



Browser-based Online Multiplayer Roleplaying Game

Final Report for CS39440 Major Project

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Abstract

Include an abstract for your project. This should be no more than 300 words.

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Chapter 1

Background & Objectives

Games are interesting projects to take on; they have a history of being difficult to make and pushing technology to its limits. There are a great many systems and features that can be included in them—AI, physics, graphics, audio, UI, multiplayer and more—and a great many ways to implement each, from simple to very complicated depending on the needs of the project.

Games also have a history of aiming for too many of these features in too little time. In most cases, every one of the features thought up would enhance the final product in some way, from a significant improvement that changes the way the game is played to a minor enhancement that makes things just a little more pleasant for the user. Many of these features may be considered mandatory for the game to be worth making at all. For example, a single-player chess game would probably not be very good if there were no AI to play against.

It is not just players who require features, however; developers of games need tools to implement the game design and a good engine to hang the design off of. A lot of game projects build custom tools that let developers and designers implement things quickly. Many game engines even provide methods for scripting and modding them after their release to players.

It is clear that, given the sheer enormity of the possible things that can be put into any one game, there is not enough time in this project to implement even half of them without a great deal of previous experience and skill. Every one of the major systems mentioned can be extremely complicated, requiring a lot of research, time and effort to make them work.

This chapter will discuss what the project is; why it was worth taking on; how a minimal system was devised that would satisfy enough of the game design requirements to be playable but also be implementable in the time given; and finally the process used to implement the design requirements.

1.1 Background

1.1.1 The Project

Before discussing the decisions made about what was doable and why it was interesting, it's useful to know what the project actually is.

The name of the project—*Browser-based Online Multiplayer Roleplaying Game*—gives a relatively good hint of the nature of the game. “Browser-based” and “multiplayer” are fairly self-evident in meaning: multiple people play together in a game hosted in the browser. “Roleplaying game” is more ambiguous. In this case, it refers to a game in the style of the classic tabletop roleplaying game *Dungeons & Dragons*.

In the context of the project that meant the following things: Firstly, there needed to be two types of players—regular players and a Game Master. A regular player plays the game as a character inhabiting the world they happen to be in. For example, they may be a dwarf in a fantasy kingdom, or a space marine on a futuristic space station.

The Game Master is a player responsible for building the world, telling the story and controlling characters that aren't controlled by the other players (known as Non-Player Characters or NPCs). Traditionally, the Game Master would also be responsible for enforcing the rules of the world. However, in this project the game was to be responsible for that instead, with the Game Master given the option of overriding or changing the rules if he or she wished to do so.

Combat is the most obvious area where the game enforcing the rules comes into effect. Combat is turn-based, with players put onto a grid and given limits on the distance they can move and number of actions they can perform in each turn. When they attempt to do something—such as attack another character or creature or escape from a trap—they have to roll dice, the result of which decides whether they were successful or not, and how well they succeeded or failed. As an example, a player failing to attack a creature with their sword could simply miss, or they could throw the sword away accidentally, depending on the result of the dice roll.

In the above scenario the dice rolls would be simulated by the game, rather than physical dice being used by the players. The game will also decide whether or not an action was valid in the first place. A player hoping to attack a creature with their sword would be unable to do so if the creature was too far away from them.

The design also called for interactions outside of combat. For instance, a player might be faced with a locked door. To get through a player could attempt to use a key they found or, alternatively, they could attempt to bash the door open with an item, such as an axe, or even their bare hands.

There are a few specific implementation details as well. Apart from the game being played via a browser, there needed to be graphics and those graphics needed to be 2D isometric tiles. Further, the server was to be written in Python with the goal of gaining experience in the language.

With this overview of the game—a full account of the original game design can be found in Appendix C—it is now important to answer why the project was worth doing.

1.1.2 Why Make The Game?

The first answer to this is that games are interesting in general. Most obviously, the final product of a game is (hopefully) something fun to play with appeal to a wide range of people. More relevant to the context of a project, however, is that games are interesting from a software perspective.

Games are made up of a lot of different parts, each one potentially being difficult to implement by itself. In this game, the most challenging individual parts are graphics and multiplayer. More important than just the individual parts, however, is making sure they integrate properly. In most cases the game needs to share data between these different pieces—game logic needs to know what an object is doing so it can perform game functions on it; the renderer needs to know what the object is doing so that it can be drawn to the screen correctly; the networking part needs to know what the object is doing so that it can forward on any relevant information to the server.

The game also offers a lot of extendibility. Given more time, more features can be added. Each feature, and fitting it together, offers a lot of potential for learning as well. For example, an extra feature could be AI, which is an interesting area in itself that offers a lot of opportunity to learn something new.

1.1.3 Reading and Research

Most of the research in the gaming world is very much a closed source, commercial affair. Being on the cutting edge of games is expensive work, requiring smart people spending a lot of time squeezing everything they can out of technology, plus a whole bunch of people to make content for the technology to show.

Even with the explosion of ‘indie’ games made by one person or a very small team that exist these days, most of them are still closed source and commercial. Even free games are rarely free (and certainly not open source)—existing as a vehicle for microtransactions, asking people to buy consumable cosmetic items or in-game advantages, such as speeding something up, for a small fee.

Of course open source games do exist, though they are relatively rare and not very well known. One of the open source games with most relevance to this project is Mozilla’s *BrowserQuest* [4–6], a multiplayer role-playing game created in 2012 to show off the capabilities of modern browsers. It has a few properties that are useful to know for this project, the main one being multiplayer.

However, despite the theoretical usefulness of having access to the source code, it was not as useful in practice as might have been desired or expected. Without documentation that describes the more high level structure of the code it is difficult to read through and understand properly without spending a lot of time on it.

The need to have a higher level overview of structure and concepts leads to books, articles and tutorials.

One of the most popular books available for this is *Game Coding Complete* [7]. It is a lengthy book but covers a lot of things, both high level and code-specific. Most of the implementation details given are inappropriate for this project because they are for 3D graphics, C++ and cover a

lot of things like custom memory management that have no equivalent or purpose in a much more simple 2D, browser-based game written in JavaScript. However, the high level aspects of game engine design the authors talk about are very useful.

The other major book that was found to be useful in this project is a free book currently available online called *Game Programming Patterns* [9]. This book describes many common design patterns used in game programming, some being game specific and others being more well known patterns but applied to game programming, such as the classic Factory pattern. Some of the patterns when put together describe a more general structure, in a way similar to *Game Coding Complete*.

The content of these two books informs a great deal of the design that was settled on for this project, with particular emphasis on the central game loop and the event manager. These two fundamental parts of the design act as the glue for the more specific aspects of the code, like the graphics renderer or input manager.

Some other books were also investigated, mostly pertaining to the more specific implementation details of the project such as HTML5 browser games. Two books were found in this area, one which talked about implementation details in HTML5 [12] and one which did the same thing but with the addition of a focus on isometric graphics [11].

These books were less useful than the previous two mentioned, however; they didn't offer much extra for structure and the majority of the code in the project is fairly platform independent and easily transferable to other languages. Where the platform is relevant, the *Mozilla Developer Network* [8] offers up-to-date APIs that are much easier to search through than a book.

There were also a few online resources used at various development stages. Initial development in the project was started by following a tutorial [10] that allowed a base-line understanding of how HTML5 games are hooked into the browser and the basics of creating tile-maps (which will be discussed in more detail in Chapter 3). The code was all replaced but it was a useful start.

Another online resource which proved to be very useful was a tutorial on how to render isometric tiles in games in a simple way [2]. This tutorial was referenced heavily in early development to get the renderer up and running, but was later adjusted to account for more advanced rendering needs.

Finally, other than the *Mozilla Developer Network*, there were APIs referenced for the various languages and libraries used in the project, which will be introduced in Chapter 3.

1.2 Analysis

With the knowledge that the scope of games can expand to encompass a ridiculous area, and that everything within that scope is likely to be time consuming to implement, it is important to define what features are absolutely mandatory for the game to be worth making, and figure out how long it might take to implement them. This section provides a discussion of how the minimal system was decided upon, with the list of features in the minimal system being available in Appendix D.

1.2.1 Necessary Features

The first of the necessary features is graphics. Graphics are the player's view into the world, letting them see the state of the game and figure out what their input needs to be. Without this view the only way to see into the world would be to debug the code as it was playing, which is not a very efficient way to play a game and the constant pausing would also break the game's timing, which is vital for games to operate correctly, particularly in a multiplayer setting. Of course, it is reasonable to operate a game with a textual interface. However, the game design specified that graphics be implemented and that those graphics be isometric tiles.

Players will need a way to interact with the game. There are two things that affect how this works: the Game Master and the isometric graphics. The Game Master needs to be able to select different characters to control and, in theory, create maps for the other players to play the game in. Using simple keyboard controls probably wouldn't work very well in this case. Isometric graphics also cause issues with keyboard controls. Players attempting to move their character using, for example, the arrow keys on the keyboard might find themselves confused as to which direction their character will move.

The solution to both of these is mouse-based interaction. The Game Master will be able to click to select characters he wants to control and place tiles and items into the world, and movement will be a case of clicking on the desired location and letting the character move there by itself, so that there is no confusion about direction.

The disadvantage to this is that mouse interaction is more complicated to handle than keyboard interaction. With a keyboard you check whether a key is pressed and perform an action based on that. With a mouse you have to work out the location of the cursor and what else is in that location. Further, mouse-based movement requires pathfinding, which ultimately adds another required feature.

The game also requires multiplayer. All interactions in the game happen between players, be they regular players or the Game Master. Without any way for them to interact the game is relatively pointless to play—all you'd get as a player is being able to walk around a map with your character.

Multiplayer implies a few things. The first is that there needs to be a way of clients communicating with some remote version of the game. This could, in theory, be a peer to peer connection. However, there are problems with this. The first is that peer to peer is not such an easy thing to support technologically with a browser, as the web operates on a client-server model.

The second problem with peer to peer is that there is no trustworthy version of the game. All the players need to have a view into the same world and the underlying data needs to be consistent between them or problems would occur. There is nothing to stop any one of the players from modifying their client to perform actions they shouldn't be able to do, and it being run in a browser using JavaScript makes this even more of an issue as all browsers come with easy access to JavaScript debuggers. A single client could be made the authoritative version (with the Game Master being the most logical choice here). However, if that client is tampered with it would affect the game for everyone.

A server solves both of the issues that peer to peer represents. It is, of course, more natural

for a browser to operate in a client-server manner. A server is also far more trustworthy than any individual client, and can be used as an authoritative base for the game so that, even if a player tampers with their client, the other players won't be affected.

The disadvantage to a server is that it requires resources and time to host and keep running. The more people who decide to play the game, the more server power is required. If the servers went down, no one would be able to play at all.

These things represent technical requirements as much as game design requirements. Their existence requires consideration in designing the structure of the game code. However, there are some other features required which could be considered purely game design issues.

The first of these is combat. In this case, combat is what makes the game a game. Without it players really only get to walk around a world together and look at how pretty it may or may not be, depending on the quality of the graphics used.

The full design of combat is fairly comprehensive and involves a lot of possible things. In the game design overview the idea of levels of success or failure was introduced, with things like throwing away a weapon if a character fails really badly on a dice roll. The game checking for valid options was also required, with the example given being whether a player was close enough to hit another character with a weapon. However, in the full game design there is also the option for ranged attacks using projectiles.

These options all make the game a lot more interesting. However, things like being able to throw away a weapon, or even just having levels of failure, require extra implementation time. It was decided that the project only needed to implement a very basic version of combat with other things considered extras to be done given more time. This basic version of combat was binary success or failure based on dice rolls; only 'mêlée' combat, requiring characters to be next to each other; and no items would be implemented in the base game, so no weapons and all combat would essentially be unarmed.

This would allow players to fight in the game, which is an important aspect of the game design, without creating too much work adding extra features that need a lot of development time and testing, such as projectiles or the use of items.

The existence of combat also implies the existence of attributes in characters and possibly other entities that allow them to interact in some way. In this case, the design specification calls explicitly for attributes called Hit Points (HP) and Mana, which represent the number of points of damage an entity can take before it is destroyed and the number of points it has to spend on magical spells respectively. Because magic would not be implemented in the minimal system, only HP and a way to affect it need to be created.

There should also be some way of interacting with the world outside of combat. Ideally these interactions would be almost limitless and allow the Game Master to specify even more based on items they add to the game. However, this is also a huge task. Because of the time consuming nature of adding interactions to the game only a few very basic ones should be included into the minimal system.

Finally, the last feature that is considered to be required in a minimal version of the game is

a chat system. This is important because the game is multiplayer and operates through players interacting with each other. It is unreasonable to rely on players to have a third party tool available for communication, so some way for them to communicate must be provided by the game. In this case, a simple chat system is the most logical choice as it is not too difficult to implement. The basic version of the chat will be global for the game but an enhanced version could allow local chatting between players who are in a specific area or private messaging between the Game Master and a player if the GM wants to do something special.

1.2.2 Unnecessary Extra Features

Given either extra time in the project or unexpected time available at the end of the project it is useful to have a list of features that could be added. Of course, ultimately it would be nice to include everything that the original design specification calls for, but it is also unreasonable to expect that enough time would ever be found to implement all of them. Therefore, the extra features should be given priority based on how worthwhile they are to implement on top of the minimal system.

Improving combat gains the highest priority because it is the most important part of the game outside of letting the players communicate with each other. The addition of items would come first, as players generally expect to be able to equip weaponry and defences like armour. After that, ranged attacks, such as using a bow. Magic would be the final part added to the game because it requires extra attributes to operate correctly and could have a wide range of effects, such as teleporting a user or causing a fire.

The next most important thing is to have a much wider range of interactions outside of combat. Supporting the ability for players to knock down doors or use a key on them, as was given as an example in the game design overview, enhances the game considerably from a player's point of view, opening up a lot of gameplay options. It may also be reasonable to include the use of weapons and magic outside of a combat context to interact with things, such as perhaps using magic to set a door on fire.

There are plenty of other features in the full design that could be implemented, such as voice chat or the ability for players to upload custom graphics. However, the extra features listed here represent a large enough amount of work that it isn't necessary to prioritise everything else.

1.3 Process

With a minimal system decided on the task becomes to decide how the time available is to be divided up between each feature and the systems necessary to support them.

The original process chosen was a custom variation of SCRUM, with many of the roles and tools taken out due to the project having just a one-person team. Primarily, this was chosen due to familiarity. There were some potential advantages to the process other than this, however: a minimal system was known and the functionality of each feature was well described from an end user's point of view, which translates well to the idea of SCRUM user stories.

The issue with this process was that, although the features were well understood in regards to their intended functionality, there was no complete understanding of how to implement them. This meant that a lot of time was needed to prototype and gain understanding of the problem area and what would be required to solve it.

The biggest example here was the structure of the code—the game engine that holds all the discrete features together and allows them to share the data they need to work. Initial research had come up with very little of how to realistically do this and much time was spent in the beginning of the project implementing, gaining understanding and then scrapping and reimplementing this fundamental part of the code. Indeed, this pattern would prove relatively true for all the features, though less extreme.

The issue this caused was that underneath each story in the SCRUM process are specific implementation tasks that are tracked. Because the implementation kept changing as the problem became better understood and the solutions improved, these tasks quickly became out of sync with what was actually occurring. The tasks began to follow the implementation, rather than the implementation following the tasks.

To deal with this wasted time, the process was transformed to do away with specific tasks. Rather, the already existing feature list was simply taken and followed in order of priority, with priority based on the understood difficulty of the feature—an area where previous research was more useful and accurate. Features were assigned to a sprint and considered to either be complete or incomplete. The completeness of a feature was decided based on its description in the minimal system specification.

This simplification dramatically reduced the administrative overhead of the process. There remained a way to keep track of what features were done and were still to do and gave a clear idea of what the current task was overall, without having to spend time writing down what the tasks specifically should be in detail, letting the dynamic and evolving nature of the implementation happen freely. The disadvantage was that there was no way to clearly point out how complete a feature was to someone else. This disadvantage was not a huge issue because the team only consisted of one person, who knew what rough level of completeness the active feature was at anyway. However, were the team to become larger this process would need adjustment to communicate task progress more effectively.

Chapter 2

Design

Game design has evolved a lot over the past few decades, taking advantage of more powerful devices and advances in programming generally. Game programmers were quick to take up the object-oriented banner, and were quick to become aware of its issues as well, eventually finding replacement patterns that solved the problems they came across.

There are a lot of frameworks and pre-made game engines around that allow a user to quickly get up and running in making their own games by handling the complicated parts such as rendering and input handling, asking the game designer to simply add some logic and art assets. However, these frameworks can have issues when you attempt to make a game that does not fit their predefined notions, and a lot of time could be spent hacking around their limitations to create an unusual game type.

Although it is extra work, implementing the game engine yourself gives you a lot of freedom in deciding what is necessary and what is not. Unusual aspects of the game design—such as a mix between real-time and turn-based interaction—can be accounted for and designed into the game engine much more easily, without having to first delve into unfamiliar code. This project also had the intention of learning by implementing these more technical aspects of the game engine, rather than to make a polished game on top of something that already existed.

This chapter will discuss the languages and frameworks that were used to implement the game and its engine, followed by the design of the engine itself, offering a higher level overview of the architecture as well as a more detailed look into the individual components that make up the game engine and how they fit together.

2.1 Languages and Tools

Even ignoring the direct specification of languages and technologies that the project required, the need for it to be run in a browser already limited the choice of languages and tools available to develop the game engine in.

2.1.1 Languages

2.1.1.1 Client-Side

Previously, the most popular and obvious choice for browser-based development of serious applications was `ActionScript`, the language that runs in Adobe's `Flash` plugin. This language has a lot of advantages over `JavaScript`—which is the language specified and the other main option—primarily in its traditional object-oriented style as well as the use of static types. Both of these are useful for creating large applications in general, but the classical object-oriented style is especially useful in game programming, as most standard patterns used in game programming were invented for languages using it; moving away from it begins to create problems of having to reinvent a lot of what has already been figured out.

`ActionScript` has also remained popular for creating games, despite its disappearance from other types of web application. This means that there are plenty of resources available for it, from books to libraries and frameworks.

However, despite all these advantages, `ActionScript` and `Flash` are unsuitable for this project for a few reasons. The first is `ActionScript`'s requirement to be run in a `Flash` container. The project specified the use of `HTML5` canvas, which is a native browser construct that isn't usable by `Flash`, because `Flash` is a plugin. Its plugin status is also a potential problem for accessibility. Although it remains the most ubiquitous browser plugin for desktop use—a status most likely still conferred by its continued use for video sites like `YouTube`—it is an issue for mobile users who cannot install it at all, and there is plenty of evidence that it is a dying platform on the web more generally [REFERENCE], even if games are slower to catch up than other forms of web application. There is also the case of it being an unfamiliar environment, particularly in regards to how to interact with the network, a problem exacerbated by the server being written in the equally unfamiliar `Python`.

`JavaScript` has the advantage of being both familiar and natively supported by browsers, letting it interact with the `HTML5` canvas element. Indeed, `JavaScript` is the only language natively supported by browsers. However, as previously mentioned, `JavaScript` has some disadvantages for creating games and other larger applications. While neither the lack of a more traditional object-oriented structure nor the lack of static typing make it unworkable for creating games, it does cause unnecessary issues. The lack of typing is of course the traditional (and commonly argued about) trade-off between easy prototyping and easier refactoring and debugging. The prototypal inheritance style verses the classical class structure is more of an issue, however, as all game design patterns are designed to be implemented in the latter.

The most extreme way to solve these issues is to look into languages that compile down into `JavaScript` while providing the features that make them more attractive to program in. Three major options exist in this area: `CoffeeScript`, Microsoft's `TypeScript` and Google's `Dart`.

`CoffeeScript` is an attempt to redo `JavaScript`'s syntax to be more succinct, while providing some quality of life enhancements in the process. Although it does offer a way of specifying classes in the classical way, it doesn't offer typing, optional or otherwise. It is probably the most popular of the options, having been available for the longest, but has the disadvantage of needing to learn its syntax, whether that syntax is better than `JavaScript`'s or not.

TypeScript is a superset of JavaScript, and regular JavaScript code is perfectly valid TypeScript code. This immediately gives TypeScript an advantage because it is already familiar. On top of JavaScript it adds classes and optional types—both the major features missing that are useful for game development.

Finally, Dart is a language that is intended as a complete replacement for JavaScript, even offering a native VM to run it within some experimental versions of the Chromium browser, though it can compile down to JavaScript as well. It offers many of the advantages of TypeScript, but with CoffeeScript's disadvantage of unfamiliarity.

All three languages also have the disadvantage of adding an extra compilation step, and potentially problems in making sure that the compiled code is actually sent to the browser, especially used inside the unfamiliar Python language and framework used on the server-side.

TypeScript was the most tempting option but was ultimately rejected because, although it is familiar in many ways, the extra steps and tooling surrounding it were considered potential issues and there was a lack of desire to add too many unfamiliar parts to the development process when the server-side would be entirely alien.

Although these options were rejected, at least one of JavaScript's problems was able to be worked around. JavaScript's prototypal inheritance style can be coerced into looking like a more classical class structure, and to that end a library known as `class.js` [REFERENCE] was selected that implemented this. Although the library cannot deal with JavaScript's other issues, such as a lack of easy scoping inside a class or the lack of types, it created an environment that was much easier to work with when implementing the common game design patterns.

2.1.1.2 Server-Side

The project specification demanded that Python be used as the server-side language, due to a desire to gain experience in it. The main reason for this is that it is a very popular language and is used in a lot of areas, from major science to simple scripting. It is also popular in games, acting either as a scripting language embedded into C++ code, or as the entire game engine itself. Indeed, several frameworks and game engines exist in the Python world that are designed to make games programming easier, offering support for interacting with common graphics libraries like OpenGL, and UI libraries like Qt.

Python is also somewhat popular in the world of web applications, offering frameworks and libraries to handle many types of networking situations, including HTTP and websockets as used in this project. However, it is certainly not the most popular language, and in some regards lags behind others in this area, particular as web development is a very fast moving world.

If Python had not been required, Node.js would likely be the choice of language for the server-side in this project. Although it is not as popular as Python in terms of the number of sites actually using it [REFERENCE], it has been steadily gaining traction in the web development world and a lot of modern tools and frameworks in this area are created for it and other trending languages over Python. The SocketIO library used in this project to implement websockets was made originally for Node.js, for instance.

Node.js also has the major advantage of being JavaScript, which means that it is not only familiar, but almost entirely the same as the client-side. Not having to switch languages when developing across the client and server is a definite advantage and, even though it also has JavaScript's weaknesses, both CoffeeScript and TypeScript can be used instead [REFERENCE] if the language replacement route is being taken.

2.1.2 Frameworks and Libraries

There are a lot of frameworks and libraries available for creating games—both in JavaScript and Python—which offer everything that was created in this project and simply require you to implement your own game logic and art assets. However, the goal of this project was not to create a well polished game, but rather to implement an engine to run the game from and gain an understanding of game programming. Because of this it was decided against using any of the available frameworks.

That said, there were some frameworks and libraries used in this project. On the client-side the `class.js` library has already been mentioned. This allowed for a more traditional object-oriented class style when writing JavaScript, instead of JavaScript's own prototypal style.

The other library used on the client-side was one that implemented the A* pathfinding algorithm [REFERENCE]. The decision to use this library over implementing it directly was because it was already well made and included some useful optimisations. This saves a lot of time compared to custom implementing it just for the project.

Across both server and client the library `SocketIO` was used, which is a more powerful implementation of the websocket technology that came about in `HTML5`. On the client this was used directly, as by default it is a JavaScript library. On the server-side a plugin for the Python framework chosen was used instead.

The Python framework mentioned above is `Flask`. `Flask` is a minimal framework for Python that provides basic features for a web application server, such as routing and rendering of templates to send to the client. Additional functionality is added in through plugins, such as the aforementioned `SocketIO` plugin to provide websockets and a plugin to provide easy database access.

Beyond these few things, all code was custom written.

2.1.3 Database

Most modern game designs offer the saving of state to the user. This can be achieved in a lot of ways, depending on the needs of the game. For a single-player game, it may be reasonable to save the game's state in the user's client-side storage offered by their browser, for example.

However, in a multiplayer game the server needs to keep track of everything, and there is also potentially more state to keep track of. Because of this a database is required.

The database implementation used in this project is `SQLite`, which stores the database in a single file and requires little set up to get running. Although it lacks many advanced features of some of the other databases available it offered enough for this project to run well. Its only disadvantage relevant

to this project is that it is not as fast as something like MySQL [REFERENCE]. However, because of the use of a Python framework to manage the database, swapping out which one is used is a case of changing only a few lines of code. This means that, should SQLite ever become a bottleneck for the game—which is unlikely—upgrades are easily implementable.

2.2 Overall Architecture

The overall architecture of a game is very important to making sure that features can be added and changed easily. A common example in the game world is that of heavy use of traditional object-oriented inheritance, where there is a very deep hierarchy. Having a few simple types of object in the world makes this manageable, but the moment you start wanting to add a lot of other different types, or special versions of something, you end up with a mess that's very hard to get out of.

The solution to this is what is known as a Component-Entity System. In this model you have generic entities that are made up of lots of individual components that each have separate functionality. In this way you can easily create a lot of different types of objects without having the mess of inheritance that the more traditional model creates. The advantage of all this abstraction is counterbalanced by vastly increased complexity in implementation. Because every part of the functionality of an entity is compartmentalised, you end up needing extra managers to handle that.

Because the game in this project was going to be very simple, with the minimal system having only two types of entity, it was decided that the Component-Entity style was not worth the extra development effort; there is only a base entity and a character type entity which inherits from it, though there is a small concession to the idea of Component-Entity on the client-side, which will be discussed in the next section.

Before getting to the details of each part, an overview is necessary to give context to their purposes. There are only a few individual components to the whole system, though they all have need to interact.

The most important component in the engine is the game loop. This is responsible for the updating of the game simulation every frame by asking each entity it knows about to update itself in turn. When asked to update themselves, the entities check their event queues for any new events and process them as required, then proceed to perform any necessary updates to their state, such as movement, as well as creating their own event to inform the server if relevant. These events are passed around the system by an event manager, which sits outside of the game loop. Any part of the system that wants to know about something registers itself to receive event updates related to that thing and is then given them the moment the event comes in. Finally, there is an input manager and a network manager, which handle input (and output in the case of the network manager) from players and the server.

This architecture applies fully to the client but the server makes some changes. These changes come about primarily due to implementation details and the differences between JavaScript and Python. However, the biggest difference by purposeful design is that the server needs to handle multiple games running simultaneously but apart, rather than having to deal with only one. This

means that the server has a higher level manager responsible for creating games and routing messages to and from the server-side games and the clients.

2.3 Detailed Design

2.3.1 Engine and Scene

The **Engine** class is the central class in the game. It manages the creation of all other system classes, including the event manager, the network and input managers and the renderer, and contains the central game loop. Once the game is loaded it tells the server that the client is ready so that it can be registered to receive network events. It is also responsible for creating and giving access to the HTML5 canvas used to render the game.

The **Scene** class is what describes the actual content of the game simulation at that moment. Each scene represents the map the players are currently on, and contains the terrain as well as all the entities. When the game simulation is updated, it is the entities in the **Scene** class that are affected.

To load the scene from the server, the **Scene** class contains several methods that first communicate with the server and then handle the result. The server keeps track of which scene is the currently active one in a game, so **Scene** gives the server its game id and is given back the scene data in response. This data is processed and turned into actual terrain and entities. No other part of the game is able to create new entities.

The **Scene** class also remains the only place where the new event manager was not implemented. Due to the issues with the previous event management system, discussed in section 2.3.4, network connectivity had to be implemented directly into **Scene**, rather than abstracted to the correct **Network** class. With the event manager, this shouldn't be necessary, but the retrofitting work was not completed in this case.

2.3.2 Game Loop

The central part of any game is what is known as the game loop. It is run from the main **Engine** class and is responsible for managing the entirety of the game, making sure every other part of it runs when it is supposed to.

An important concept to understanding the purpose of the game loop is the **frame**. This is a slice of time in the game world, with the amount of time each frame represents being decided by how many frames you wish to have per second. Common numbers chosen here are 30 and 60, meaning a frame is 33.3 milliseconds and 16.7 milliseconds respectively. While it is usually trivial to have a simple game running at 60 frames per second, it isn't always the right choice. More frames per second means more processor time used, which drains more power or could cause issues on weak devices. For this project it is also unnecessary, as the game world does not require a simulation at that level of fidelity. 30 frames per second was chosen as a good balance between smoothness of gameplay (such as moving around) and demands on power.

The purpose of the game loop is to update the simulation every frame while keeping track of whether the simulation is running at the correct speed. Every time it runs it first needs to check how much time has passed since the last frame was processed. If, for some reason, a frame took too long to process the last time then the next update will run as many times as necessary to catch back up to where it should be, regardless of whether that means things are moving too quickly in real-time or not.

The game loop itself is not directly responsible for updating the simulation, however. Rather, it calls every entity that is currently active and asks it to update itself. Once all entities have updated themselves, the network manager is asked to inform the server of everything that happened it might need to know about and the frame is complete.

2.3.3 Entities

Entities are the next most important part of the game architecture, alongside the event manager, which will be discussed next. Each entity is an object in the game world. In the Component-Entity System mentioned previously, it would be made up of many individual components, linked to a component manager so that they could talk to each other and share necessary state. The entity itself would have no real idea about what it is or what it does, it simply gets each component to do something in turn, in a way similar to the game loop asking the entity to update in the first place.

However, because implementing this is very complicated, entities in the project game don't work this way. Instead, they are more traditional objects, with methods and properties. This works fine because there are only two types of entity in the game: a basic `Entity` and a `Character`.

The basic `Entity` class is a simple object in the game world like a wall. It has no properties beyond its size, position and the sprite that represents it if one exists. A `Character` is a lot more complicated, and has methods for handling user input and updating its position, as well as dealing with any other interactions that might occur, such as taking damage from another entity.

When an entity is asked to update itself, it checks the list of events that it has received from the event manager since the last update and runs through them, applying a series of functions in order. Once it is done the game loop asks the next entity along to do the same thing. Basic entities don't do anything on an update, whereas `Characters` will check for input from a player or the server and update their positions or perform an action.

The existence of two types of player with different capabilities created some issues. Initially there was actually a third entity type that inherited from `Character`, called `Player`. The `Player` class had extra functionality to find paths for itself, and interpreted player input but not server input. However, because a Game Master needs to be able to change which entity they are controlling, the `Player` class was merged with `Character` and a method for swapping between them was created.

As there were two ways to interpret any input events, and they needed to be switched out, two functions were made into components: input handling and path finding. The input handler for an active player listens for events from the input manager, whereas the input handler for a remote player listens for network events. The pathfinding component on an active player actually creates paths, whereas the remote entities simply get given them from the network.

2.3.4 Event Manager

The event manager is an important piece of the game engine, and is the communication method for all the other system components, acting as a sort of glue between them.

Unlike almost all the other parts of the game, the event manager is not run per frame or controlled by the game loop. Rather, it receives and propagates events as it gets them. This means that events that are created in the middle of a frame's update are still sent to the things that need them.

This has some advantages. The main advantage is network latency. Because the network latency is several frames long, the ability to have the network send events back in the same frame that they happen helps to reduce any time wasted. Another small time-saver in this regard is that an entity affecting another entity may be able to have that effect be known about in the same frame, as long as the acting entity is processed before the entity being acted upon. In the case of an affected entity being updated first, however, it will only take into account the new information in the next frame. This isn't a huge issue, and a user should never really notice that something has happened one frame after, but the inconsistency is there and could potentially cause problems in situations where frames are taking a long time to process.

Despite the seeming obviousness of its use, the event manager originally didn't exist, and input was handled by having a single event queue stored in the `Engine` class. This event queue was given to entities from the update call in the game loop and they ran over each event looking for something relevant to them. It was also very difficult for entities to put anything into the event queue themselves, such as network input. Because of this, network events were created directly. Worst of all, because there was no way to know whether events were handled, the entire event queue was cleared on each frame, which meant that no events could be carried over.

Obviously this approach had several disadvantages. Firstly it was inefficient. Although generally there was only going to be one or two events in any given frame, there are potentially a lot of entities that have no interest in events that are stored in the event queue, so having them loop over those events is useless. Secondly, in order to update the network or add anything back into the event queue, entities had to be given the network and engine objects and pass them around. The emptying of the entire queue also meant that in situations where one entity wanted to affect another but was updated after the entity it was affecting, the affected entity would never know about it.

Replacing this system with a proper global event manager allowed for entities to no longer care about events that don't matter to them, as well as much more easily carry over events from frame to frame, even leaving events unhandled for a long time if necessary. Unfortunately the refactoring to use the event manager wasn't entirely completed, as seen with the previously mentioned `Scene` class. However, the vast majority of the game uses it.

2.3.5 Renderer

The renderer is responsible for displaying frames to the player, acting as the view into the simulation. It is also another part of the game engine that is separated from the game loop. It isn't required for this to be the case in order for the game to function; indeed, with the simplicity of the game in this

project the renderer could be tied to the game loop's frames pretty easily and cause no problems.

It is, however, considered to be good practice to separate them, and for good reason. The renderer is almost always the most taxing part of the whole game. By adding the renderer to the central game loop's update process you cause each frame in the simulation to take a lot longer to complete. If this addition doesn't cause the frame to run over time then no problems will be noticed. Unfortunately, it is very easy for the renderer to cause frames to run over time and, if it happens consistently, the game loop could get stuck in an infinite loop attempting to catch up.

By separating the renderer out, you can make sure that the central game loop always updates correctly and keep the simulation running, regardless of how many frames the renderer is managing to actually display to the user. It is, of course, desirable to make sure that the renderer is managing to display all the frames, but it's less of a problem if the renderer can only display 20 of them than it is to have the central game loop stuck trying to catch up.

The renderer does not render the world in one go. Rather, it renders the terrain first, and then renders entities on top of it. The reason for this is one of efficiency. The terrain never moves and never crosses tile boundaries. It also comes pre-ordered in a grid. These attributes make it easy to render by simply drawing each tile to the screen one by one in order. Entities, however, can have different heights and can move around and cross tile boundaries, which requires that they get sorted properly, creating rendering overhead. By rendering the terrain first, there is less that needs sorting afterwards, thus speeding up the renderer.

2.3.6 Input Manager

A game isn't much of a game if the user cannot create any input. To handle the user's input there is an input manager, which is responsible for capturing all of a player's input, working out what purpose that input has and then creating an event for it in the event manager, which propagates it to all interested parties.

The input manager is only able to work out what user input means, not what that input applies to. In other words, it knows that a user clicking means the user wants to move somewhere, checks that it is a valid input and then creates an event to say that there has been a movement input and the tile to move to. This event is passed to all entities that subscribe to movement events and it is up to them to work out whether it is relevant or not.

2.3.7 Network

The `Network` class is responsible for managing the connection the game has to the server. At the end of every frame it will inform the server of anything the client's player has done, such as moved his character to a new location.

If the server sends a message, however, the network manager will immediately create an event for it. Although this is mostly due to technical implementation reasons, there are advantages in this. Primarily, it means that entities being affected by network events can be updated sooner as they don't necessarily have to wait till the next frame. This is important for the same reason as the

event manager, by reducing latency from a very high latency aspect of the game.

2.3.8 Server Differences

The server's purpose is to act as a central version of the game that links all the clients together, and is responsible for being something of an authority in the game simulation to make sure that clients see the correct things. Because of this it makes sense that the server and client have the same structure.

However, there are, in fact, differences between them. The reason for this is entirely due to implementation—which will be discussed in more detail in the next chapter—but regardless of the reasons it's important to understand these differences.

The most important and major difference is that the server runs many games simultaneously, rather than just a single game at a time. To handle this, a higher level is needed to manage the games and route messages to and from players.

The router that handles this is a traditional web application router, made using the Flask framework. It takes incoming HTTP connections and works out what they are supposed to do based on the URL. Once a game is up and running and users are connected, they communicate with it through the SocketIO library providing websockets, which the router also manages.

Each game itself is run in a separate thread, providing an architecture as similar to the one in the client as possible. Communication between the router and any individual game is handled through thread-safe queues, as it is impossible to call a method in the thread directly due to the game loop blocking and taking control.

The game loop itself is probably the most major difference in the internal game architecture, entirely by way of implementation details. The client's JavaScript version of the game loop is essentially non-blocking as it has to always yield control back to the browser. However, Python has no native way of achieving this style—known as an event loop—and the libraries available to implement it are complicated. Because of this, the Python implementation of the game loop is a more traditional `while` loop, running until a flag indicating the game is to be shut down is set to false.

An implementation of the JavaScript style was tried without using complicated libraries and in some ways it worked. However, when making the game simulation run at the full 30 frames per second, it ended up blocking the thread anyway, making it no better than the more traditional loop but with a lot of extra logic.

Although this does not affect the fundamental way of updating entities, which is the bulk of the work the game simulation performs on the server, other aspects of the architecture are changed because of it.

There is no proper event manager in the style that was added to the client, as there is no easy way for it to be run outside of the game loop without creating another separate thread for it—an undesirable option for a server that will already be having to manage many of them. Because of this, the server event management remains in the original style that the client had before the event manager was implemented: the game loop contains a data structure that stores all the events and asks the entities to take a look at them in turn and see whether they care.

In a concession to sanity, however, the server uses a queue to store input events (accessible by the router so that they can be passed in) and doesn't delete unhandled events at the end of every frame. Output is placed into another queue that the router can check in order to inform clients of anything interesting.

Other parts of the architecture are simply removed: there is no renderer because the server's view is entirely remote—no one is ever going to be trying to play the game on the server directly. The server also doesn't have an input manager for the same reason. The network manager is pushed up into the router, rather than being a special part of the game engine.

This design is, of course, not perfect. The biggest issue is one of scalability. This model works fine for one or two games running at once, but because the router has to manage connections for all active games it can very quickly get overloaded, especially when players decide to spam actions that create network events such as movement commands.

Ideally each game would be responsible for handling its own connections and the router would simply exist to get players connected to the right game. This creates independence of the router and game servers and is a much more scalable solution. The reason it doesn't do this, however, is just because the implementation knowledge necessary for this was not available and time did not allow for further investigation into it. A less than ideal working solution was considered to be the better choice than potentially having no solution at all because the implementation was too hard given skill, knowledge and time available.

Chapter 3

Implementation

INTRODUCTION GOES HERE

3.1 Renderer

The graphics renderer was the first piece of the game engine worked on. Having the graphics to provide a view into the game world was important in order to easily see whether things were behaving as expected and proved extremely useful in detecting problems with other parts of the game later on.

This section will go over firstly what isometric projection is and then the ways that graphics are actually drawn to the screen. Finally, the difficulties that the renderer caused during implementation will be discussed.

3.1.1 Isometric Tiles

3.1.1.1 What Is Isometric?

When talking about isometric projection in the videogame world it is important to know that it is not truly isometric. True isometric is an “axonometric projection in which the three coordinate axes appear equally foreshortened and the angles between any two of them are 120 degrees” **TODO: reference**. What the gaming world calls ‘isometric’ is in fact *dimetric* projection **TODO: reference**—a projection where two axes are the same but the third is not.

The reasons for doing this are essentially one of aesthetics when drawing objects at a very low resolution with visible pixels. At these very coarse resolutions, true isometric projection creates an aesthetically displeasing line. However, by changing to a dimetric projection, where the line grows twice as fast horizontally as it does vertically, the line becomes much more consistent and visually appealing. **TODO: figure**

3.1.1.2 Cartesian To Isometric

The term “2D isometric tile” used in this report is a little ambiguous. The game world itself is represented by simple 2D Cartesian coordinates that map to a grid of tiles. Isometric space, however, is 3D. The term used here refers to the type of graphic used to represent the tiles in isometric space, rather than the isometric space itself. These graphics are simple 2D images, drawn in such a way as to make them look 3D. **TODO: figure showing cartesian and isometric**

Of course, this means that a conversion has to be made between the two coordinate systems in order for the renderer to be able to display things in their proper place. As an example, figure **TODO: figure** shows what the game world looks like if it is rendered without this coordinate conversion—clearly very wrong.

In order for the renderer to show things correctly in the isometric space there needs to be a way of converting between the game world’s Cartesian coordinates and the renderer’s isometric coordinates. Luckily, this is incredibly simple:

```
1 function cartesianToIsometric(cartesian_x, cartesian_y)
2 {
3     var isometric = {};
4
5     isometric.x = cartesian_x - cartesian_y;
6     isometric.y = (cartesian_x + cartesian_y) / 2;
7
8     return isometric;
9 }
```

Listing 3.1: JavaScript implementation of a function to turn Cartesian coordinates into game isometric coordinates. Original algorithm from [3].

Now when the renderer draws the game to the HTML5 canvas, it can first call the `cartesianToIsometric` function, letting it place the tile graphics in the correct place as seen in figure **TODO: figure**.

3.1.2 Rendering

After the renderer has converted between Cartesian and isometric spaces it needs to be able to draw things to the canvas. The actual drawing of a game tile to the canvas is straightforward, simply requiring a call to the canvas’s `drawImage()` function and supplying it the image you wish to draw and the canvas coordinates for where you wish it to be drawn.

The difficult part comes before that. Firstly, you need to be able to work out what the canvas coordinates are. The conversion between isometric coordinates and the canvas coordinates works as follows:

```
1 canvas_x = isoCoords.x * (TILE_WIDTH / 2);  
2 canvas_y = isoCoords.y * (TILE_HEIGHT / 2) - (image_height - (TILE_HEIGHT / 2));
```

Listing 3.2: Conversion between isometric coordinates and canvas coordinates.

A few things should be explained about this. Firstly, `TILE_WIDTH` and `TILE_HEIGHT` refer to the set size of a single tile and are used to work out the tile's positioning in the world. The `image_height` value refers to how tall in pixels an image is. Theoretically an image can have any size and isn't limited to how large a tile is. However, in practical terms, an image can only be arbitrarily tall; width needs to be kept within the tile limits or there will be problems with depth sorting, for reasons seen in section 3.1.2.2.

TODO: a figure showing the difference between a tile and the image representing it

Also worth noting is that there are separate rendering functions used for the terrain and the entities. The terrain has no height value, but even if it did it is rendered in such a way as to make it irrelevant, so the drawing of terrain tiles excludes the `image_height` part of the calculation.

Once you have the coordinates you then need to get the tile graphic to use as the image being rendered. Getting the image itself is a very simple task, but getting the order in which to draw them right is more difficult.

The HTML5 canvas is a very simple element and it has no ability to specify the relative depth of things being drawn to it; whatever is drawn first will be occluded by what comes afterwards if they overlap. This overlapping is often not a problem when drawing simple 2D tiles with a top-down or side-on perspective. However, because the isometric perspective is 3D the issue of depth becomes an important one.

TODO: Figure of what it looks like when depth sorting is broken

There are two methods for solving this used in the renderer: a simple painter's algorithm and a depth sorting algorithm. The first is used for the terrain and the second for entities.

3.1.2.1 Terrain Rendering

The terrain is very simple to render as far as isometric projection goes. Terrain images are the same size as the tiles, which means that as long as they are drawn in order the images will never overlap.

The method for achieving this ordering is known as a painter's algorithm¹ and is very simple. Firstly, all the terrain is stored in a pre-sorted, two dimensional array. Columns are labelled y and rows are labelled x. Images are drawn by looping through each row in each column and drawing them one by one, rendering the images from back to front, row by row.

TODO: Diagram showing how the painter's algorithm works

¹The painter's algorithm is so called because of a common painting technique whereby distant parts are painted before closer parts that might cover them.

This is a very efficient and cheap way to render the images to the screen, and works perfectly for the terrain. Even if the terrain were to be made no longer flat, as long as it never broke out of the tile grid there would be no need to change how it is rendered.

3.1.2.2 Entity Rendering

Unfortunately, entities are less easy to deal with. At least some entities can move around—crossing tile boundaries when they do so—which means they cannot be stored in the same grid that makes up the tiles themselves. Because of this, some other method has to be devised in order to make sure that they are drawn to the screen in the right order.

Chapter 4

Testing

Detailed descriptions of every test case are definitely not what is required here. What is important is to show that you adopted a sensible strategy that was, in principle, capable of testing the system adequately even if you did not have the time to test the system fully.

Have you tested your system on “real users”? For example, if your system is supposed to solve a problem for a business, then it would be appropriate to present your approach to involve the users in the testing process and to record the results that you obtained. Depending on the level of detail, it is likely that you would put any detailed results in an appendix.

The following sections indicate some areas you might include. Other sections may be more appropriate to your project.

4.1 Overall Approach to Testing

4.2 Automated Testing

4.2.1 Unit Tests

4.2.2 User Interface Testing

4.2.3 Stress Testing

4.2.4 Other types of testing

4.3 Integration Testing

4.4 User Testing

Chapter 5

Evaluation

Examiners expect to find in your dissertation a section addressing such questions as:

- Were the requirements correctly identified?
- Were the design decisions correct?
- Could a more suitable set of tools have been chosen?
- How well did the software meet the needs of those who were expecting to use it?
- How well were any other project aims achieved?
- If you were starting again, what would you do differently?

Such material is regarded as an important part of the dissertation; it should demonstrate that you are capable not only of carrying out a piece of work but also of thinking critically about how you did it and how you might have done it better. This is seen as an important part of an honours degree.

There will be good things and room for improvement with any project. As you write this section, identify and discuss the parts of the work that went well and also consider ways in which the work could be improved.

Review the discussion on the Evaluation section from the lectures. A recording is available on Blackboard.

Appendices

Appendix A

Third-Party Code and Libraries

If you have made use of any third party code or software libraries, i.e. any code that you have not designed and written yourself, then you must include this appendix.

As has been said in lectures, it is acceptable and likely that you will make use of third-party code and software libraries. The key requirement is that we understand what is your original work and what work is based on that of other people.

Therefore, you need to clearly state what you have used and where the original material can be found. Also, if you have made any changes to the original versions, you must explain what you have changed.

As an example, you might include a definition such as:

Apache POI library ☒ The project has been used to read and write Microsoft Excel files (XLS) as part of the interaction with the client's existing system for processing data. Version 3.10-FINAL was used. The library is open source and it is available from the Apache Software Foundation [?]. The library is released using the Apache License [?]. This library was used without modification.

Appendix B

Code samples

2.1 Random Number Generator

The Bayes Durham Shuffle ensures that the psuedo random numbers used in the simulation are further shuffled, ensuring minimal correlation between subsequent random outputs [?].

```
#define IM1 2147483563
#define IM2 2147483399
#define AM (1.0/IM1)
#define IMM1 (IM1-1)
#define IA1 40014
#define IA2 40692
#define IQ1 53668
#define IQ2 52774
#define IR1 12211
#define IR2 3791
#define NTAB 32
#define NDIV (1+IMM1/NTAB)
#define EPS 1.2e-7
#define RNMX (1.0 - EPS)

double ran2(long *idum)
{
    /*-----*/
    /* Minimum Standard Random Number Generator */
    /* Taken from Numerical recipies in C */
    /* Based on Park and Miller with Bays Durham Shuffle */
    /* Coupled Schrage methods for extra periodicity */
    /* Always call with negative number to initialise */
    /*-----*/
}
```

```
int j;
long k;
static long idum2=123456789;
static long iy=0;
static long iv[NTAB];
double temp;

if (*idum <=0)
{
    if (-(*idum) < 1)
    {
        *idum = 1;
    }else
    {
        *idum = -(*idum);
    }
    idum2=(*idum);
    for (j=NTAB+7;j>=0;j--)
    {
        k = (*idum)/IQ1;
        *idum = IA1 *(*idum-k*IQ1) - IR1*k;
        if (*idum < 0)
        {
            *idum += IM1;
        }
        if (j < NTAB)
        {
            iv[j] = *idum;
        }
    }
    iy = iv[0];
}
k = (*idum)/IQ1;
*idum = IA1*(*idum-k*IQ1) - IR1*k;
if (*idum < 0)
{
    *idum += IM1;
}
k = (idum2)/IQ2;
idum2 = IA2*(idum2-k*IQ2) - IR2*k;
if (idum2 < 0)
{
```

```
    idum2 += IM2;
}
j = iy/NDIV;
iy=iv[j] - idum2;
iv[j] = *idum;
if (iy < 1)
{
    iy += IMM1;
}
if ((temp=AM*iy) > RNMX)
{
    return RNMX;
}else
{
    return temp;
}
}
```


Appendix C

Game Design Specification

An online, multiplayer roleplaying game similar to *Dungeons & Dragons* hosted in the browser. The game will have a Game Master and several players in a group. The players move around the world and interact with it and the people/creatures in it and the Game Master guides the players, sets rules and manages the experience. They will be able to manipulate the game world and do things players can't do. For example, they could teleport a player to another location, spawn new monsters or change the weather.

It will include isometric graphics and aim to be as permissive as possible in what players are allowed to do (for example, interact with the environment using items they have, such as burning down a house with a torch). This means that there will be several systems, including combat, movement, character/creature creation, interacting with other characters (players and non-players, with chat as well as game system rules) and the environment (things like objects having heat and a burning point, in the fire example).

The nature of the design means that the project is open-ended, allowing for a basic game with a few simple systems and a single dungeon and character type to a game with several systems, full environmental interaction, a map and character editor and the ability to upload your own artwork.

It will require a server to manage the clients and let them interact, relay chat and act as an authority in the game world to keep clients in sync. It will also have to keep track of where players are in the world and whether they can see and interact with each other. There will be a graphical front end client that the players use and, in theory, multiple different clients could be made, such as a mobile app.

Appendix D

Minimal System

Minimal System specification goes here.

Annotated Bibliography

- [1] “Roll2o, online tabletop game engine.” [Online]. Available: <http://roll2o.net/>

Roll2o, an online game engine for playing tabletop games on your computer.

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Tutorial series used to understand the basics of rendering isometric graphics.

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