.Object);
    service.process(new Mock<BoardGame>().Object, colour: 0);
    mockService.Verify();
}
```

AI testing

There were two main questions to answer around the performance of the AI. How well did they adapt and were the adaptive AI more or less fun than the non-adaptive. For the former the testing method included running fifty games against one of the adaptive AI and any other AI. Originally there was only one adaptive AI, the Good dad, which simply made moves that’s reward was close to the average reward of the opponent. However, after the first round of testing it was decided that a second implementation of an adaptive AI would be implemented. This implementation would use the average placement of the opponent and take a move within two standard deviations of that then randomly choose a move in that range. Moreover, some checks were made to both implementations, such as choosing the winning move if it was an option. This change was made as during the game an average move is not the winning move, so the adaptive AI would delay the game until the opponent won. These rounds of games were also used to quantify how fun the adaptive AI was using the methods proposed by Tan, C.

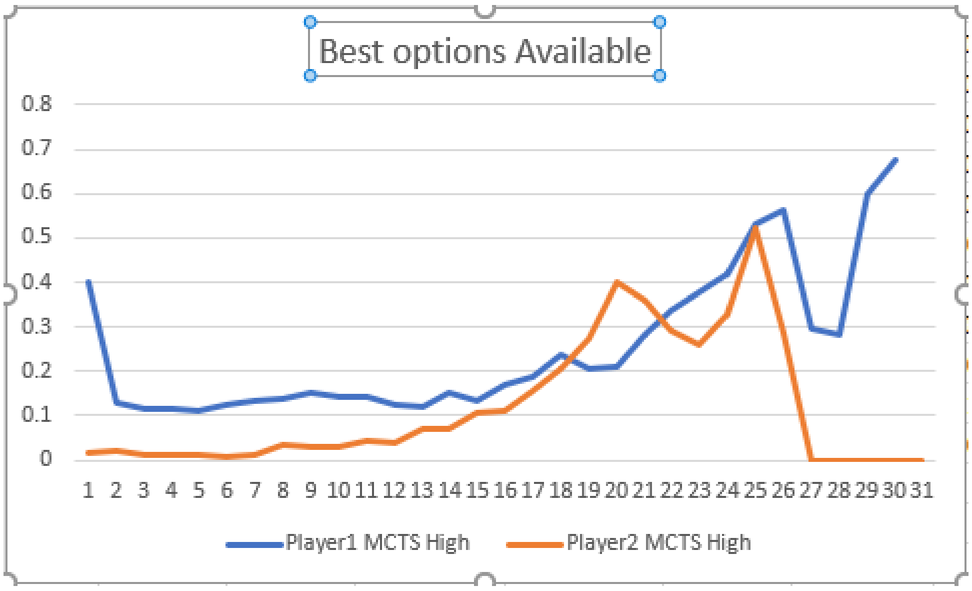
H., Tan, K. C. & Tay, A. The AI were also tested with human players. This testing consisted of having the player play some non adaptive then adaptive AI and record how much fun they had. They were also asked how hard they felt the AI player, this was done to confirm the work done by Chanel, G. &. R. C. &. B. M. &. P. T. in that harder and easier AI should be less fun. It was intended for an external AI to be used in the project as a better benchmark of how well the AI performed. The AI chosen for this was implemented by the OFekFoundation (TheOFekFoundation, n.d.). Due to integration issues the AI implemented in this project did not play the OFekFoundation AI. This means that the AI in this project do not have any measure of how well they play the game.

Results and Evaluation

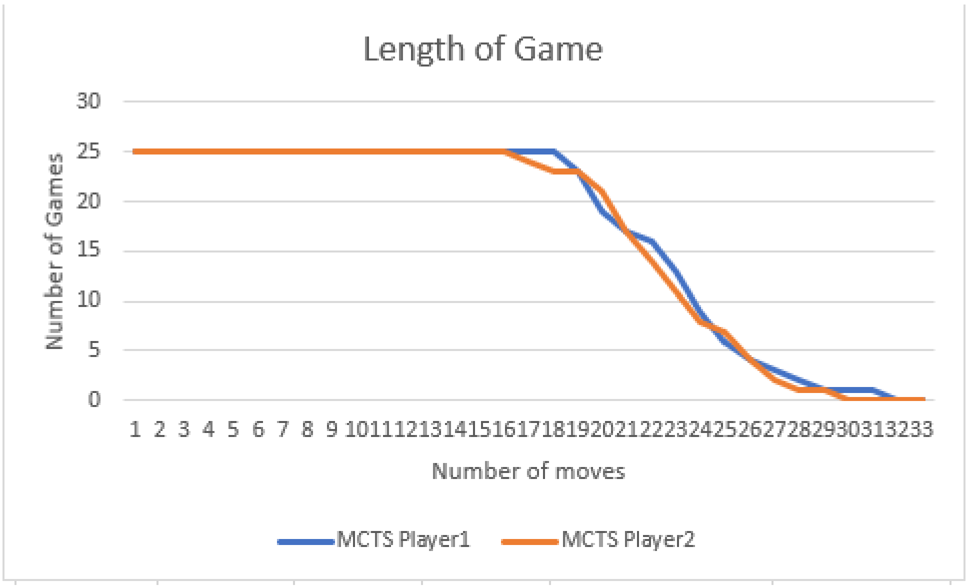
The intention of this project was to develop an adaptive AI system which was primarily fun to play against. To evaluate the success of the project in this regard users were asked to evaluate the AI in a single game. In this section the results of a six hundred and fifty games will be reviewed and discussed to access the success of the adaptive AI in creating a fun game as well as some observations made about the game in general.

The Game

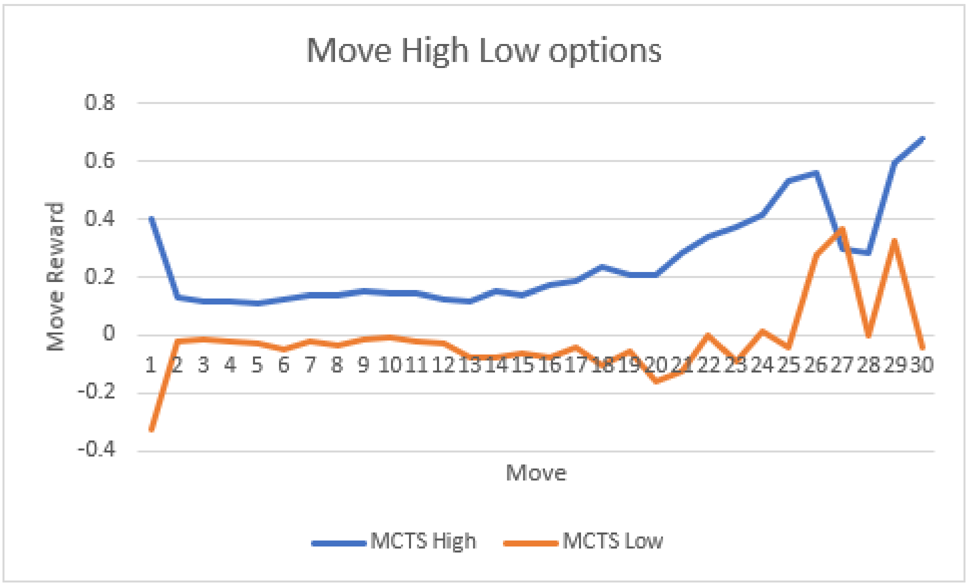
As discussed previously, as there are no external rulers used to measure the performance of the AI developed. Instead the highest and lowest score achievable were logged for fifty games to produce an average progression of an average game. As seen in the figure



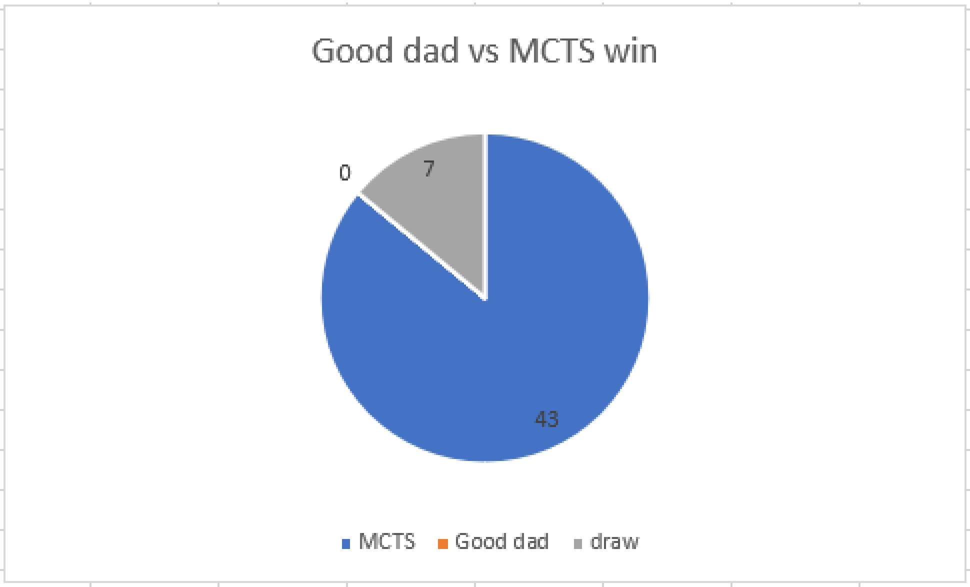
above the first move seems to have a massive advantage, however, the implementation of MCTS only took three thousand samples of the game space. The opening move has eighty-one options so if the tree is built symmetrically each child of the root is only visited thirty-seven times. Obviously, MCTS will not build the tree like this but, it may still not gain an accurate picture of the game state as there are so many options. The



longest game played when playing optimally was thirty-two moves and the shortest was sixteen moves. In figure (Number) the odds of winning or losing in the average game converge before becoming farther apart in the later parts of the game. This observation

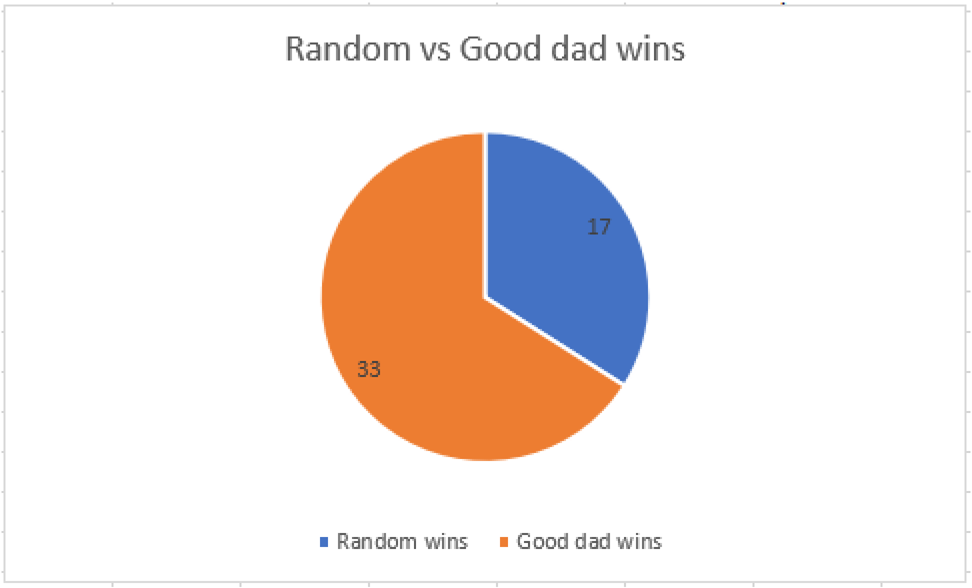


lead to the design decision to weight the average against the latest move. The original weighting was set at 60% to 40% but this was changed as more experiments were conducted. The initial Good dad performed poorly against the MCTS player, even though the Good Dad adapted well the MCTS play style, in a set of fifty games it only won twice. The second set of games had the adaptive AI weight average to latest moves at 80% to 20%, this proved to be ineffective at achieving the desired behaviour. The resulting AI did not win a single game against the MCTS player, drawing seven times and losing the rest. The fact that the average move made is not a winning move, or

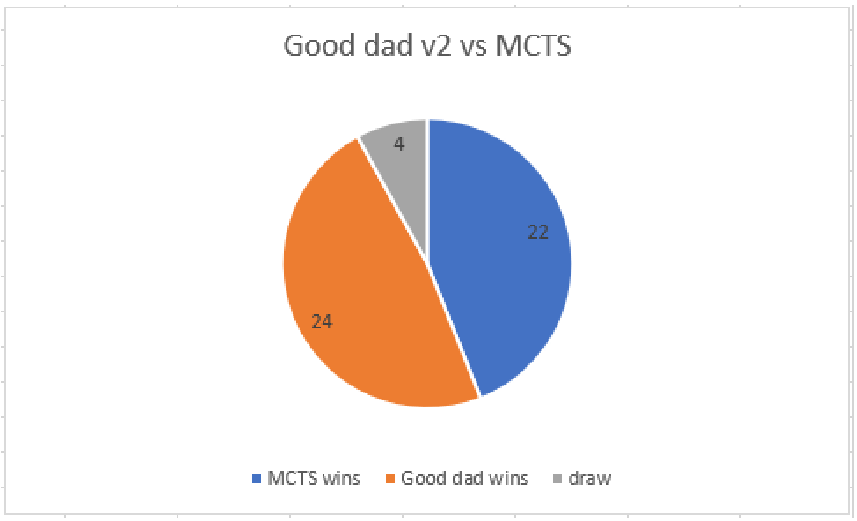


indeed a very good move, forced another change to be made to the adaptive AI. The next iteration had a small piece of logic added that dictated that if a winning move was available. Moreover, the adaptive was not behaving as intended. The MCTS player always picked the move that maximised its reward, but the adaptive AI would every so often choose a move which was not optimal. This is simply because that move would have been exceptionally good and out with the norm, the MCTS player would have taken advantage of the situation, however. To combat this, two changes were made. Firstly a small piece of code was added to the adaptive AI that would force it to make a winning move if ever given the opportunity, secondly a whole new adaptive AI was implemented, this one took the average place of the moves the opponent made, in the case of the MCTS player this was always first, and randomly selected a move with a placement within two standard deviations of the average, named Good dad v2. This resulted in an adaptive AI which consistently played the best move when playing the MCTS player. The initial implementation of the adaptive AI still did not perform at a reasonable standard as it was routinely beat by almost every other AI implemented in the system. The only AI which the 80-20 balanced AI performed well against was the

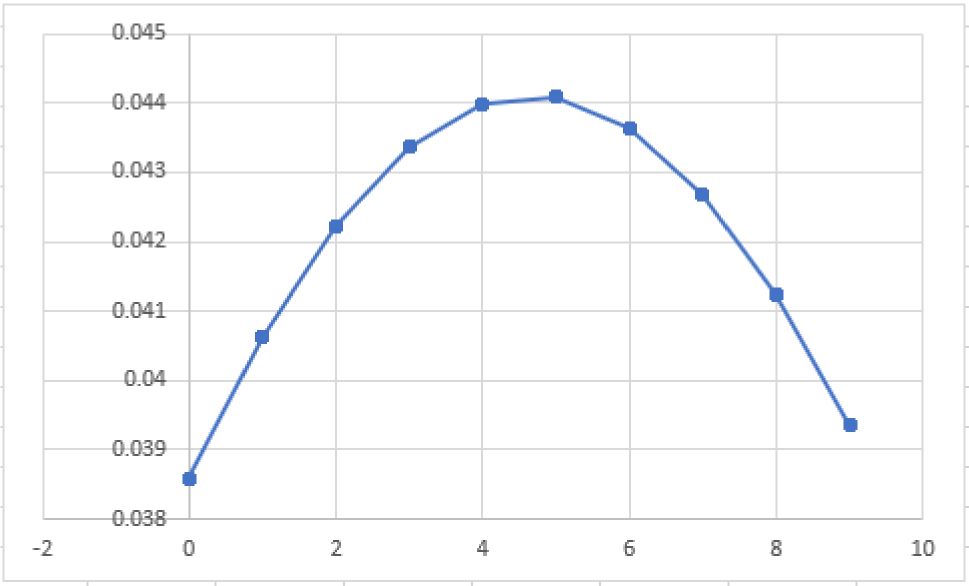
RandomAI which had no decision making process and so did not pick winning moves. Even though this system may have been able to beat the RandomAi at a semi consistent



rate it still did not produce a fun game as defined by Tan, C. H., Tan, K. C. & Tay, A. as the difference of wins and losses for the random player are quite high at sixteen, which is just one away from the number of wins the RandomAI had in total. The Good dad v2 performed at a much higher standard and adapted its' behaviour to match the MCTS and RandomAIs much more readily. Though it still did beat the RandomAI at a dispraportiontly high rate, it encountered more draws which is to be expected when the



opponent does not play to win. Both AI had issue with the MinefieldAI though. This AI was designed to play moves that would win it subboards by placing tiles in straight lines that were not interupted by the opponents tiles. The assessment of why this might be is the MCTS algorithm may opt to send the opponent to a subboard that gives the opponent lots of options, as the roll out is random there is a chance the opponent does not pick the winning move, and so that move may be given a placement that is inaccurate. Or the Minefield AI play is so poor that the adaptive AI simply makes bad moves the entire game, not building its possition while the MinefieldAI did just that. The standard



deviation of the MineField is quite large at nine, meaning the Good dad v2 was basically playing randomly. This would explain how the MineFieldAI routinely out plays the adaptive AI soloutions beating both Good dad and Good dad v2 with ease.

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