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Using Blockchain for Video Game Distribution

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Abstract

Centralised video game marketplaces are in a large cost to game developers, are at a greater risk of censorship, and result in brittle ownership of games that is fully dependent on the platform.

Using blockchain technology, IPFS and a custom peer-to-peer file sharing network this project creates a proof-of-concent decentralised video game marketplace. This application allows for the uploading, updating and purchasing of games through direct interactions between developers and users.

This shows the potential for a decentralised video game marketplaces and how they offer an alternative to existing platforms that benefit both developers and their users.

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Acknowledgements

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Chapter 1

Problem Statement

1.1 The Problem

Video games are large, highly popular pieces of software that are typically obtained through centralised platforms, like Steam or Epic Games. These platforms offer high availability, social features and customer support at the expense of:

- taking a large cut of revenue from developers[1],
- being prone to censorship from entities like governments[2],
- relying on a single platform to stay active, distribute games and maintain a user's ownership[3], and
- collecting large amounts of data from their users.

1.2 Goals

This project aims to produce a proof-of-concept, decentralised video game marketplace, using blockchain technology, that will allow developers to continuously release and update their games on a public network where they directly interact with their users. This network should be built on top of a peer-to-peer file-sharing network to allow users to to distribute games in return for some reward.

1.3 Scope

This project will consist of the following components:

1. An Ethereum smart contract that will allow us to maintain a library of games that can be queried and added to by any user. This will then be deployed to an Ethereum test-net.
2. An application to be run by users to interact with the smart contract and allow them to join a peer-to-peer network where they can download and upload games.

[1] Steam take a 30% cut [1, 2]
[2] See the Chinese version of Steam [3]
[3] For example, the Nintendo eShop closing down [4]

Chapter 2

Background Research

2.1 BitTorrent

Motivation The storage requirements for games make it impractical for every user to have a copy of every game. Therefore, it is important that I understand how a popular example of a peer-to-peer P2P file sharing system works when data is fragmented across the network.

BitTorrent [5, 6] is a protocol for sharing data across a distributed network[1] and it was chosen because of its popularity, being responsible for 3.35% of global bandwidth [10]. In BitTorrent, users barter for blocks of data from a network of peers in a tit-for-tat fashion, such that users with a high upload rate will also typically have a high download rate.

Key Ideas

Trackers A tracker server keeps track of which peers have what data, which of those peers are available at, and will provide network statistics to *recommend* which peers to connect to first.

Block Priority Users will download blocks from other peers using the following priority:

1. **Strict Priority** Data is split into pieces and sub-pieces where pieces are ideally downloaded together.
2. **Rarest First** Download pieces that have the fewest copies to boost availability.
3. **As Soon As Possible** A user with no pieces will try to get a random piece quickly so they can contribute to the network.

Hashing Hashing generates a unique fingerprint of some data, which can be used to verify the integrity of it. When a user downloads a piece they generate its hash and compare it with the expected value; they can then decide to re-fetch it or not.

Optimistic Unchoking A peer allocates a portion of their bandwidth for communicating with unknown peers. This allows new users to join the network and be able to contribute without being ignored and gives a way for existing peers to seek better peers.

[1] Popular implementations include BitTorrent Web [7], qBittorrent [8], and µTorrent [9]

Availability

One of the most significant issues facing BitTorrent is the availability of torrents, where *'38% of torrents become unavailable in the first month'* [5] and that *'the majority of users disconnect from the network within a few hours after the download has finished'* [6]. This paper [11] looks at how the use of multiple trackers for the same content and DHTs can be used to boost availability. However, good availability requires users to *choose* to contribute and often the built-in incentives aren't enough to encourage users to contribute for a long period of time.

2.2 Ethereum

Ethereum [12, 13] is a distributed transaction-based blockchain that comes with a built-in Turing-complete programming language that allows any user to design their own transactions. Each block will include a list of transactions, where each transaction includes bytecode that can be run by each node in the network to update their copy of the global state.

Smart Contracts

A smart contract is an executable piece of code, usually written in Solidity [14], that will automatically execute on every node in the Ethereum network when certain conditions are met. Smart contracts are enforced by the network, remove the need for intermediaries and reduce the potential of contractual disputes, due to their transparency and immutability.

Gas is the computational effort of running a smart contract and must be paid, in Ether, before a transaction can be processed and added to the blockchain. This helps prevent DoS attacks and provides economic incentives for users to behave in a way that benefits the whole network.

Miners receive Ether for mining transactions based upon their gas price, which results in gas price varying according to supply and demand. For example, in a period of congestion users will offer a higher gas price to have their transaction be processed more quickly.

Test Networks

An Ethereum test network is an instance of Ethereum in which users can deploy their smart contracts and test them in a live environment. Ether for these networks can be gained for free from a faucet provided by a node from the network. Some notable examples include Sepolia [15], Goerli [16], and Ropsten[2].

[2]The Ropsten test-net is declared as end of life as of December 2022 [17]

Chapter 3

Literature Review

3.1 Blockchain-Based Cloud Storage

This project will need to maintain an immutable and public record across a P2P network such that it searchable and can be trusted. Table 3.1 shows how blockchain technology has been used to provide a solution distributed cloud storage systems.

Paper	**Description of Solution**
Blockchain Based Data Integrity Verification in P2P Cloud Storage [18]	The Ethereum blockchain is used to add trust to a data verification system for a P2P network. It analyses how varying structures of Merkle Trees affect the performance of verification of data stored in the network.
Deduplication with Blockchain for Secure Cloud Storage [19]	This paper implements a deduplication scheme by uploading storage information to Ethereum and uses smart contract based protocols to provide secure deduplication over encrypted data.
Block-secure: Blockchain based scheme for secure P2P cloud storage [20]	Users divide their own data into encrypted blocks and upload them randomly into a blockchain, P2P network. It uses a custom genetic algorithm to solve the file block replica placement problem and ensure data availability.
Blockchain-Based Medical Records Secure Storage and Medical Service Framework [21]	Describes a blockchain-based platform that would allow for the secure and immutable storage of user medical records, such that they are independant from any individual medical institution and users have greater control over who can access their personal data.
A Blockchain-Based Framework for Data Sharing With Fine-Grained Access Control in Decentralized Storage Systems [22]	An attribute-based encryption scheme that allows the distribution of access keys to users based upon their allocated groups. Data is uploaded to IPFS and an Ethereum smart contract is used to implement a keyword search of the data stored.
Blockchain based Proxy Re-Encryption Scheme for Secure IoT Data Sharing [23]	A distributed cloud system for encrypted IoT data that uses a proxy re-encryption scheme that allows the data to only be visible to the owner and any persons present in the smart contract.

Table 3.1: *Examples of blockchain cloud storage systems [24]*

Some common themes found include:

- **Access Control** If these platforms offer access control it is typically up for the owner of the data to distribute access rights.
- **Data Integrity** The blockchain is primarily used to add trust across a distributed network in the form of immutability or providing data integrity services.
- **Data Location** Data stored on the blockchain is commonly metadata that refers to some data stored elsewhere, typically on a form of distributed storage network.

3.2 P2P File Sharing

Table 3.2 looks at various implementations of P2P file-sharing networks. Using the pros and cons of each will help me identify key considerations of my own implementation.

System	Description of Solution
IPFS [25]	IPFS is a set of protocols for transferring and organising data over a content-addressable, peer-to-peer network. IPFS is open source and has many different implementations, such as Estuary [26] or Kubo [27].
Swarm [28]	Swarm is a distributed storage solution linked with Ethereum that has many similarities with IPFS [6]. It uses an incentive mechanism, Swap (Swarm Accounting Protocol), that keeps track of data sent and received by each node in the network and then the payment owed for their contribution.
BitTorrent [6]	See Section 2.1.
AFS [29, 30]	The Andrew File System was a prototype distributed system by IBM and Carnegie-Mellon University in the 1980s that allowed users to access their files from any computer in the network.
Napster [31]	Napster uses a central cluster of servers that maintain an index of every file on the network and which users have a copy of it. Clients will query the cluster for this information and will choose peers based upon their bandwidth. This protocol is dependant on a central cluster existing and will not function properly without it.
Gnutella [31]	In Gnutella, nodes form an overlay network and will discover other peers through *ping-pong* messages, where any node that receives a *ping* message will forward it to their neighbours and send a *pong* message to the originator. A user will flood a download request to their peers until they find a suitable peer to download off of. A network flood in a large network will result in a significant amount of congestion and and a large amount of *pong* messages going to a single node results in a DDoS attack.

Table 3.2: *Various global distributed file systems.*

Some of the common themes found include:

- **Trust** Nodes are typically anonymous so users have to trust that the data they download isn't malicious.
- **Illegal Content** There are no measures in place to stop or prevent the distribution of illegal content across these networks.

- **Payment** None of these networks natively support payment and thus don't support the access control systems required for payment systems.

It is clear that using blockchain in conjunction with these systems could mitigate a lot of their issues and thus a combination of these two ideas will be used for this project.

Chapter 4

Design

4.1 Analysis

4.1.1 Stakeholders

Game Developers PRIMARY

This group will upload games, and any subsequent updates, to the applications. Users will purchase access to their games and contribute to the distribution of it in return for some reward that could be provided by this group.

Players PRIMARY

This group will use this application to downloaded and update their games off of. They may also contribute to the distribution of the games to other players for an incentive provided by the developers.

Other Platforms SECONDARY

This group consists of platforms like Steam or Epic Games, which serve as the main competitor to this application. It is likely that as more developers choose this application, this group will see a loss in revenue.

4.1.2 Requirements

Tables 4.1 and 4.2 show the functional and non-functional requirements of this project organized using MoSCoW prioritisation.

Functional

ID	Description
	Must
F-M1	Developers must be able to release games by uploading metadata to the Ethereum blockchain.
F-M2	Developers must be able to release updates to their existing games.
F-M3	An owner of an existing game must be an owner of all future updates to that game.

F-M4	This application must include a smart contract that is deployable to the Ethereum blockchain[1].
F-M5	Users must be able to purchase games off of develoeprs.
F-M6	Users must be able to prove they have purchased a game.
F-M7	Users must be able to create and maintain many concurrent connections to other users.
F-M8	A user must be able to communicate with other users by exchanging structured messages.
F-M9	A user must be able to upload and download data to and from other users.
F-M10	A user must be able to verify the integrity of all data that they download.
F-M11	A user must be able to download games in their entirety.
F-M12	A developer must be able to upload a hash tree[2] of a game such that all users can access it.
	Should
F-S1	Users should only upload game data to users who own that game.
F-S2	Users should interact with the application using a GUI.
F-S3	Users should be able to prove the amount of data that they have uploaded to other users.
F-S4	Users should have a way to discover new peers from their existing ones.
	Could
F-C1	Developers could be able to release downloadable content (DLC) for their games.
F-C2	Allow developers to upload promotional materials such as cover art and an overview to be shown to the user.

Table 4.1: *These requirements define the functions of the application in terms of a behavioural specification*

Non-Functional

ID	**Description**
	Must
NF-M1	This application must be decentralised and cannot be controlled by any singular party.
NF-M2	Any user must be able to join and contribute to he network.
NF-M3	Developers who upload games to the network must be publically identifiable.
NF-M4	The data required to download a game must be immutable.
NF-M5	Only the original uploader must be able to make any changes or release any updates to a game.

[1]This project will only test deploying to an Ethereum test network
[2]See Section 4.2.

	Should
NF-S1	This application must be scalable, such that many users can upload and download the same game at the same time.
NF-S2	This application's GUI should be intuitive to use for new users.
	Could
NF-C1	This application could include measures to prevent/stop the distribution of illegal content.
NF-C2	The GUI could include detailed support and or instructions for new users.

Table 4.2: *Requirements that specify the criteria used to judge the operation of this application*

4.2 Design Considerations

Data

Table 4.3 discusses the different types of data we are going to need to store and where they should be stored based upon their properties.

Data	**Size**	**Location**	**Explanation**
Game Metadata (**F-M1**)	100 – 200B	Ethereum	This data is the minimal set of information required for the unique identification of each game. See Section 4.2. This data is appropriate to store on Ethereum as it is public, small in size, and essential to the correct functioning of the application as all users will need to be able to discover all games.
Game Hash Tree (**F-M12**)	˜15KB	IPFS	This will be the compressed hash tree that will allow users to identify and verify the blocks of data they need to download for a game. The user will download this immediately after purchasing the game. This data is public but its size will make it costly to store on Ethereum at a large scale and given that only a subset of users will actually ever want access to it, it would be wrong to store it on Ethereum. Instead IPFS can be used for reliable and fast access at a very large scale and we can embed the generated CID, from the upload to IPFS, in our smart contract instead.

Game Assets (**F-C2**)	Variable[3]	IPFS	This will represent any promotional material provided for the game that can be viewed on the game's store page. This will typically include cover art and a markdown file for the description and isn't required to purchase or download the game. The user will download this when they first view the game in the store. For similar reasons as the hash tree, this data will be also be stored on IPFS and have its CID stored on Ethereum instead.
Game Data	*avg. 44GB* [4]	Peers	This will the data required to run the game and will be fetched based upon the contents of the game's hash tree. This data is very large and has restricted access so wouldn't be appropriate to store on either Ethereum or IPFS[5]. Therefore, this project will use a custom P2P network for sharing data, which is described in Section 4.2.

Table 4.3: *The different types of data required for each game.*

Swarm [28] was considered as a decentralised storage and distribution platform over IPFS but was decided against as it would couple this project more tightly with Ethereum and the fact that IPFS has a much greater adoption.

Blockchain

Type of Blockchain

To satisfy (**NF-M1**) and (**NF-M2**), we will need to use a public blockchain. This will benefit my project by:

- being accessible to more users, which will boost both availability and scalability (**NF-S1**),
- reducing the risk of censorship (**NF-M1**), and
- providing greater data integrity (**NF-M4**)

Ethereum is a public blockchain that allows developers to publish their own distributed applications to it. It comes with an extensive development toolchain so is an obvious choice for this project (**F-M4**).

Uploading Games

To satisfy (**F-M1**) and (**F-M2**), the data stored on the blockchain will be used for the identification of games. Table 4.4 shows the fields that will stored as part of the smart contract for each game and to manage the whole collection of games. Fields in *italics* are generated for the user and non-italic fields are entered manually.

[3]Some games may include many promotional materials, whilst some could include none. Therefore, it is hard to estimate the expected size.

[4]Calculated based off of the top 30 games from SteamDB [32].

[5]IPFS and similar platforms provide no access control for the data stored there and any encryption based technique would be unviable.

Name	Description
	Metadata for each game
title	The name of the game.
version	The version number of the game.
release date	The timestamp for when the game was uploaded.
developer	The name of the developer uploading the game (**NF-M3**).
uploader	The Ethereum address of the developer (**NF-M3**).
root hash	The root hash of the game that uniquely identifies the game and is based upon its contents.
previous version	The root hash of the most previous version of the game if it exists.
price	The price of the game in Wei.
hash tree CID	Required for downloading the hash tree from IPFS.
assets CID	Required for downloading the assets folder from IPFS.
	Managing the Collection of Games
library	A mapping for all games uploaded to the network, where a game's root hash is the key used to find its metadata.
game hashes	Solidity doesn't allow us to enumerate maps so we will also store a list of hashes for all games uploaded.
purchased	A mapping which allows us to easily check if a user has purchased a game (**F-M6**).

Table 4.4: *the data to be stored on Ethereum using a smart contract*

Purchasing Content

Users will purchase games from developers over Ethereum by transferring Ether (**F-M5**). The user's address will then be added to a public record, on the smart contract, of all users who have purchased the game (**F-M6**). Upon purchasing a game, a user will broadcast their new library to all of their peers.

Distributed File Sharing

Hash Tree

The hash tree of a given directory is used to represent its structure as well as the contents of its files. Each file is represented by an ordered list of SHA-256 hashes that match a fixed-size block of data. This allows users to easily identify and verify game data (**F-M10**).

Uploading Content

For a developer to upload their game (**F-M1**), they must provide the following:

- the metadata outlined in Section 4.2,
- a hash tree created from the root directory of the game, and
- an assets folder containing a piece of cover art *(cover.png)* and a description file *(description.md)*.

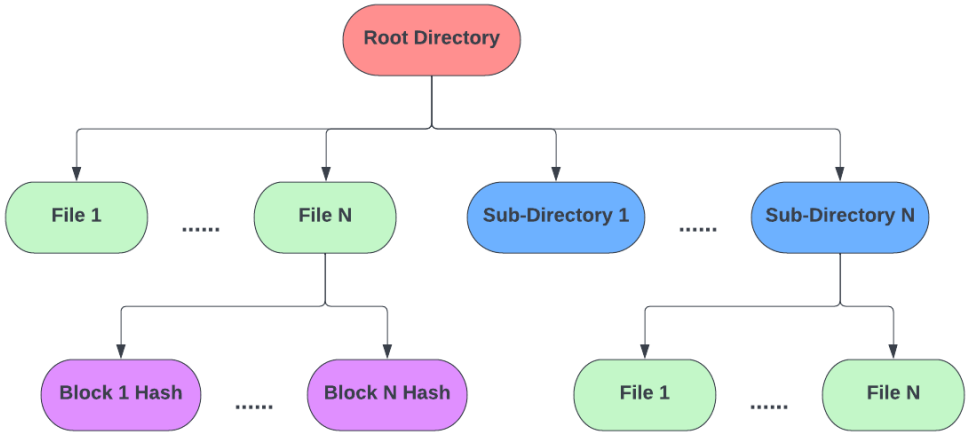


Figure 4.1: *The structure of a hash tree*

The developer should be able to enter the required fields into an upload page of the GUI and have the data generated and uploaded for them (**F-S2**).

Downloading Content

Like mentioned in Section 4.2, it is impractical to store the game's data on the blockchain or IPFS. Instead we will consider ideas from decentralised file-sharing networks, like discussed in Sections 3.2 & 2.1.

Games are content addressable using their root hash field, which will allow users to request data from that game from other users. When a peer seeking data $P_{downloader}$ forms a connection with another peer P_{seeder} they will:

1. Perform a handshake to determine each other's Ethereum address and public key.
2. P_{seeder} will verify that $P_{downloader}$ owns the game by checking the *purchased* mapping on the smart contract (**F-M6**) (**F-S1**).
3. $P_{downloader}$ will send requests for individual blocks to P_{seeder} (**F-M9**).
4. Upon receiving a block, $P_{downloader}$ will verify the contents using the block's hash (**F-M10**) before writing it to disk in the appropriate location.
5. Repeat Steps 3–4 until the entire game has been downloaded (**F-M11**).
6. P_{seeder} may request a signed receipt that details the blocks they uploaded (**F-S3**) to $P_{downloader}$.

Users will be able to connect to many peers at once (**F-M7**) and will send download requests to the subset of their peers who also own the game. Requests will be sent in a round-robin fashion to evenly distribute the requests and prevent overloading a single peer (**NF-S1**). Requests that cannot be completed will be retried when connecting to a new peer or when a peer has a change in library.

See Figure 4.3 for a diagram showing these interactions fully.

Updating Content

To satisfy (**F-M2**), developers will perform the same steps outlined in Section 4.2 but must also provide the root hash of the most previous version of the game. Any users who have purchased the previous version will be added to the list of users who have purchased

the new version (**F-M3**). Additionally, this will include the restriction that only the original uploader can upload an update for their game (**NF-M5**).

Each version is considered its own game and will require users to download the updated version separately. Whilst this isn't reflective of how updates are typically managed, this will be acceptable for the scope of this project.

Downloadable Content

Downloadable Content (DLC) (**F-C1**) represent optional additions for games that users will buy separately. DLCs will act similarly to how updates are treated. Each DLC will need:

1. **Dependency** The root hash of the oldest version of the game this DLC supports.
2. **Previous Version** (Optional) The root hash of the previous version of the DLC.

Users must own the original game to buy any of its DLC.

Proving Contribution

As a user downloads blocks of data, they will keep track of which users have sent them which blocks. A peer may then request their contributions in the form of a signed message that can be sent to the developer (**F-S3**) in return for some kind of reward. The contents of the reward isn't specified for this project but could include in-game items, digital assets or Ether. This solution assumes that developers have knowledge of which Ethereum address maps to which of their game's users.

4.3 Architecture

This application is structured using the Model-View-Controller MVC pattern to create a separation of concern between its main layers. Figure 4.2 shows a high level overview of the architecture and below I discuss the purpose for each.

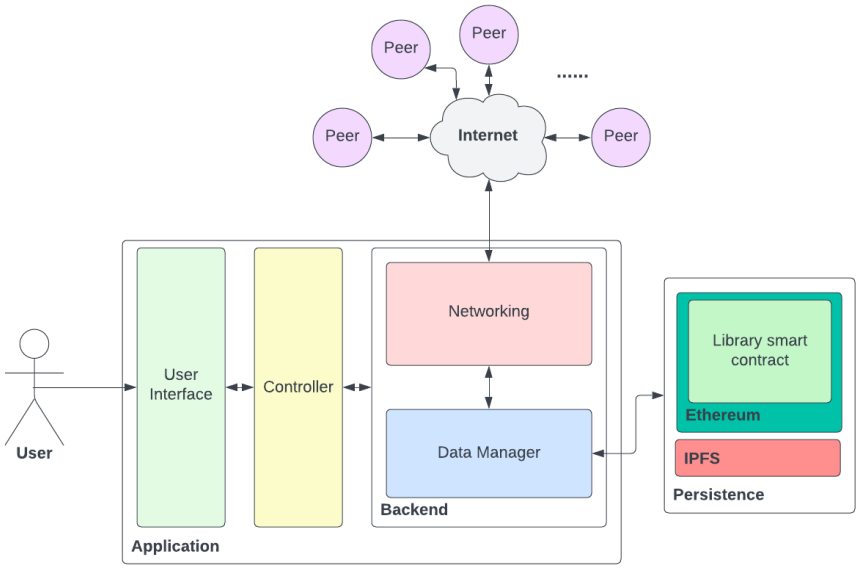


Figure 4.2: *The layers of the application*

Persistence

The Persistence layer shows how the data for the application is divided across several mediums; namely the **Ethereum Smart Contract**, **IPFS**, and a **P2P Network**. Each component stores a different type of data, which is outlined in Section 4.2.

There are several things to note about using Ethereum as a platform for selling games:

- Ethereum is a less stable currency than most traditional currencies like GBP or USD so games may fluctuate largely in price. This design describes no solution to this issue but an example solution might attempt to map a real-world currency to Ether.
- All write functions to the smart contract will incur a gas fee so uploading or updating data will not be free.
- Users will have to source Ether from elsewhere before being able to purchase games, which may be intimidating to users who are not already familiar with the Ethereum ecosystem. Moreover, many people are sceptical of blockchain technology so may be hesitant to adopt the application.

This layer will also provide interface functions that will allow our backend code to interface with our smart contract. Interactions with IPFS will be very simple uploads or downloads of compressed data.

Backend

The Backend can be broken down into two major components:

- **Networking** The creation and maintenance of network connections with other peers over the internet with the purpose of sharing data.
- **Data Manager** the management of local data and the processing of data received and to be uploaded by the Networking component.

Networking

Users running this application will be a part of a distributed network of peers by creating and maintaining a set of TCP connections with other users (**F-M7**) in the network and will communicate by sending structured messages to each other (**F-M8**). Section 4.3 describes these commands in detail.

Address Verification When two peers connect they will perform a handshake to exchange their Ethereum addresses and public keys by sending signed messages to each other. This will allow a peer to identify what games another peer is allowed access to.

Message Handling One of the responsibilities of this component is to respond to requests sent by the Data Manager by sending and tracking messages to other peers to fetch requested data. Each message should be tracked by the peer for a given time period and resent if an appropriate response has not been received. Any duplicate requests sent by the data manager will be ignored if a pending request is active.

Commands Structured messages (**F-M8**) will typically come as part of a request/response pair involving the sharing of information between peers. Command responses are not awaited to remove unnecessary blocking of the connection channel as a user may be

responding to many different requests at once by the same peer. Table 4.5 shows the list of commands used bu the application.

Message Format	Description
LIBRARY GAMES;[$hash_1$];[$hash_2$];...;	Request that a peer sends their library of game. The user sends a list of their games as a series of unique root hashes. These root hashes will map to games on the blockchain.
BLOCK;[$gameHash$];[$blockHash$];	The user will request a block of data off of a peer by sending the root hash of the game and the hash of the block being requested. The response will be a SEND_BLOCK message (**F-M9**).
SEND_BLOCK;[$gameHash$]; [$blockHash$];[$compressedData$];	The user sends a block of data in response to a BLOCK message (**F-M9**). The data is compressed using the *compress/flate* package to reduce message size (**NF-S1**).
VALIDATE_REQ;[$message$]	The user is requesting for a message to be signed using the receiver's Ethereum private key. This is used to verify the receiver's identity and thus their owned collection of games (**F-S1**).
VALIDATE_RES;[$signedmessage$]	The user responds to a VALIDATE_REQ message with a signed version of the received message. From this signature, the receiver can determine the address and public key of the user (**F-S1**).
REQ_RECEIPT;[$gameHash$]	A user will request a RECEIPT message from a peer detailing the data that has been sent by the user for a specific game (**F-S3**).
RECEIPT;[$gameHash$];[$signature$] ;[$message$]	A user will respond to a REQ_RECEIPT message with a signed message detailing all of the blocks that the requester has sent to the user from a given game. This will allow for users to prove their contributions to the game developer who could then reward them (**F-S3**).
REQ_PEERS	A user requests the list of peers which the receiver peer is connected to. This will be sent immediately after a peer's identity is validated and will help increase the connectivity in the network (**F-S4**).
PEERS;[$p_1 hostname$] : [$p_1 port$];...	A user will send a list of their active peers. This will be limited to those peers which they have connected to and thus know the hostname and port of their server (**F-S4**).
ERROR;[$message$]	An error message that can be used to prompt a peer to resend a message.

Table 4.5: *The set of structured messages sent between peers*

Data Manager

The Data Manager has several responsibilities:

1. Track the user's owned games and know which are installed locally and which aren't.
2. Interact with the Library contract deployed to the Ethereum blockchain to discover, upload and purchase games (**F-M1**) (**F-M2**) (**F-M5**).
3. Fetch shards of game data from the disk to send to other peers.
4. Interact with IPFS to upload/fetch a game hash tree and assets (**F-M12**) (**F-C2**).
5. Sending requests to the networking layer to find and retrieve blocks of data from peers in the network.
6. Generate hash trees for games.

Frontend & Controller

Frontend

This application will have a GUI (**F-S2**) (**NF-S2**) where users can interact with the platform. Having a GUI is essential to making the platform as easy to use as possible so that it is accessible to new users. At minimum it will need to include the following pages:

- **Library** The user's collection of owned games, where they can view details for each game as well as manage their download status.
- **Store** Where user's can find and purchase new games that have been uploaded by other users.
- **Upload** Where users can fill in details about their new or updated game and have it be uploaded to the network.
- **Downloads** Where user's can track all of their ongoing downloads and see their progress.
- **Peers** Where users can manage their list of connected peers. Here a user can form new connections, break existing ones and request specific data from their peers.
- **Help** A help page to describe the application and all of its functionality (**NF-C2**)

To satisfy (**NF-M3**), a developer must always be displayed with both their chosen name and their Ethereum address. A developer should publically provide their Ethereum address to ensure their users can identify it.

Controller

The Controller will be represented as a set of interface functions that allow the backend and frontend code to communicate. This can be done to trigger actions such as starting a game download or to fetch data like the list of a user's owned games.

4.4 Benefits

This application presents the following benefits when compared with centralised game marketplaces:

- **Privacy** A user's personal information and usage isn't collected. Traditional platforms require users to enter personal information and will actively collect data about a user's actions through the platform.
- **Ownership** A user's ownership of a game isn't tied to a single platform and use of Ethereum means that a user's ownership is upheld by all computers in the network.

- **Censorship** Similar to the previous point, no one party has control over the platform so it is much harder for third parties, such as governments, to restrict the content uploaded to it.
- **Profits** Developers and gamers communicate directly and this means developer's won't have to pay a hefty fee for a middle-man. This will result in potentially larger profits for the developers.

4.5 Limitations

This application presents the following limitations when compared with a centralised game marketplace:

- **No Social Features** Social features, such as friends or achievements, were not included within the scope of this project.
- **Availability** Section 2.1 highlights the issue of availability within P2P file-sharing systems and it is likely this platform will face similar issues. The use of a contribution system was implemented to help identify those users who have been contributing but there is no automatic rewards system[6].
- **Inefficient Updates** As updates are treated as individual games, they will require users to download the entire game again. This is highly inefficient and results in lots of duplicate data being downloaded.
- **Hash Trees** Modelling data as a hash tree means that each file will need at least one block so a game may have a large amount of blocks for not a lot of data and as each block has to be requested separately this will add a lot network overhead.

[6] An example would be how the micro-payment system works in Swarm [28]

4.6 Sequence Diagram

Figure 4.3 shows how all of the components from this section are combined to download a game off of a single peer in the network.

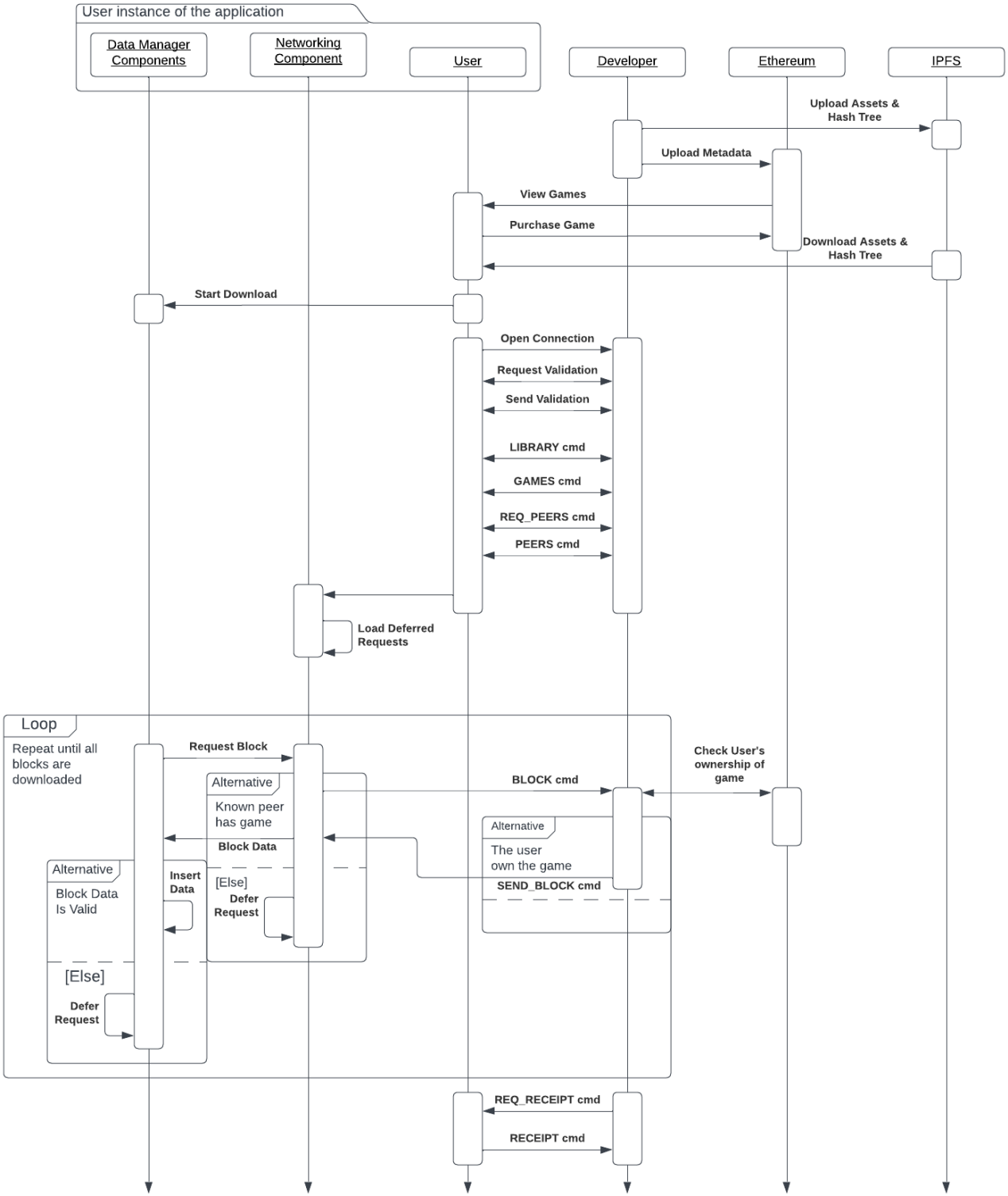


Figure 4.3: *A sequence diagram showing the main interactions needed to download a game from a single peer*

Chapter 5

Implementation

5.1 Backend

Table 5.1 shows the tools to create the backend of my application as it was described in Section 4.3.

Tool	Description & Reasoning
Go [33]	Go was chosen because of its simple syntax, high performance, strong standard library and third party packages for interacting with Ethereum.
go-ipfs-api [34]	A Go package used for interacting with the Kubo implementation of IPFS [27] that gave an easy interface for downloading and uploading data to Kubo.
go-ethereum [35]	A collection of tools used for interacting with Ethereum including an Ethereum CLI client (Geth), and a tool for converting Ethereum contracts into Go packages (abigen). This was essential for interfacing with the smart contract.
Zap [36]	A logging library that performs much better and provides easier customisation when compared to Go's standard library implementation.
Viper [37]	A configuration file management library that helps read, write, and access configuration options written to file. This makes it simple to access global configuration settings and made it easy to configure test profiles.

Table 5.1: *The tools used to develop the backend*

5.2 Smart Contract

Table 5.2 shows the tools used to create and deploy the Library smart contract as it was described in Section 4.2.

Tool	Description & Reasoning
Solidity [14]	The first language used to write smart contracts for the Ethereum blockchain. Most tutorials are focused around Solidity so it made the most sense to learn it for this project.

Sepolia [15]	An Ethereum test-net that used to deploy my smart contract to. One of the main benefits was that it provides a fast transaction time for quick feedback. It was chosen of Goerli [16] as the faucet gave out 5 times as much Ether.
Alchemy [38]	Alchemy provides useful tools for interacting with Ethereum and specifically Sepolia, such as an ETH faucet and an RPC URL.
MetaMask [39]	A browser-based wallet that can easily be connected to other tools such as Alchemy or Remix. This tool can generate new accounts and show you the transaction history of each using an intuitive UI.
Remix [40]	A browser-based IDE for writing smart contracts that allows for easy deployment. I did have an implementation that would deploy using go-ethereum but due to a bug in package it was unable to work for the Sepolia test-net.
Ganache CLI [41]	Ganache CLI was used to create a local Ethereum test-net that I could develop my application with. With one command I could quickly boot a lightweight blockchain with a predetermined set of keys. When compared to Geth, from go-ethereum, Ganache CLI was much more beginner friendly.

Table 5.2: *The tools used for deployment of my smart contract*

The contract was successfully deployed [42] to the Sepolia test-net and can be interacted with by any user.

5.3 Frontend

The frontend code was developed from Section 4.3 to provide a user a GUI to interact with. Table 5.3 details the list of tools used.

Tool	**Description & Reasoning**
Wails [43]	Allows you to add a webkit frontend to a Go application, so that you can use a modern web framework. This allowed me to easily create a reactive UI using tools I was previously familiar with. Wails allows you to implement a controller using functions written in that can be called from the frontend and can emit events that trigger actions in the frontend.
Vue.js v3 [44]	A reactive, component based web-framework that allows me to create reusable components that react to changes in state and can trigger events at different points in a components lifecycle. The Vue Router [45] package was used to add multiple pages to the application and markdown-it [46] was used to render markdown files. Vue was chosen over other frameworks (like React or Angular) because it is my personal favourite and the one that I have had the most experience working with.

Pinia [47]	A state management tool for Vue.js that boosts the reusability of components and reduces the overall complexity of the frontend by allowing state to be accessed globally through stores. Pinia integrates directly with Vue's composition API and is very beginner friendly and well documented, especially when considered to similar tools from other frameworks.
SASS [48]	An extension of CSS that is used to style DOM elements. This was essential in making the UI look nice and be accessible without having styling that was hard to maintain and search through.

Table 5.3: *The tools used to develop the application's GUI*

5.4 Other Tools

Table 5.4 shows the other tools used for the design, development and write-up of this application.

Tool	Description & Reasoning
Git [49] GitHub [50]	A version control system used in conjunction with GitHub. Creating periodic commits meant I always had a recent backup available and could easily backtrack to help find issues. Use of a GitHub Actions helped remind me that not all of my tests passed at all times :(.
LaTeX [51]	Used for the write-up of this document. LaTeX was useful in creating a large document and has many packages that help with referencing and design.
VSCode [52]	My code editor of choice for this project as it allowed me to seamlessly work on both my frontend and backend code at once.
Lucidchart [53]	Lucidchart was used to create all of the diagrams for this project. Lucidchart offers a better user experience when compared to alternatives like Draw.io but locks several features behind a paywall.
Zotero [**noauthor_zotero_nodat**]	A reference manager used to help me organise all of the documents cited in this paper. This includes a browser extension to easily add new references.

Table 5.4: *General purpose tools used for this project*

Chapter 6

Testing

6.1 Overview

My approach to testing will consist of the following principles:

1. **Test Driven Development** [54] Tests should be written alongside the code to reduce the risk of bugs and improve robustness.
2. **Fail Fast (Smoke testing)** Automated tests should be ran in a pipeline where the fastest tests are always ran first to reduce the time spent running tests.
3. **Documentation** Test cases should be well documented and grouped contextually such that they are easy to maintain and add to.

Tools

In Table 6.1 I detail the different tools I used to write automated tests for my application.

Tool	Description & Reasoning
Go Testing [55]	The testing package included with Go's standard library was sufficient to produce most of the test cases required for this project.
testify [56]	This package is included as it provides several useful testing features that aren't present in the standard library testing package. This includes assert functions to boost code readability, mocking tools for better unit testing, setup/teardown functionality, and more.

Table 6.1: *The tools used for testing my project*

6.2 Unit Testing

Unit tests were written alongside the code they were testing to ensure my code was robust and responded appropriately to all inputs. Generic functions like getters or setters were ignored and I aimed for a 70% test coverage to ensure a significant amount of the application was tested. Table 6.2 shows a breakdown of test coverage by package.

Package	Coverage	Tests Written
model/manager/hashtree	75.1%	69
model/manager/games	61.4%	107
model/manager/ignore	90.6%	13
model/net/tcp	71.6%	27
model/net/peer	50.4%	111
model/persistence/ethereum	81.7%	20
model/util	61.2%	24
Total	70.3%	371

Table 6.2: *Code coverage by package. Missing entries do not have code in them for example model/manager is only a wrapper for its child packages.*

Automated tests were also written for the smart contract functions and tested locally using Ganache CLI [41]. However, tests were not written for the controller functions as those functions were generally wrappers around model functions that cast between data types. Equally, automated UI tests were omitted due to time constraints and that UI components were partially tested by the user walkthroughs.

6.3 Integration Testing

Profiles

A profile is used to mimic a specific type of peer that a user may find through this application. This is to allow me to test my application under different conditions and see how it reacts. Table 6.3 details the used profiles.

Name	Purpose
Listen Only	A peer who will listen and respond to all requests perfectly but will never request anything. This is useful for testing when we want a lightweight client to just download data off of. This will also be able to upload a game to the locally running smart contract.
Sender	This peer will respond to requests but will also periodically send requests. This can be used to show how my application reacts to more realistic peers.
Unreliable	This peer will pseudo-randomly not respond to messages or send incorrect data in response. This is used to show how my application recovers from faults sent by other users.
Selfish	This peer will send requests but will never respond to any. This is used to show how my application handles expired requests.

Table 6.3: *The different profiles used to simulate real-world peers.*

The main outcome from these different profiles shows the need for a reputation system where a user can distinguish between peers that reliably respond to requests and peers

that don't. This would help mitigate some of the overhead of timed-out requests or receiving incorrect data.

6.4 Acceptance Testing

A series of user walkthroughs are provided to show that this application meets the requirements set out in Section 4.1.2. Table 6.4 describes each user walkthrough and Appendix A shows the evidence given for each (e.g. logs showing network messages (**F-M8**)). All user walkthroughs use a contract deployed to the Sepolia test-net [42], satisfying (**F-M4**), (**NF-M2**) and (**NF-M1**).

Id	Requirements	Description	Success
1	(**F-M1**) (**F-M5**) (**F-M12**) (**F-S2**) (**F-C2**) (**NF-M3**)	1. P_1 uploads a game G_1. 2. P_2 finds G_1 on the store. 3. P_2 purchases G_1. 4. P_2 shows G_1 added to their library.	YES
2	(**F-M6**) (**F-M8**) (**F-M9**) (**F-M10**) (**F-M11**) (**F-S1**) (**F-S2**) (**F-S3**) (**NF-M2**)	1. P_2 connects to P_1. 2. P_1 and P_2 exchange Ethereum addresses. 3. P_2 starts a download for G_1. 4. P_2 sends requests for blocks to P_1. 5. P_1 queries the smart contract to verify that P_2 owns G_1. 6. P_1 will respond to P_2 with the requested data. 7. P_2 will verify each block of data received using its hash. 8. P_2 will have full downloaded G_1. 9. P_1 will request and receive a contributions receipt for G_1 from P_2.	YES
4	(**F-M2**) (**F-M3**) (**F-M6**) (**NF-M5**)	1. P_1 is the original uploader of G_1. 2. P_1 uploads an update to G_1, G_2. 3. P_2 owns G_1 and thus G_2. 4. P_2 will successfully download G_2.	YES
5	(**F-S4**) (**F-M7**) (**NF-M2**)	1. P_1 is connected to P_2 and P_3. 2. P_4 forms a connection with P_1. 3. P_4 requests a list of P_1's peers and P_1 responds with the details of P_2 and P_3. 4. P_4 forms connections with P_2 and P_3.	YES

Table 6.4: *The set of user walkthroughs used to prove the completeness of this project's requirements.*

6.5 Benchmarking

This project uses benchmarking to determine the overall performance and scalability of the application (**NF-S1**), whilst also being useful in discovering any bottlenecks or bugs.

To ensure consistency in these results, I've included the following constraints:

- All benchmarks should be ran on the same hardware using the same OS,
- All tests should be ran three times,
- Test data should be pseudo-random, and
- All projects should aim for the target size of 40GB to match the average game size given in Section 4.2.

All graphs made with Matplotlib [].

Number of Peers

For each run, we will create a project with 500 files, each of size 80MB and a shard size of 4MiB. We will then run N peers locally to simulate a perfect network connection.

	Runtime (s)			
Peers	**1**	**2**	**3**	**avg.**
1	1,513	1,511	1,511	1,512
2	777	775	777	776
4	397	397	396	397
8	227	223	224	225

Table 6.5: *Raw data from peer count benchmark*

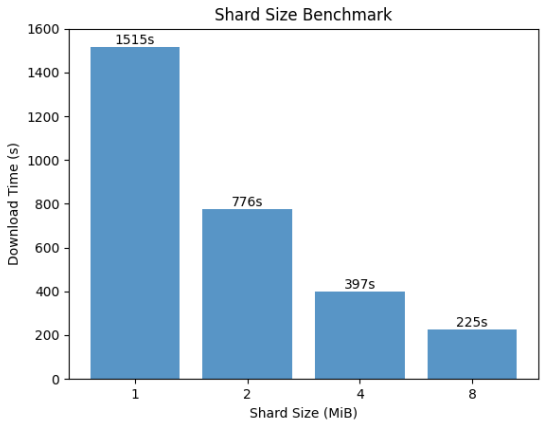


Table 6.6: *Graphical version of Table 6.5*

This result shows us that we can massively increase the download speed by increasing the number of peers we are connected to. This shows that my application can correctly handle many concurrent peers (**F-M7**) and uses the increased connections to boost performance (**NF-S1**).

Game Size

For each run, we will create a project of F files of size SMB, such that $F \times S = 40GB$. We will download the game off of 4 peers that are running locally on the same machine.

File		Runtime (s)			
Count	**Size (MB)**	**1**	**2**	**3**	**avg.**
200	200				
100	400				
50	800				
25	1,600				

5	8,000				
1	40,000				

Table 6.7: *How varying file count and size affects download speed*

From these results, we can see that distributing data across a larger pool of files results in a greater download speed. This occurred for several reasons:

1. A file can only be written to by one process at one time so having less files will reduce the potential for parallelisation.
2. For each block downloaded: we open a writer to a file, write a single block, and close the writer. This adds a lot of overhead for files that have many blocks.

Chapter 7

Project Management

7.1 Risk Assessment

Risk	Loss	Prob	Risk	Mitigation
Difficulty with blockchain development	2	3	6	I will seek advice from my supervisor about how to tackle certain problems and decide on any changes my project might need. I could also use online documentation or forums for support.
Personal illness	3	2	6	Depending on the amount of lost time, I will have to choose to ignore some lower priority requirements. Use of effective sprint planning will help ensure I can produce at least a minimal viable product.
Laptop damaged or lost	3	1	3	Thorough use of version control and periodic backups to a separate drive will ensure I always have a relatively recent copy of my work. I have other devices available to me at home and through the university to continue development.
The application is not finished	2.5	4	10	Effective use of agile development and requirement prioritisation will ensure that even if I do not complete the project I will have the most significant parts of it developed. It is important to consider a cut off point for development, where I will have to purely focus on the write-up and final testing.
Lack of large-scale testing infrastructure	2	5	10	Local benchmarks can be used to determine theoretical upper limits on my application or could be tested using a variety of hardware owned personally. Other tests may show it working on a smaller scale over the internet but it would be difficult and expensive to obtain the hardware to test it at a large scale.

Table 7.1: *The risk assessment of this project*

7.2 Sprint Plans

Sprints were used in accordance of the Agile Methodology [57] to help me incrementally build on my project through prioritisation of the most important requirements.

Sprint 1

I anticipated that the P2P game distribution network would be the most complex and time consuming set of requirements in this project so I decided to focus on it for this first sprint. Table 7.2 shows the requirements included for Sprint 1 and whether they were completed or not.

Req.	Complete	Evidence/Reasoning
(**F-M7**)	YES	Unit tests for the model/net/tcp package and the peer count benchmark tests.
(**F-M8**)	YES	Unit tests for the model/net/peer/message_handlers file test the handling of structured messages and the structured responses sent back.
(**F-M9**)	YES	All benchmark tests show the downloading of data to a large scale.
(**F-M10**)	YES	Unit tests to show incorrect messages being rejected.
(**F-M11**)	YES	User walkthrough shows the download of a game in its entirety.
(**F-M12**)	STARTED	The algorithm to generate a hash tree and the using of it to download data was implemented but no way to upload it anywhere.
(**NF-M2**)	YES	User walkthrough 2 shows that any user can establish a connection with any other user.
(**NF-S1**)	STARTED	Users will form many connections concurrently and optimisations were made using the producer/consumer pattern to complete actions like inserting data, or requesting data.

Table 7.2: *Requirements included for Sprint 1*

Sprint 2

Sprint 2 was about increasing the scope of the application by focusing on two main aspects:

1. The integration with Ethereum using a Smart Contract, and
2. Allowing users to interface with the application via a GUI.

This sprint had a much slower start compared to the first one as I was largely unfamiliar with smart contract development and the related packages needed to interface with them. On top of this, I considered several UI framework's before settling on my final choice which increased the length of this sprint.

Table 7.3 shows the requirements pitched for Sprint 2 and whether or not they were completed.

Req.	Complete	Evidence/Reasoning
(**F-M1**)	YES	Unit tests for the Library smart contract and user walkthrough 1 show the ability to upload game metadata to Ethereum.
(**F-M2**)	YES	Unit tests for the Library smart contract and user walkthrough 4 show the ability to upload an update to an existing game to Ethereum.
(**F-M3**)	YES	Unit tests for the Library smart contract show users of an existing game being given ownership of an updated version.
(**F-M4**)	YES	The smart contract was successfully deployed the Sepolia test-net [42]. All user walkthroughs will form connections to this smart contract.
(**F-M5**)	YES	Unit tests for the Library smart contract and user walkthrough 1 show the successful purchase of a game.
(**F-M6**)	YES	Unit tests for the Library smart contract show a user being added to a mapping containing all users who have purchased the game.
(**F-M12**)	YES	Hash trees are now uploaded to IPFS and the CID is stored on Ethereum.
(**F-S2**)	STARTED	Basic pages were added according to Section 4.3. These pages had little styling or reactivity but could perform the required basic functions. See Appendix B for screenshots of the final versions.
(**NF-M1**)	YES	The use of the Ethereum blockchain means that no single user can control what is uploaded to the network.
(**NF-M3**)	YES	Developers can be uniquely identified using their Ethereum address. This should be made publically verifiable by the developers.
(**NF-M4**)	YES	Data stored on Ethereum is inherently immutable.
(**NF-M5**)	YES	Unit tests for the smart contract show the restriction that only the original uploader can release an update.

Table 7.3: *Requirements included for Sprint 2*

Sprint 3

This sprint was about extending the minimum viable application reached by the end of Sprint 2 with some necessary additions. Table 7.4 shows the list of requirements for this sprint and whether or not they were completed.

Req.	Complete	Evidence/Reasoning
(**F-S1**)	YES	Users will validate each other's Ethereum address after forming a connection and unit tests for the model/net/peer/message_handlers file show this being performed.
(**F-S2**)	YES	The UI was overall improved to improve the user experience.

(**F-S3**)	NO	Users will track the blocks sent to them by each of their peers but this application has no mechanism for redeeming these. Due to time constraints, I was unable to implement a sufficient solution. Moreover, I felt that a micropayment system, like present in Swam [28], would be a much better implementation.
(**F-S4**)	YES	Users will exchange the REQ_PEERS/PEER commands to discover neighbouring peers. However a better implementation might have the developer of the game be able to provide a list of peers who have the game. This would allow a user to easily find peers who are interested in the same content.
(**F-C1**)	NO	Due to time constraints I was unable to implement this at all.
(**F-C2**)	YES	Game assets are uploaded to IPFS and the CID is stored with the game metadata on Ethereum.
(**NF-S1**)	YES	Benchmark tests show the scalability of my application by varying certain parameters and that the target file size can be downloaded within an acceptable best-case.
(**NF-S2**)	YES	Changes to the UI made it more interactive and easier to navigate. Designs were inspired by pages from existing platforms to make the UI feel familiar. See Appendix B for screenshots of the final versions.
(**NF-C1**)	NO	Completing this requirement would be incredibly complex and was decided against being completed. Preventing the distribution of illegal content is an important consideration moving forward to help keep the platform safe.
(**NF-C2**)	YES	A help page was included answering some questions that new users may have about the application.

Table 7.4: *Requirements included for Sprint 3*

7.3 Gantt Chart

A Gantt chart was used to give a high-level overview of my project to give myself a realistic timetable of when different aspects had to be completed by. Figure 7.1 shows the complete version.

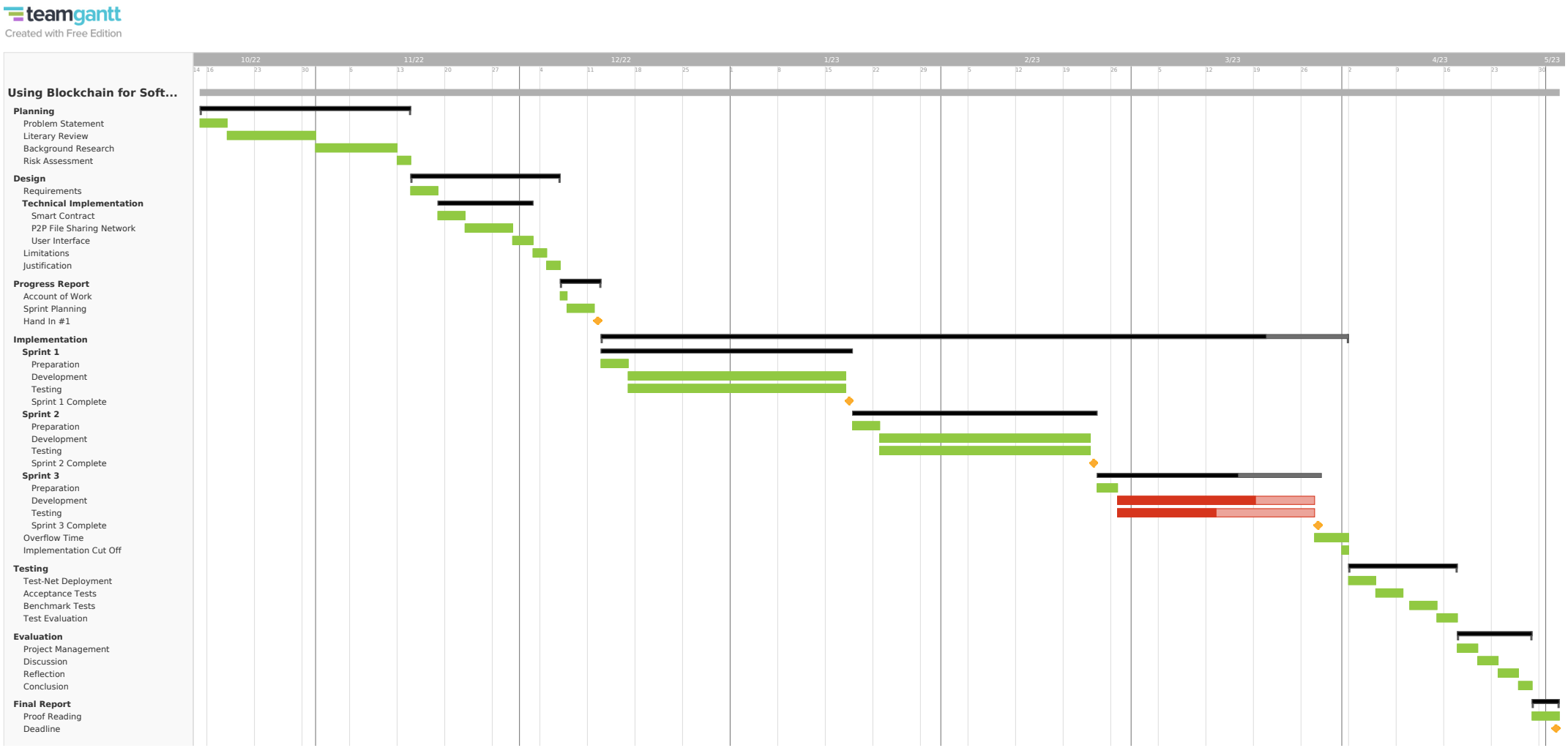


Figure 7.1: *The Gantt chart showing a breakdown of my project by task and milestones, where the red areas incidicate incomplete work. Created with TeamGantt [58].*

Chapter 8

Evaluation

8.1 Discussion

Due to the scale and complexity of the platforms this project was aiming to replace, this project was never going to be more than a proof-of-concept as to what a distributed games marketplace could look like. However, this application does have several benefits over its centralised competitors, which are outlined in Section 4.4

This project presents interesting ideas surrounding how games, and other proprietary software, can be distributed without the need for a middle-man. This follows modern web ideas of taking away reliance on large data-centres and having a system built and maintained by the people who use it. Moreover, this type of project is usually open source, which can help attract community contributions to improve the security and user experience of the application.

8.2 Reflection

Risk Assessment

Difficulty with blockchain development As expected there were several difficulties with blockchain development:

- A decent amount of the documentation is minimal or outdated. As blockchain development is a smaller field there are little in the ways of forum postings.
- Some of the libraries used had bugs in them that hindered development. For example, I could deploy the smart contract to the Sepolia testnet from Remix easily but not through Geth.

Despite the problems mentioned above, I was able to complete the blockchain aspect of the project successfully. Effective use of sprint planning meant that I had considered this to be a potential issue and had allocated time to being able to deal with it.

The application is not finished Section 7.2 shows that not all of the requirements were finished and Section 4.5 discusses the limitations with my current implementation. It was expected that this project would not be entirely finished but a lot of the major requirements were met.

The application ended up being incredibly large and took a lot more time to implement

and test than expected. Table 8.1 shows a breakdown of the source code. Agile development could only help me so much so by having a hard cut-off point for the implementation I was still left with plenty of time to complete the report.

Language	Files	Comments	Code
Go	44	683	4621
Go Tests	29	791	3205
Vue.js Components	18	147	2855
JavaScript	19	74	209
Solidity	1	30	51

Table 8.1: *The lines of code written for this project calculated using CLOC [59]*

Lack of large-scale testing infrastructure Testing distributed applications is challenging due to many factors, such as having to source homogenous devices, having access to networks that would allow me host a peer, and more. However, several useful results were produced from the benchmarks (Section 6.5) and acceptance tests (Section 6.4) that can be used to improve the application. If this project were to move forward then testing it on a large-scale would be essential.

Using Agile Development

The use of an agile methodology alongside test-driven development meant I could incrementally expand the scope of my application and ensure that existing code was tested sufficiently. Separating my implementation into three sprints benefitted me by:

- having a smaller set of requirements to focus on at once helped me to feel less overwhelmed,
- working on the most important aspects first to ensure I was able to produce a minimum viable product, and
- taking time in-between sprints to take a break from the project and prepare for the next sprint.

On top of this, using a Gantt chart (Figure 7.1) allowed me to have a clear overview of my project timeline so I could realistically gage just how much time I would need for each section.

Chapter 9

Conclusion

9.1 In Conclusion

This project set out to demonstrate how video game distribution could be migrated to a distributed platform with the aim of reducing the risk of censorship, improving ownership and increasing profits for developers.

By researching related topics and reviewing the literature around key areas of this project, I was able to combine modern ideas and technologies to develop a functional proof-of-concept application. The heavy use of automated testing allowed me to continuously write robust and correct code and the successful deployment to an Ethereum development meant I was able to demonstrate the correctness of my implementation.

As most of the requirements set out in Section 4.1.2 were met, I can say that this project was a success.

9.2 Future Work

New Features

Some notable features that would serve as excellent extensions to this application:

- Fleshing out the store page will make it easier for users to discover new content. Games could be given extra metadata to help make them more searchable.
- Allowing users to post reviews or posts to message boards for individual games will allow for greater community integration.
- Add customisable user profiles and allow for users to add each other as friends. Friends would auto-connect as peers to help maintain a network.

Optimisations

There are several optimisations we could add to improve the overall performance and scalability of the application:

- **Peer Reputation** By ranking peers based upon their reliability we can improve the success rate and latency of requests we send. An optimistic unchoking algorithm like seen in BitTorrent could also be used.
- **Block Selection** Currently blocks are not ranked in any way but by considering ideas from Section 2.1 we could improve the efficiency, availability and throughput

of our network.

Chapter 10

References

Peer-to-Peer File Sharing

[5] S. Kaune et al. "Unraveling BitTorrent's File Unavailability: Measurements and Analysis". In: *2010 IEEE Tenth International Conference on Peer-to-Peer Computing (P2P)*. 2010 IEEE Tenth International Conference on Peer-to-Peer Computing (P2P). ISSN: 2161-3567. Aug. 2010, pp. 1–9. DOI: 10.1109/P2P.2010.5569991.

[6] Johan Pouwelse et al. "The Bittorrent P2P File-Sharing System: Measurements and Analysis". In: *Peer-to-Peer Systems IV*. Ed. by Miguel Castro and Robbert van Renesse. Lecture Notes in Computer Science. Berlin, Heidelberg: Springer, 2005, pp. 205–216. ISBN: 978-3-540-31906-1. DOI: 10.1007/11558989_19.

[7] BitTorrent Inc. *BitTorrent Web — The Best Online Torrent Downloader*. BitTorrent. URL: https://www.bittorrent.com/products/win/bittorrent-web-free/ (visited on 04/08/2023).

[8] *qBittorrent Official Website*. URL: https://www.qbittorrent.org/ (visited on 04/08/2023).

[9] BitTorrent Inc. *µTorrent (uTorrent) — A Very Tiny BitTorrent Client*. uTorrent. URL: https://www.utorrent.com/ (visited on 04/08/2023).

[10] *Application Usage & Threat Report*. URL: https://www.paloaltonetworks.com/blog/app-usage-risk-report-visualization/# (visited on 04/08/2023).

[11] G. Neglia et al. "Availability in BitTorrent Systems". In: *IEEE INFOCOM 2007 - 26th IEEE International Conference on Computer Communications*. IEEE INFOCOM 2007 - 26th IEEE International Conference on Computer Communications. ISSN: 0743-166X. May 2007, pp. 2216–2224. DOI: 10.1109/INFCOM.2007.256.

[25] Juan Benet. *IPFS - Content Addressed, Versioned, P2P File System*. July 14, 2014. DOI: 10.48550/arXiv.1407.3561. arXiv: 1407.3561[cs]. URL: http://arxiv.org/abs/1407.3561 (visited on 11/02/2022).

[26] *Estuary*. URL: https://estuary.tech (visited on 04/09/2023).

[27] *ipfs/kubo*. original-date: 2014-06-26T08:14:34Z. Apr. 9, 2023. URL: https://github.com/ipfs/kubo (visited on 04/09/2023).

[28] J.H. Hartman, I. Murdock, and T. Spalink. "The Swarm scalable storage system". In: *Proceedings. 19th IEEE International Conference on Distributed Computing Systems (Cat. No.99CB37003)*. Proceedings. 19th IEEE International Conference on Distributed Computing Systems (Cat. No.99CB37003). ISSN: 1063-6927. June 1999, pp. 74–81. DOI: 10.1109/ICDCS.1999.776508.

[29] James H. Morris et al. "Andrew: a distributed personal computing environment". In: *Communications of the ACM* 29.3 (Mar. 1, 1986), pp. 184–201. ISSN: 0001-0782. DOI: 10.1145/5666.5671. URL: https://doi.org/10.1145/5666.5671 (visited on 11/25/2022).

[30] John H. Howard et al. "Scale and performance in a distributed file system". In: *ACM Transactions on Computer Systems* 6.1 (Feb. 1, 1988), pp. 51–81. ISSN: 0734-2071. DOI: 10.1145/35037.35059. URL: https://doi.org/10.1145/35037.35059 (visited on 11/25/2022).

[31] Stefan Saroiu, P. Krishna Gummadi, and Steven D. Gribble. "Measurement study of peer-to-peer file sharing systems". In: *Multimedia Computing and Networking 2002*. Multimedia Computing and Networking 2002. Vol. 4673. SPIE, Dec. 10, 2001, pp. 156–170. DOI: 10.1117/12.449977. URL: https://www.spiedigitallibrary.org/conference-proceedings-of-spie/4673/0000/Measurement-study-of-peer-to-peer-file-sharing-systems/10.1117/12.449977.full (visited on 11/23/2022).

Blockchain

[12] Dejan Vujičić, Dijana Jagodić, and Siniša Randić. "Blockchain technology, bitcoin, and Ethereum: A brief overview". In: *2018 17th International Symposium INFOTEH-JAHORINA (INFOTEH)*. 2018 17th International Symposium INFOTEH-JAHORINA (INFOTEH). Mar. 2018, pp. 1–6. DOI: 10.1109/INFOTEH.2018.8345547.

[13] Chris Dannen. *Introducing Ethereum and Solidity: Foundations of Cryptocurrency and Blockchain Programming for Beginners*. Berkeley, CA: Apress, 2017. ISBN: 978-1-4842-2534-9 978-1-4842-2535-6. DOI: 10.1007/978-1-4842-2535-6. URL: https://link.springer.com/10.1007/978-1-4842-2535-6 (visited on 11/23/2022).

[16] *Goerli Testnet*. Goerli Testnet. URL: https://goerli.net (visited on 04/03/2023).

[17] *Ropsten Testnet*. original-date: 2017-03-22T16:17:48Z. Mar. 23, 2023. URL: https://github.com/ethereum/ropsten (visited on 04/03/2023).

[18] Dongdong Yue et al. "Blockchain Based Data Integrity Verification in P2P Cloud Storage". In: *2018 IEEE 24th International Conference on Parallel and Distributed Systems (ICPADS)*. 2018 IEEE 24th International Conference on Parallel and Distributed Systems (ICPADS). Dec. 2018, pp. 561–568. DOI: 10.1109/PADSW.2018.8644863.

[19] Jingyi Li et al. "Deduplication with Blockchain for Secure Cloud Storage". In: *Big Data*. Ed. by Zongben Xu et al. Communications in Computer and Information Science. event-place: Singapore. Springer, 2018, pp. 558–570. ISBN: 9789811329227. DOI: 10.1007/978-981-13-2922-7_36.

[20] Jiaxing Li, Jigang Wu, and Long Chen. "Block-secure: Blockchain based scheme for secure P2P cloud storage". In: *Information Sciences* 465 (Oct. 1, 2018), pp. 219–231. ISSN: 0020-0255. DOI: 10.1016/j.ins.2018.06.071. URL: https://www.sciencedirect.com/science/article/pii/S0020025518305012 (visited on 11/23/2022).

[21] Yi Chen et al. "Blockchain-Based Medical Records Secure Storage and Medical Service Framework". In: *Journal of Medical Systems* 43.1 (Nov. 22, 2018), p. 5. ISSN: 1573-689X. DOI: 10.1007/s10916-018-1121-4. URL: https://doi.org/10.1007/s10916-018-1121-4 (visited on 11/24/2022).

[22] Shangping Wang, Yinglong Zhang, and Yaling Zhang. "A Blockchain-Based Framework for Data Sharing With Fine-Grained Access Control in Decentralized Storage Systems". In: *IEEE Access* 6 (2018). Conference Name: IEEE Access, pp. 38437–38450. ISSN: 2169-3536. DOI: 10.1109/ACCESS.2018.2851611.

[23] Ahsan Manzoor et al. "Blockchain based Proxy Re-Encryption Scheme for Secure IoT Data Sharing". In: *2019 IEEE International Conference on Blockchain and Cryptocurrency (ICBC)*. 2019 IEEE International Conference on Blockchain and Cryptocurrency (ICBC). May 2019, pp. 99–103. DOI: 10.1109/BLOC.2019.8751336.

[24] Pratima Sharma, Rajni Jindal, and Malaya Dutta Borah. "Blockchain Technology for Cloud Storage: A Systematic Literature Review". In: *ACM Computing Surveys* 53.4 (July 31, 2021), pp. 1–32. ISSN: 0360-0300, 1557-7341. DOI: 10.1145/3403954. URL: https://dl.acm.org/doi/10.1145/3403954 (visited on 11/22/2022).

Tools Used

[14] *Solidity — Solidity 0.8.18 documentation*. URL: https://docs.soliditylang.org/en/v0.8.18/ (visited on 03/22/2023).

[15] *Sepolia Resources*. Sepolia Resources. URL: https://sepolia.dev/ (visited on 03/30/2023).

[33] *The Go Programming Language*. URL: https://go.dev/ (visited on 03/22/2023).

[34] *go-ipfs-api*. original-date: 2015-05-13T05:09:55Z. Mar. 29, 2023. URL: https://github.com/ipfs/go-ipfs-api (visited on 03/30/2023).

[35] *go-ethereum*. go-ethereum. URL: https://geth.ethereum.org/ (visited on 03/22/2023).

[36] *Zap*. original-date: 2016-02-18T19:52:56Z. Mar. 30, 2023. URL: https://github.com/uber-go/zap (visited on 03/30/2023).

[37] *viper package - github.com/dvln/viper - Go Packages*. URL: https://pkg.go.dev/github.com/dvln/viper (visited on 03/30/2023).

[38] *Alchemy - the web3 development platform*. URL: https://www.alchemy.com/ (visited on 03/30/2023).

[39] *The crypto wallet for Defi, Web3 Dapps and NFTs — MetaMask*. URL: https://metamask.io/ (visited on 03/30/2023).

[40] *Remix - Ethereum IDE*. URL: https://remix.ethereum.org/ (visited on 03/30/2023).

[41] *trufflesuite/ganache*. original-date: 2017-03-27T17:04:47Z. Mar. 31, 2023. URL: https://github.com/trufflesuite/ganache (visited on 04/01/2023).

[42] etherscan.io. *Deployed Smart Contract*. Ethereum (ETH) Blockchain Explorer. URL: http://sepolia.etherscan.io/address/0x2899dab55a4a20d698062bbf4d4ce9f1073ce052 (visited on 03/30/2023).

[43] *The Wails Project — Wails*. URL: https://wails.io/ (visited on 03/22/2023).

[44] *Vue.js - The Progressive JavaScript Framework — Vue.js*. URL: https://vuejs.org/ (visited on 03/22/2023).

[45] *Vue Router — The official Router for Vue.js*. URL: https://router.vuejs.org (visited on 03/30/2023).

[46] *markdown-it*. original-date: 2014-12-19T22:54:53Z. Mar. 30, 2023. URL: https://github.com/markdown-it/markdown-it (visited on 03/30/2023).

[47] *Pinia — The intuitive store for Vue.js*. URL: https://pinia.vuejs.org (visited on 03/22/2023).

[48] *Sass: Syntactically Awesome Style Sheets*. URL: https://sass-lang.com/ (visited on 03/22/2023).

[50] *Github*. GitHub. URL: https://github.com (visited on 03/30/2023).

[51] *LaTeX - A document preparation system*. URL: https://www.latex-project.org/ (visited on 03/30/2023).

[52] *Visual Studio Code - Code Editing. Redefined*. URL: https://code.visualstudio.com/ (visited on 03/30/2023).

[53] *Lucidchart*. Lucidchart. URL: https://www.lucidchart.com (visited on 03/30/2023).

[55] *testing package - testing - Go Packages*. URL: https://pkg.go.dev/testing (visited on 04/12/2023).

[56] *Testify - Thou Shalt Write Tests*. original-date: 2012-10-16T16:43:17Z. Mar. 30, 2023. URL: https://github.com/stretchr/testify (visited on 03/30/2023).

[59] *AlDanial/cloc: cloc counts blank lines, comment lines, and physical lines of source code in many programming languages*. URL: https://github.com/AlDanial/cloc (visited on 03/30/2023).

Project Management

[49] *Git*. URL: https://git-scm.com/ (visited on 03/30/2023).

[54] Kent Beck. *Test-driven Development: By Example*. Google-Books-ID: CUlsAQAAQBAJ. Addison-Wesley Professional, 2003. 241 pp. ISBN: 978-0-321-14653-3.

[57] S. Ilieva, P. Ivanov, and E. Stefanova. "Analyses of an agile methodology implementation". In: *Proceedings. 30th Euromicro Conference, 2004.* Proceedings. 30th Euromicro Conference, 2004. ISSN: 1089-6503. Sept. 2004, pp. 326–333. DOI: 10.1109/EURMIC.2004.1333387.

[58] *Free Online Gantt Chart Maker That's Easy to Use — TeamGantt*. URL: https://www.teamgantt.com/h2 (visited on 04/12/2023).

Other

[1] Tom Marks. *Report: Steam's 30% Cut Is Actually the Industry Standard*. IGN. Oct. 7, 2019. URL: https://www.ign.com/articles/2019/10/07/report-steams-30-cut-is-actually-the-industry-standard (visited on 12/10/2022).

[2] Andy Brown. *Valve defends taking 30 per cent cut of Steam sales in response to lawsuit*. NME. July 30, 2021. URL: https://www.nme.com/news/gaming-news/valve-defends-taking-30-per-cent-cut-of-steam-sales-in-response-to-lawsuit-3007255 (visited on 12/10/2022).

[3] *Steam China officially launched*. SteamDB. URL: https://steamdb.info/blog/steam-china-launched/ (visited on 04/06/2023).

[4] "Nintendo receives backlash from fans over ending eShop purchases". In: *BBC News* (Feb. 16, 2022). URL: https://www.bbc.com/news/technology-60405561 (visited on 04/06/2023).

[32] *Steam Charts · Most Played Games on Steam*. SteamDB. URL: https://steamdb.info/charts/ (visited on 03/22/2023).

Appendix A

User Walkthroughs

This section will go through each of the acceptance tests outlined in Section 6.4 and provide the evidence that they pass. This evidence will be given in the form of:

- Smart contract transaction logs from the Sepolia test-net. These are public at https://sepolia.etherscan.io/address/0x2899dab55a4a20d698062bbf4d4ce9f1073ce052. The smart contract code was uploaded so all functions called and data uploaded are visible.
- Snippets of logs written that correspond to certain actions. For example, receiving a message over the network.
- Screenshots to show changes being reflected in the user interface.

For this the game will be a simple folder of text files that we can easily compare to show correctness.

- G_1 = [title="User WT", version="1.0", developer="tcs1g20", uploader=0xfBC8D99Bb9ab8F781fF04F9b45Fe5c97AACE1916, previousVersion=None, price=0, rootHash='']
- G_2 = [title="User WT", version="2.0", developer="tcs1g20", previousVersion=G_1, price=0, uploader=0xfBC8D99Bb9ab8F781fF04F9b45Fe5c97AACE1916, rootHash='']

User Walkthrough 1

User Walkthrough 1 shows a user P_1 uploading a new game G_1 and another user P_2 purchasing it.

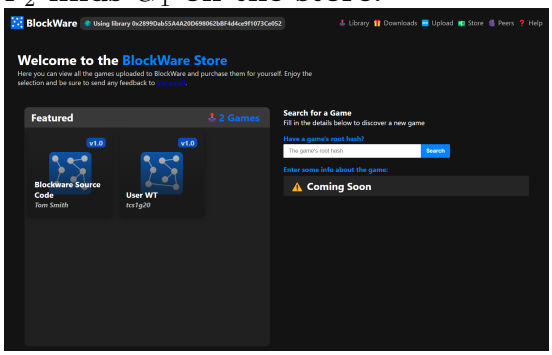
1. P_1 **uploads a game** G_1**.**

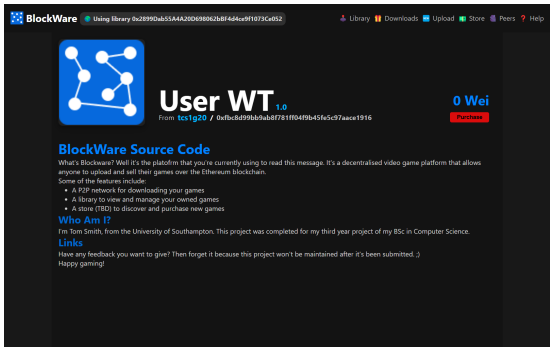
   Transaction hash = 0x0df539d51bc0a505f0a82524066d14631228684facc67a0e5a72138162be5b54

   Function: uploadGame((string,string,string,string,bytes32,bytes32,uint256,address,string,string))

#	Name	Type	Data
0	_game.title	string	User WT
0	_game.version	string	1.0
0	_game.releaseDate	string	2023-04-13 12:40:59.0103398 +0100 BST m=+29.566096101
0	_game.developer	string	tcs1g20
0	_game.rootHash	bytes32	0x795417059cee199df9874f951ac1b5a0df51e7a4610764aac8dd76aa3ff27664
0	_game.previousVersion	bytes32	0x0000000000000000000000000000000000000000000000000000000000000000
0	_game.price	uint256	0
0	_game.uploader	address	0xfBC8D99Bb9ab8F781fF04F9b45Fe5c97AACE1916
0	_game.hashTreeIPFSAddress	string	QmPxKfsF8tFDKjWYeVcWdCkwDfyjWycfDTQjR9ecSJPxSK
0	_game.assetsIPFSAddress	string	QmcCmtQgwaHAmEjgN4tZpeop9uUz37xx7uh9xWT9TXuHHc

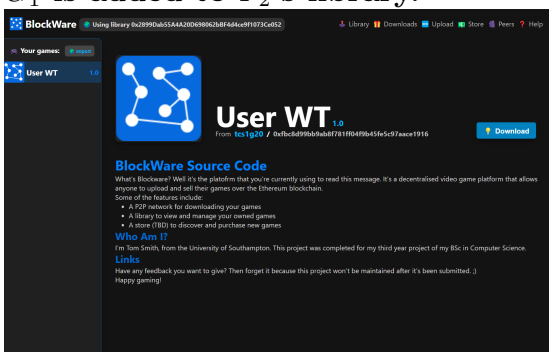
2. **P_2 finds G_1 on the store.**





3. **P_2 purchases G_1.**
Transaction hash = 0x2e3923becf503a0c75646f430037aed5bb26f8d168a67913e6eca8f68a143985

4. **G_1 is added to P_2's library.**



User Walkthrough 2

User walkthrough 2 shows a user P_1 downloading a game G_1 off of another user G_2. Both P_1 and P_2 already own G_1.

1. **P_2 connects to P_1.**
Logs showing P_2 forming a TCP connection with P_1:

```
2023-04-13T13:03:45.069+0100  [INFO]  tcp/client.go:42  Attempting to open
    ↪ connection to localhost:6051
...
2023-04-13T13:03:45.376+0100  [INFO]  controller/peers.go:52  Connected to peer
    ↪ localhost:6051
```

2. **P_1 and P_2 exchange Ethereum addresses.**

Logs showing P_2 sending P_1 a VALIDATE_REQ message and receiving a VALIDATE_RES to verify its address:

```
2023-04-13T13:03:45.376+0100  [INFO]  ethereum/identity.go:54 Generating address validation
2023-04-13T13:03:45.376+0100  [DEBUG] tcp/client.go:93  Sending VALIDATE_REQ ;323032332 d30342d31332031333a30333a34352e33373636363231202b303130302042535420 6d3d2b32392e393936343634313031
...
2023-04-13T13:03:45.379+0100  [DEBUG] tcp/client.go:79  message received VALIDATE_RES;4 b711e654d929c6a9b7b6db2a0fa53877a3d78f6bf64134cc6b1e35f2ff029682fbb484d74 a5645fb3d6b9806b1888abce1b29 eaa02730ace98151ad55aff3c100
2023-04-13T13:03:45.379+0100  [INFO]  ethereum/identity.go:80 Checking signature
2023-04-13T13:03:45.379+0100  [INFO]  ethereum/identity.go:97 Signature valid: true
```

3. P_2 **starts a download for** G_1
   P_2 Hits the download button in the libraray entry page.
4. P_2 **sends requests for blocks to** P_2
   Logs showing P_2 choose a block and send a request for it P_1:

```
2023-04-13T13:32:48.197+0100  [DEBUG] games/download.go:339 Requesting file downloads\User WT-1.0\test.txt for game 795417059 cee199df9874f951ac1b5a0df51e7a4610764aac8dd76aa3ff27664
2023-04-13T13:32:48.197+0100  [DEBUG] games/download.go:343 Requesting shard 8 ad06d76f6ac8729ab24e81b5e8d273c33bd6914f40c6709f2e6c02534428923 for file downloads\User WT-1.0\test.txt in game 795417059 cee199df9874f951ac1b5a0df51e7a4610764aac8dd76aa3ff27664
...
2023-04-13T13:32:48.197+0100  [DEBUG] peer/requests.go:14 Processing request for block 8ad06d76f6ac8729ab24e81b5e8d273c33bd6914f40c6709f2e6c02534428923
...
2023-04-13T13:32:48.197+0100  [DEBUG] tcp/client.go:93  Sending BLOCK;795417059 cee199df9874f951ac1b5a0df51e7a4610764aac8dd76aa3ff27664; 8 ad06d76f6ac8729ab24e81b5e8d273c33bd6914f40c6709f2e6c02534428923
```

5. P_1 **queries the smart contract to verify that** P_2 **owns** G_1
6. P_1 **will respond to** P_2 **with the requested data.**
   Logs showing P_2 receive a SEND_BLOCK message with the specified data:

```
2023-04-13T13:32:48.576+0100  [DEBUG] tcp/client.go:79  message received SEND_BLOCK ;795417059cee199df9874f951ac1b5a0df51e7a4610764aac8dd76aa3ff27664;< DATA OMITTED >
```

7. P_1 **will verify each block of data received using its hash.**
   The data matches the expected contents, no error is thrown and the shard is inserted:

```
2023-04-13T13:32:48.582+0100  [DEBUG] peer/message_handlers.go:272  Successfully inserted shard 8 ad06d76f6ac8729ab24e81b5e8d273c33bd6914f40c6709f2e6c02534428923
```

8. P_1 **will have a full downloaded copy of** G_1
   The output of a diff command comparing the original directory with the downloaded one. An empty output here indicates they are identical.

```
thoma@TOM-LAPTOP MINGW64 ~/coursework/part-iii-project (main)
$ diff -rq ./blockware/test/data/testdir/ ./live-test-data-p2/downloads/User\ WT-1.0/
```

9. P_1 **will request and be sent a contributions receipt for** G_1 **from** P_2**.**
   Logs showing P_1 send a REQ_RECEIPT message to P_2 and receive a signed RECEIPT back:

```
2023-04-13T18:44:18.882+0100  [DEBUG] tcp/server.go:147 Sending REQ_RECEIPT ;795417059cee199df9874f951ac1b5a0df51e7a4610764aac8dd76aa3ff27664
```

```
2 2023-04-13T18:44:18.890+0100  [DEBUG] tcp/server.go:135 message received RECEIPT
      ↪ ;795417059cee199df9874f951ac1b5a0df51e7a4610764aac8dd76aa3ff27664;
      ↪ e53da088782e02e933b62c20e9e5897db2dfd56f7011357d55c5cbb2844374b40a77186ca2
      ↪ 498727a311156f181d89ff356b9a485c0b952209d1d61b11a6e69d00;< BLOCKS OMITTED >
3 2023-04-13T18:44:18.890+0100  [INFO]  peer/message_handlers.go:422  Received
      ↪ receipt for 6 blocks
```

Appendix B

Screenshots

Figure B.1: *The login page where a user will enter their Ethereum private key and connect to a BlockWare contract instance.*

Figure B.2: *The home page where users can navigate between the main individual pages.*

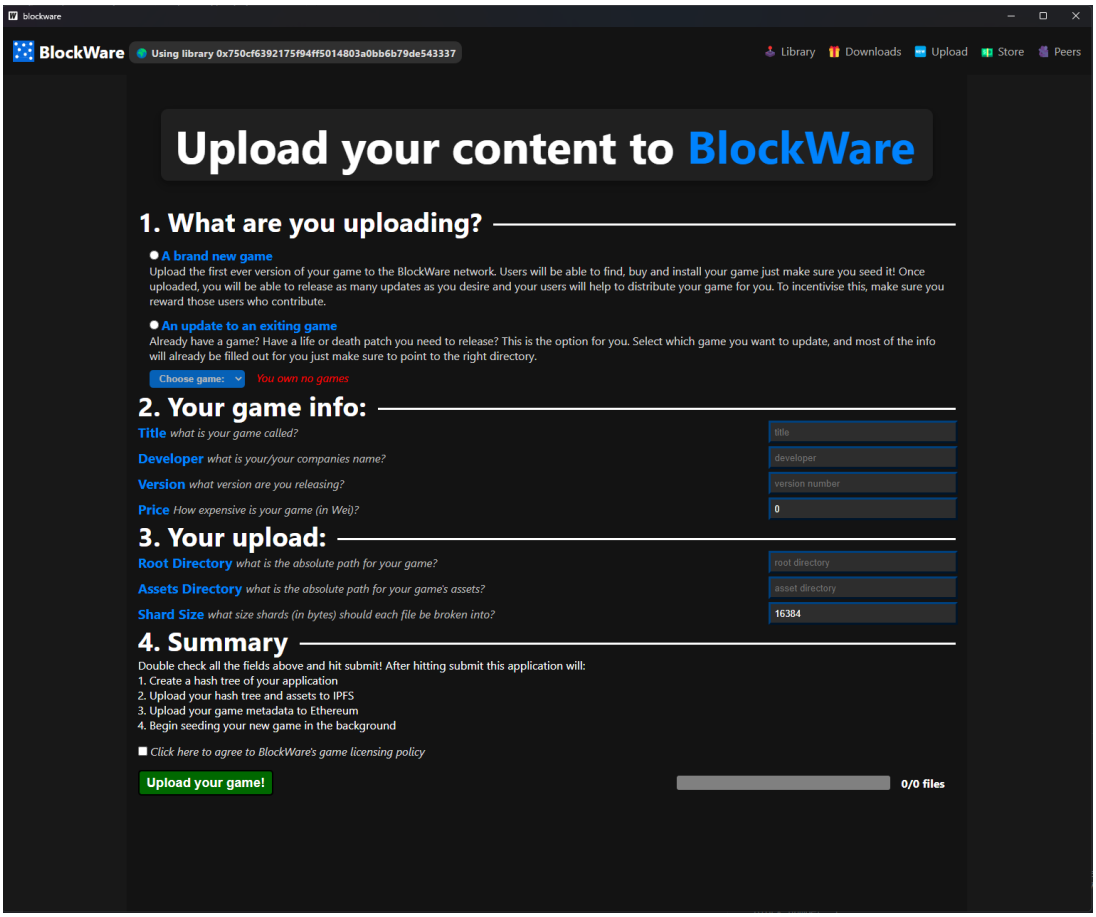


Figure B.3: *The page where users input the details about their game and can upload it to the Ethereum network.*

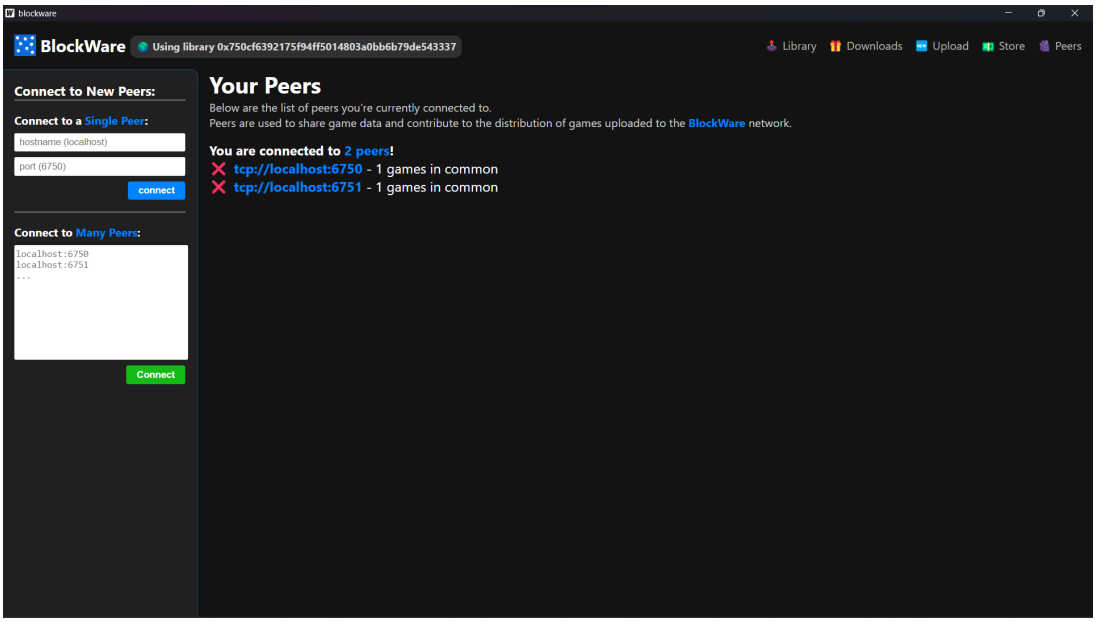


Figure B.4: *The page where users can manage their connections to peers with whom they will download game data off of.*