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DEPARTMENT OF COMPUTER GRAPHICS AND INTER-  
ACTION

Bachelor's thesis

**Crafting game with focus on economy**

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Guidelines:

1. Analyze three games with complex economic systems, list interesting mechanics.
2. Define the economic system of your game, describe item types, item fountains/sinks, the game's gathering, crafting and trading mechanics and provide an overview in a visual and written form.
3. Define non-economic aspects of your game including but not limited to combat, locomotion, distribution of gathering resources. Design a crafting tree that includes resource subtypes, intermediate items and finished products. Include relations between items.
4. Explain AI behaviour of enemies and neutral characters with focus on navigation, spawning logic and combat states (melee, ranged combat, passive mode, flight).
5. Discuss methods of procedural generation of resource spawn points and environmental objects.
6. Design a user interface that allows the player to organize their inventory, craft items and perform simple mini-games.
7. Create a playable prototype that includes all aforementioned features.
8. Conduct user testing of your game with at least five participants.

Bibliography / sources:

1. SCHELL, Jesse. The Art of Game Design: A Book of Lenses. 1st ed. CRC Press, 2008. ISBN 978-0123694966.
2. LEHDONVIRTA, Vili. CASTRONOVA, Edward. Virtual Economies - Design and Analysis. 1st ed. MIT Press, 2014. ISBN 978-0262535069.

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## Abstrakt

Cílem semestrálního projektu je navrhnout craftovací hru s důrazem na systém virtuální ekonomiky.

**Klíčová slova** videohra, virtuální ekonomika, analýza, návrh, implementace



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## **Abstract**

The objective of this semetral project is to design a crafting game with heavy emphasis on virtual economy.

**Keywords** video game, virtual economy, analysis, design, implementation



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# Introduction

Video games have evolved into immersive and dynamic universes, offering players opportunities to explore, engage, and create. Crafting games have emerged as a distinct genre, offering players the opportunity to gather resources, craft items, and build structures, among various other activities.

The purpose of this thesis is to analyse games with interesting economic systems and mechanics and subsequently, design and implement a crafting game that places a deliberate emphasis on its economic framework.



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# Analysis

In this chapter, we will analyze some video games with interesting economic systems and their interesting mechanics.

## 1.1 Puzzle Pirates

### 1.1.1 Overview

Puzzle Pirates is an MMO game developed by Three Rings Design and released in 2003. Every player takes on the role of a pirate, who can join a crew, buy a ship, plunder ships, own a shop, or house, and other pirate activities. Most of the player's actions, such as crafting or fighting, are represented by puzzles, hence the name Puzzle Pirates. Players can play on different servers, which are called oceans, there are three types: Subscriber, Doubloon, and Testing. Testing oceans gets new updates sooner than others. Subscriber Oceans allows unlimited free play for a regular fee paid by real money and in Doubloon Oceans, players can play for free but advanced functions require doubloons.

### 1.1.2 Islands

A server consists of multiple islands, that have multiple buildings. Players may teleport between them using ferries, ships, and whisking potions. Whisking potion teleports the player to another island that the player has visited before. Players can also teleport to their home island for free. A ferry can be used to get to an island in the same archipelago (collection of islands) as the player's current island.

## 1. ANALYSIS

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Apart from the ferry, players can discover new islands by sailing a boat and using a chart. The chart is an item that describes a route between two adjacent islands, they can be bought at a shipyard in the current island to any island in the same archipelago. If an island has no shipyards on both sides or between archipelagos, the chart to the said island must be pillaged from brigands (computer-controlled ships) or bought from other players. Every chart has a decay rate, several days before the chart disappears from the game. The chart on a navigation table decays based on real days and the chart in the player's inventory is based on log-in days.

A colonized island has citizens (players who have a home on that island), a governor, and a controlling flag. Flag is a collection of crews and the only political unit that can blockade an island. Players in a flag can have four ranks (listed from highest to lowest): Monarch, Royalty, Titled, and Member. The Governor of an island is a chosen representative of the controlling flag. The royalty of the flag can choose him by voting. The governor has the power to decorate and place buildings on an island. He has deeds (items representing ownership of a building or a ship) to the infrastructure buildings like a bank, commodities market, estate agent, fort/palace, housing, construction sites, bazaars, and shoppe deed if the island is an outpost island. The governor can give these deeds to any player, but they transfer to the new governor when the new governor is appointed. The palace deed gives the governor the power to change a "tax slider".

Property tax is paid by shoppe and stall owners to the fort or palace every week. Some of the tax is lost as a PoE sink and the rest goes to the island government. The tax that goes to the island government is expressed as a percentage of the tax baseline and increases the overall property tax paid. If the island has a fort, these additional taxes can be less than or equal to 50%, if the island has a palace, they can go up to 100%.

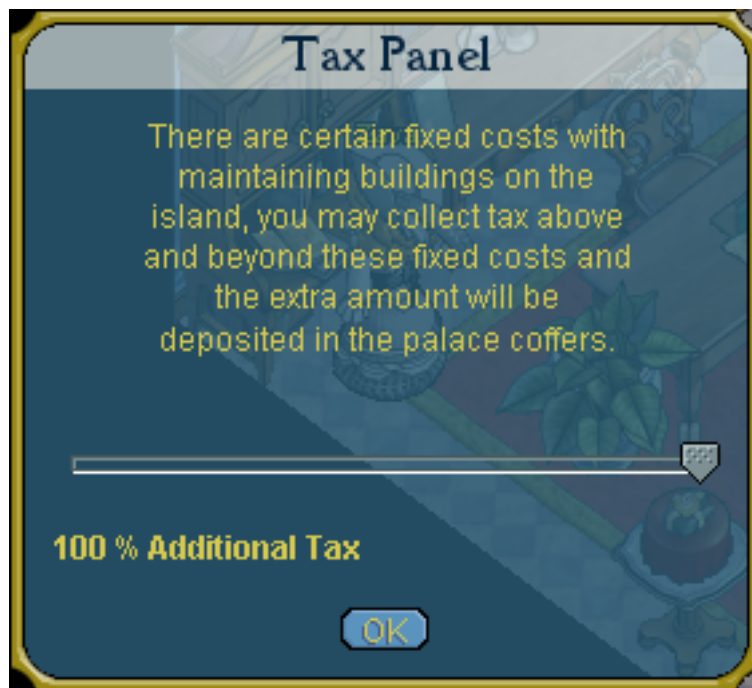
The most common way for a flag to take control of an island is a *blockade*, which is a multi-ship sea battle structured in several rounds. If the flag controlling the island wishes to transfer the island to another flag, they must pay a certain fee. The receiving flag can refuse the transfer.

Flag must have the required fame for owning an island. Fame is a measurement of the flag's activity. There are, from lowest to highest, nine levels of fame: Aspiring, Obscure, Rumored, Noted, Established, Renowned, Celebrated, Eminent, and Illustrious.

There are three types of islands based on their size: Outpost island, Medium island, and a Large island.

	Required fame for owning	Island transfer pricing
Outpost island	Noted	50 000 PoE
Medium island	Established	150 000 PoE
Large island	Renowned	250 000 PoE

**Table 1.1:** Required fame and pricing for different island sizes (96) (95)



**Figure 1.1:** The tax slider in-game UI (48)



**Figure 1.2:** Admiral island (large island) (47)

### 1.1.3 Buildings

The building is a structure on an island that players can enter. There are three main types of buildings: Shoppes, Infrastructure buildings, and Houses. Houses are buildings that players can buy and modify in various ways. Shoppe is a building where pirates combine labor and commodities to make products, it can be earned by acquiring a deed. There are seven types of shoppes that differ in products: Apothecaries, Distilleries, Furnishers, Iron mongers, Shipyards, Tailors, and Weaveries. Infrastructure buildings are the core of the island. They consist of Banks, Commodities markets, Estate agents, Forts, Inns and Palaces. Other types of buildings include Bazaars, which are like shoppes, but host multiple mini-shoppes, and Attractions, which consists of Black markets, Explorer's halls, Trading posts, and Estate agent (the building used for upgrading other buildings). Black markets offer players a black box that they can purchase, that contains a random item inside. Explorer's halls sell maps or compasses to different expeditions and Trading posts allow players to trade trinkets they've earned for prizes.



Attraction buildings typically have higher tax rates than standard buildings. The following table shows different baseline rent (additional tax is set to 0%) for buildings on an island with a population above 250. (90)

	Shoppe	Deluxe stall	Medium stall	Small stall
Tailor	6 750	5 500	4 250	3 000
Iron monger	1 750	1 500	1 250	1 000
Shipyards	6 750	5 500	4 196	2 891
Distillery	1 750	1 500	1 300	1 000
Weavery	3 625	3 000	2 375	1 750
Apothecary	3 625	3 000	2 500	2 000
Furnisher	6 750	5 500	4 167	3 000
Fort / Palace	5 500			

**Table 1.2:** Baseline rent for shoppes, stalls, forts, and palaces (100)

Base tax	
Explorer's hall	5 000
Trading post	3 000
Black market	3 000

**Table 1.3:** Baseline tax table (100)

At a population less or equal to 250, the tax is computed using the following formula:

$$rent = \left( 0.25 + 0.75 \cdot \frac{island\_population}{250} \right) \cdot baseline\_rent \quad (1.1)$$

### 1.1.4 Currency

There are two types: Pieces of Eight (PoE) and doubloons.

PoE is the basic currency of Puzzle Pirates, players can earn them by completing various tasks and spending them on different items. The purchasing power of PoE fluctuates over time, this is not done by the developers, but by the game's economy reacting to variances in the money supply. PoE and doubloons can be exchanged for each other in a bank between two players. The player making the offer sets a rate. (97)

Doubloons are inserted into the game by real money purchases or sponsored tournaments. They are primarily used as a delivery cost, a fee required to pick up items in a shoppe. Doubloons are also required for setting up a crew, shoppe, or purchasing items in a palace shoppe, where players can earn different cosmetic items, pets, and badges, which enable users to do various tasks. Once a doubloon is spent, it disappears from the economy, unlike PoE, which usually transfers to another player. (93)

### 1.1.5 Commodities

Commodities are items that can be used in a shoppe or stall with labor to produce other items. Commodities never decay. They are divided into two categories: raw, refined, and finished. Raw commodities can be obtained at commodities markets, by pillaging merchants, or by setting a competitive buy price in the shoppe or stall. Most of them consist of materials spawned by the game itself. They include Basic commodities (Hemp, Hemp oil, Iron, Kraken's ink, Lacquer, Stone, Sugar cane, Varnish, Wood), various Herbs, Minerals, Fruits and Gems.

Refined commodities are manufactured commodities that can be further processed. By processing a commodity, it disappears, and a new different commodity is created. They consist of Ship supplies, Cloth, Dyes, Enamels, and Paints. Ship supplies are rum, cannon balls, and lifeboats. When a ship is sailing, each pirate consumes a certain amount of rum depending on the time spent at sea. Running out of rum will result in a gradual drop in the efficiency of his ability to work and fight. There are three types of rum, which, ranked from worst to best, are: swill, grog, and fine rum. The better the quality, the longer the rum lasts. Cannon balls are used during sea battles. There are small, medium, and large cannon balls. The bigger the cannon ball is, the bigger the damage it deals. Every ship has a certain "Gun size", which determines the size of the cannon ball it can fire. Lifeboats are used for Kraken hunts (a type of Sea Monster Hunt where pirates smuggle out valuable treasure chests including Kraken's eggs and Kraken's ink). There must be one lifeboat per entry. Ship supplies disappear from the economy by usage.

Commodities cannot be held in a player's inventory, they have to be in a building or a ship. They can be moved from island to island only with a ship.

Individual players cannot craft items from commodities on their own, items can be crafted and purchased from a shoppe, or a stall (a mini-shoppe). Crafting items in a shoppe requires labor that is done by players. On Doubloon Oceans, a labor badge is needed for labor. Shoppe owners can hire players to do labor and set a wage. There are three grades of labor: basic, skilled, and expert. The better the grade, the faster it takes to craft an item. The grade of labor is dependent on the player's performance during labor-associated puzzles.

An item's price is influenced by the materials that were used to craft it. For example, a gold-coloured shirt can cost more than a blue shirt.

Commodities are removed from the economy by sinking a ship that held them during a blockade or while attacking a flotilla. Or by a Black ship, which is a very strong NPC that sometimes punishes ships that are attacking a significantly weaker ship.

When a player loses against an NPC, it takes 10% of the commodities and 20% of PoE stored in the player's ship. In a PvP <sup>1</sup> scenario, the winning side takes 25% of commodities and 50% of PoE. (91) (92)

### 1.1.6 Economy

The economy of Puzzle Pirates is almost fully player-driven, where players can own various commodities and items and trade them among themselves. Shoppe owners need commodities to make a product that they can sell and players need easy access to items needed for their voyages. Usually, players get commodities from pillaging or foraging and then sell them on an island. Players can also make money by purchasing a commodity at a certain island and then selling it on another island for a higher price. But they risk being attacked by other players or NPCs while travelling between the islands.

When ordering commodities or items in a shoppe, a sales tax is paid in addition to the normal cost of the order. Sales tax is calculated by adding up the tax value of the commodities used in crafting the product. 90% of the sales tax is sunk, and the remaining 10% goes to the palace. The shopkeeper does not get any money from the tax.

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<sup>1</sup>PvP (Player versus player) is a type of multiplayer interactive conflict within a game between human players (88)

## 1. ANALYSIS

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The tax value of a commodity is changed dynamically by the system and drives the dynamic spawn of commodities. The sales tax's primary effect is to make the price of an item the same, regardless of where it was produced or purchased.

PoE enters the economy from PoE fountains. The PoE fountains are loot from non-player enemies, rewards for completing navy missions, selling commodities obtained by foraging uncolonized islands, prize money from sponsored tournaments, bounties issued for sinking non-player enemies and treasure chests found on the bottom of the sea. PoE circulates within the economy between players by trading, laboring, purchases and other activities.

Doubloons enter the economy mainly by real-money purchases and once used, they disappear from it. To do crafting (which is needed for labor) and multiplayer puzzles, players need to own an appropriate badge that costs doubloons, but each day there are some puzzles free to play for everyone. There are certain free puzzles for each day of the week.

Commodities enter the economy from foraging uncolonized islands and from merchant brigands. Merchant brigands are NPCs that spawn on uncolonized islands, gather commodities, and sail them to colonized islands. They sell them to shoppes and stalls randomly selected from all the highest listed buying prices. Commodities circulate within the economy mainly by trading between players and pillaging other players.

Commodities are used for crafting an item in a shoppe. Certain items can decay after a set amount of time, that is called a decay rate. Different items have different decay rates. Once an item is decayed, it is removed from the game. This forces players to collect commodities for a new item, or outright buy the item again, thus passing resources and money on in the economic cycle.

Apothecary produces a Whisking potion, that lets the player teleport to an island and has several charges (when depleted, it is no longer usable), Appearance altering potion, dyes, some refined commodities, paint and a paintbrush. Paintbrush is the only item that decays. The whisking potion also costs doubloons, this can force players to sail instead of buying the potion.

Distillery mainly produces rum and mugs. Mugs decay gradually after 60 login days and provide certain advantages while playing a Drinking game puzzle.

Furnisher provides players with furniture, that is used to customize the appearance of any building or ship. Furniture decays each time it is moved from one place to another. After it decays it disappears. Wardrobes, sword racks and bludgeon trunks will halt the decay of stored items.

Iron monger produces swords and cannon balls. Swords are used in any kind of battle (sea battles, swordfights, brawls, ...). Every sword has its damage values and sword patterns, that are used when playing the battle puzzle. Swords decay with time but can be stored in a sword rack. They still need to be used in battle, therefore ensuring they will decay for at least a day because players will equip them before combat.

Shipyards provide players with Ships, Bludgeons, Lifeboats and charts. Each ship has different mass, cannon sizes, speed and capacity of pirates, duty stations and commodities it can carry. Ships don't decay, but every ship has some amount of HP, when that reaches zero, all the commodities and PoEs stored in the ship get lost forever. When a ship loses its HP during a blockade, flotilla battle, imperial outpost attack, sea monster hunt, or a battle with a ship under a warring flag, it sinks. In other cases, the ship is teleported to a port.

When the ship sinks, the owner of the ship receives an item that decays after 60 days. This item can be used in the shipyard to restore the ship for the cost of a new ship of the same base type. This process also restores all furniture placed in the ship before sinking. Bludgeons are weapons used in the Rumble puzzle, which is another type of puzzle for battle. Similarly to swords, they each have their stats and patterns. All bludgeons decay but can be placed in a bludgeon trunk to halt the decay. Lifeboats are used for Kraken hunts and are destroyed upon usage.

Every ship has a mass (in kg) and a volume (in liters) value. The total mass or volume of the commodities inside a ship cannot exceed this value.

## 1. ANALYSIS

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Ship Name	Pirates	Sails	Carp	Bilge	Guns	Gun Size	Shots	Mass	Volume
Sloop	7	3	2	2	1	small	4	13,500	20,250
Cutter	12	5	3	2	2	small	8	40,500	60,750
Dhow	12	5	3	2	1	medium	4	13,500	20,250
Fanchuan	12	5	3	2	1	large	4	13,500	20,250
Longship	15	5	3	3	3	small	12	13,500	20,250
Baghlah	18	6	4	4	3	medium	12	18,000	27,000
Junk	18	6	4	4	3	large	12	18,000	27,000
Merchant brig	20	6	9	6	2	medium	8	90,000	135,000
War brig	30	9	6	4	4	medium	16	54,000	81,000
Merchant galleon	30	9	14	14	3	large	12	270,000	405,000
War galleon	40	12	8	7	6	large	24	90,000	135,000
Xebec	45	14	9	8	6	medium	24	121,500	182,250
War frigate	75	18	18	12	6	large	24	216,000	324,000
Grand frigate	159	30	24	16	6	large	24	540,000	810,000

**Table 1.4:** Table of different boat types (98)

Tailor produces clothing for players. The clothing's only purpose is to visibly change the appearance of the player's in-game avatar. Players can intimidate others by wearing expensive clothing, made with an expensive colour. Every type of clothing decays at a certain rate, this can be stopped by putting it in a wardrobe.

Weavery produces cloth used to make clothing.

PoE disappears from the economy via PoE sinks, such as different fees or taxes, rent, some purchases, losing bets to NPCs, sinking a ship and being pillaged by NPCs. (94) (99)

Puzzle Pirates' economy is based on supply and demand. Each player acts as a supplier, making decisions on how much of a commodity to produce and sell based on prevailing prices. The law of supply is evident as players weigh the benefits and costs of producing more items. If the virtual economy rewards players with sufficient in-game currency for producing and selling items, they are likely to increase their production. However, just as in the real-world economy, they are also increasing marginal costs associated with spending more time on production.

If multiple players are involved in producing and selling the same commodity, their combined output forms the market supply at a given price. An increase in the price offered for a commodity may lead to more players participating in production. On the demand side, players act as consumers in Puzzle Pirates, seeking to purchase items for their voyages or other in-game needs. Overall, the economic dynamics in Puzzle Pirates mirror real-world economic principles.

(60)

## 1.2 Albion Online

### 1.2.1 Overview

Albion Online is a sandbox MMORPG developed by Sandbox Interactive and released in 2017. The game's main features are a player-driven economy and a classless system. Unlike most MMORPG games, a player's abilities and fighting style are determined by his equipment, rather than by a class.

The most common way for a player to make a profit is to gather resources, refine resources, craft items, find the town with the biggest selling price and travel there with the goods while risking ambush from other players.

### 1.2.2 World Map

Albion Online has four types of regions: Safe, Yellow, Red, and Black. When a player loses a battle in Safe or Yellow regions, they are knocked down and all of his equipable items lose 5% durability. After a short period, the player will get up in the same position they were knocked. Losing a battle in the Red and Black region means that the player will drop all equipped items in their inventory and respawn at the last visited city or hideout.

Safe regions are designated for activities like gathering, crafting, or trading. They offer low risk, but also low reward. Players don't have to be afraid of being attacked by other players or NPCs. Only players that are a part of a warring faction can engage in combat. Resources up to tier four can spawn in a safe region.

Yellow regions are for moderate-risk activities such as trading, gathering, and PvP combat. Resources up to tier five can spawn in a yellow region.

Both Red regions and Black regions are high-risk, high-reward areas. They feature boss fights and various dungeons. Resources up to tier eight can spawn in a black region and up to tier seven in a red region.

Every region has a biome, that determines which resources are available in the region and which enemies roam there. There are Forest, Highlands, Mountain, Steppe and Swamp biomes. (16)



Forest	<b>Wood</b> , Hide, Stone
Highland	<b>Stone</b> , Ore, Wood
Mountain	<b>Ore</b> , Stone, Fiber
Steppe	<b>Hide</b> , Fiber, Ore
Swamp	<b>Fiber</b> , Wood, Hide

**Table 1.5:** Various Biomes and their resources. The resources that are highlighted are found in greater quantities in this biome compared to the other listed resources. (5)

### 1.2.3 Cities

There are 11 cities in the world of Albion Online, five Starter Towns, five Royal Cities and one capital city called Caerleon. All major cities contain preexisting buildings.

There is a Starter Town for each biome. It offers players various buildings that can craft weapons and equipment and refine resources up to tier three. These buildings do not belong to players, so they are free to use. There is also a Repair Station, a local Marketplace, and a bank.

Every Royal City has a local Bank, local Marketplace, a local Island Merchant, and 80 Building Plots. Players can buy a building plot and construct other types of buildings. When other players use those buildings, they must pay a usage fee that is set by the owner.

Caerleon has a local Bank, local Marketplace, a local Island Merchant, a unique Black Market, and 118 Building Plots. It is surrounded by Red regions, making the way to Caerleon very difficult and rewarding. Caerleon offers the fastest way to cross the map and its proximity to all biomes makes it the strongest economic hub of Albion Online. (7) (15)

### 1.2.4 Resources

Resources are materials that are gathered from the environment or skinning animals. They are used to create weapons, armour and buildings. Gatherable resources are Fiber, Hide, Ore, Wood, and Stone. Their refined counterparts are Cloth, Leather, Metal, Plank, and Brick. Before a resource can be used in crafting, it must be refined in its corresponding building. Refining transforms gatherable resources into refined resources.

## 1. ANALYSIS

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They are divided into eight tiers and tier four – eight resources may be found in normal, uncommon, rare, or exceptional qualities. A tool of the same tier or higher as the resource must be used to harvest it.

Resource nodes are interactible objects, from which players can gather resources. Their spawn point is stationary for one day, after that it is randomly selected from potential spawn locations. There are normal nodes and plentiful nodes. Plentiful nodes contain significantly more resources than normal nodes. The resources recharge slowly throughout the day. The bigger the tier of the resource is, the slower it recharges.

All resources can spawn enchanted (uncommon, rare, or exceptional). Weapons and armour crafted with enchanted fiber, hide, ore, or wood will be stronger.

Players can purchase islands to construct unique buildings not found in cities. Player Islands are only accessible to the owning player and others they allow to visit, it cannot be contested for ownership. They also provide the player with the ability to farm (which can be built only on an island), raise animals, refine resources, and craft armour. Farming allows players to plant seeds bought from an NPC or a Market Place to grow crops, that are used to craft food. Food serves for Nutrition and player buffs. Nutrition is needed to maintain guild territories and buildings. Every building has a favorite food, that doubles the nutrition gain. The amount of nutrition that a territory or building needs depends on its tier. A player buff is given to a player who consumes food, it lasts 30 minutes and the type and potency of the buff is determined by the type and tier of the consumed food. For example, a Sandwich increases maximum health, healing received, and crowd control duration. (8) (13)

### **1.2.5 Currency**

There are two types of currency in Albion Online, silver and gold. Silver can be used to buy Gold and Gold to buy Silver.

Silver is the primary in-game currency, it is used for everything except purchasing cosmetic items. Players get silver for various activities, including combat, trading, completing dungeons, etc. (14)

Gold is used to purchase a Premium account (which gives players several benefits allowing faster progression) and to obtain cosmetic items. To obtain an island, players must possess a Premium account. Once the purchase is complete, they can use the island, regardless of their Premium status. When gold is used, it disappears from the economy. Unlike silver, gold cannot be lost or stored in banks. Gold can be purchased with real money or traded using silver in the Gold Market. (9)

The Gold Market is a place for trading silver and gold. Players can buy or sell gold immediately for the current amount of silver worth, or place buy orders to set their price. Buy and sell orders have a fee of 10 silver.

### **1.2.6 Items**

Most items have durability, that decreases as the item takes damage or is used, and an item power. Durability is expressed in percentages, new items have 100% durability. If an item's durability reaches 0%, it becomes trash (a useless item) and cannot be repaired. Item power is a number that scales up the base attributes of the item, it is mainly used as a measurement of the item's strength. The item power is determined by four factors, tier, type, enchantment and quality. When an item's durability decreases, item power also decreases. (10)

### **1.2.7 Buildings**

Buildings are structures used for refining resources, crafting equipment and improving item storage capacity. All major cities contain preexisting buildings and some can contain player buildings. Both preexisting and player-made buildings can be owned by players. The owner of a building can set a usage fee and an associate's fee. Usage fee is paid by other players using the building. The owner of the building can set players or guilds as associates and set a different fee for them.

Among buildings that are used for crafting and refining, there is a Repair station. It allows players to repair their items, salvage them for resources or improve the item's quality for a Silver fee. The Repair Station only repairs items that are the same tier as the Repair Station or lower. Item quality does not affect the repair cost. The repair cost increases with both the item's tier and its lack of durability.

If a player wishes to store an item to prevent losing it on his travels, they can use a bank. All banks are zone-specific and not shared globally, meaning that the player cannot access his items in a bank in another town. Players can buy tabs for silver, to organize and enlarge storage space in banks. There are two types of tabs, private and general. The private tab cannot be shared between players, unlike the general tab. (6)

### 1.2.8 Economy

There is no global marketplace. Players have to travel and explore various buying and selling prices so they can make a profit. All cities have a marketplace, where players can buy or sell items. If a player wants to sell an item, it must have 100% durability. Players are charged for using the marketplace, and a 2.5% setup fee is paid instantly any time a player places or updates an order. A transaction tax of 8% is paid when you successfully sell an item, and players with a premium pay only 4%. Apart from orders made by players, there are a few orders made by the system, for example, the Black Market is a specialized marketplace that has system-generated orders for various combat equipment.

Silver can be obtained by defeating NPCs, duelling, finding treasures, completing dungeons, and going on expeditions, and it can be transferred among players by selling resources and items in the marketplace. Silver disappears from the economy through various taxes.

Gold can be purchased with real money or with silver. When it is spent, it disappears from the economy.

Resources are introduced to the economy via resource nodes. They can be refined and used to craft an item or a building, or sold in the marketplace. When a player dies, they drop all of his items and resources. There is a 30% chance that an item will turn into trash. All dropped items incur a durability loss, that scales with the number of attackers. Items are removed from the economy by turning them into trash. (11) (12)

## 1.3 Factorio

### 1.3.1 Overview

Factorio is a single-player sci-fi sandbox game released in 2016 by Wube Software LTD. It is a game in which player can build, maintain, and mainly automate factories. Factorio can be played alone or with friends in cooperative multiplayer. There are multiple different game scenarios (Wave defence, Supply challenge, Team production, etc.) but Freeplay is the main and intended way of playing. In Freeplay, the main goal is to launch a rocket into space. Factorio does not have any type of currency, it is mainly about crafting and resource management, where players create complex production systems. (29)

### 1.3.2 Resources

There are seven basic resources in Factorio, coal, copper ore, iron ore, raw fish, stone, uranium ore, and wood. Player can get resources either by mining them or using automatic drills. Wood and Coal are the only basic resources that can also be used as fuel. Wood is the only crafting material that cannot be harvested or produced using automation. Resources can be transported using Inserters over short distances, usually to a transport belt or a train. Resources can be crafted into materials and crafting components, that are then used for crafting final products.

A special kind of resource is fluid, such as water and oil. Fluid can only exist inside entities for fluid handling, such as pipes, barrels, and various structures used for their refinement.

Structures such as mining drills, Offshore pumps, and Pumpjack are used for resource extraction. Furnaces are used to process raw minerals to their base metal. Oil refineries and Chemical plants can process fluids, and Centrifuge can process uranium ore.

Most structures run on electricity, which can be produced from multiple different sources. The player can build an offshore pump near water and connect it using pipes with boilers (that run on coal) and steam engines to produce electricity. Solar panels are effective during the day, but their production will drop at night. Additionally, uranium can be processed to create uranium fuel cells, which are then burned in a nuclear reactor to generate heat that is used to convert water to steam and transfer it to steam turbines.

All resources are found in finite groups, that will run out eventually. However, the map is almost infinite (four trillion square tiles, where one tile represents one meter), which means that almost infinite groups of resources may be found. This also means that new resources are always further away from the player's factory, forcing the player to build a train system or make necessary adjustments. (26) (32)

### **1.3.3 Crafting**

Most crafting can be done by the player, especially at the beginning of the game. As the player progresses, some products require items that must be crafted using automated crafting. Player can craft one item at a time. The more advanced or expensive an item is, the longer it takes to craft. Automated crafting is done outside of the player, allowing multiple products to be crafted at once. Structures used for automated crafting are Assembling machines, that can be set to craft one specific item. Once the required resources are supplied to the Assembling machine, it takes a set amount of time to craft the product. The crafting speed is determined by the type of Assembling machine and final product. (27)

### **1.3.4 Research**

Research is used to unlock new structures, technologies, and various bonuses. It is performed by structures called labs. Research is done by providing labs with different types of science packs, which the labs consume. The player can choose what technology they want to research, but some technologies require prior research of other technologies. While most technologies can be researched either once, or a small amount of times, few are infinite, meaning the player can research them over and over again. For example, artillery shell range can be extended infinitely. More advanced Technologies require more advanced science packs, that are harder to craft. To make research progress smoothly, players need to automate their crafting. The rocket silo technology, which is at the end of an extensive research tree, is the final requirement for winning the game. (33) (34)

### 1.3.5 Pollution

Many structures involved in processing items produce some amount of pollution. The larger the factory becomes, the greater the level of pollution it generates. A small portion of pollution can be absorbed by the environment (trees, grass, sand, etc.). The amount of pollution affects the evolution of Biters and Spitters, enemy entities that want to harm the player. Biters and Splitters undergo four evolutions, with each one being stronger than the previous. They are periodically spawned by their nests. Every 4-60 minutes, a group of biters/spitters will leave their base to create a new base, this happens globally. Player can destroy an enemy base by destroying all nests. When a nest is exposed to pollution, it will absorb a great amount of the pollution and assign enemies to attack the player. Every 1-10 minutes, enemies that are assigned will attack the factory or the player. This forces the player to invest in various weapons, armour, automated turrets, ammunition, and walls to protect his base.

Every structure has some amount of health, when an enemy decreases the structure's health to zero, it is destroyed, meaning a new structure has to be built in its place. When a player is killed they will left behind a corpse containing all items in his inventory and respawn 10 seconds at the center of the world. The player's corpse lasts 15 minutes, after that, it disappears. (31)  
(28) (30)





## Economic system

In this chapter, we define the economic system of the game while focusing on item types, item fountains/sinks, and the game's gathering, crafting and trading mechanics.

### 2.1 Economy diagram

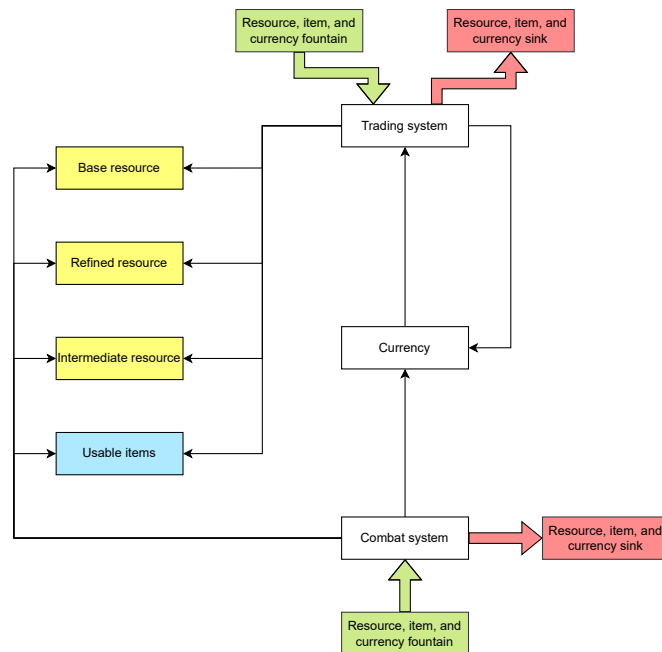


Figure 2.1: Economic diagram focused on combat and trading system

## 2. ECONOMIC SYSTEM

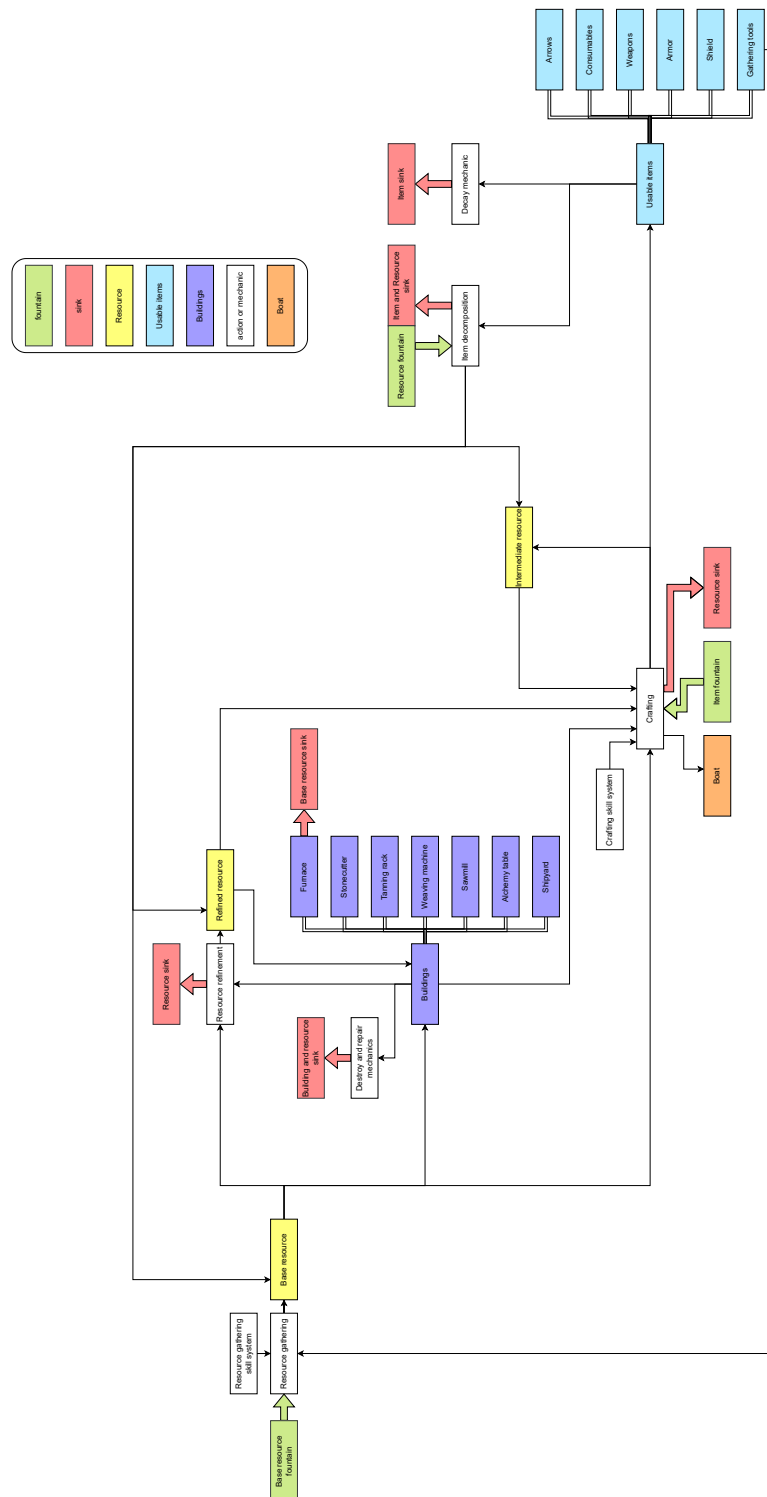


Figure 2.2: Base economic diagram

## 2.2 Skills

Player can have certain skills in both resource gathering and crafting. There are three levels, inexperienced, proficient, and masterful. Players begin with an inexperienced skill level and increase their skill by engaging in actions associated with that skill (e.g., crafting to enhance their crafting skill). Resource gathering skill affects the player's gathering speed and Crafting skill defines the stats of the crafted item.

## 2.3 Resources

Base resources can be collected from their designated spawn locations, and they automatically replenish after a certain amount of time has passed. They can be refined in the corresponding buildings. The refining process incorporates a ratio that determines the quantity of base resources lost. For instance, when refining wood using a 2:1 ratio, two units of wood are transformed into one plank.

Resource	Spawn	Refined	Refinement or crafting structures
Wood	Tree	Plank	Sawmill
Stone	Boulder	Stone Block	Stonecutter
Iron ore	Iron stone	Iron	Furnace
Fiber	Fiber crop	Cloth	Weaving machine
Hide	Animal	Leather	Tanning rack
Coal	Coal stone	-	-
Herb	Bush	-	Alchemy table

**Table 2.1:** Base resources, their spawn, refined counterpart, and structure

Intermediate resources are acquired through crafting and serve as essential components for crafting final items. For example, sticks, crafted from wood, can be used to craft a weapon or a tool.

Wood, Stone, Iron ore, Fiber, and Hide are used mainly for crafting. Coal and Wood can be used to fuel the Furnace, doing so will sink the resource. Herbs can be used to heal the player.

### 2.4 Buildings

There are five refinement structures: Sawmill, Stonecutter, Furnace, Weaving machine, and Tanning rack. Among the other buildings, there is the Alchemy Table, used for crafting potions from herbs, and the Shipyard, a structure specifically designed for crafting a boat, which is needed to complete the game. Each building has a designated construction site on the map. To build a building, the player must provide the construction site with a variety of resources. Each building has its own set of resources needed for its creation. Buildings have a set amount of HP, when it reaches zero, it is destroyed, with the construction site of that building taking its place. Damaged buildings can be repaired using resources. The type of resources are determined by the type of resources used to build the damaged building, and the amount of the resources depends on how much the building is damaged.

### 2.5 Crafting

Crafting can be used to transform resources into either intermediate resources or final items. Players can craft items through structures that can craft any item requiring resources associated with that particular structure. The only exception is the Shipyard. All items have 100 durability when crafted. If an item reaches zero durability, it is destroyed and disappears from the economy. Items can also be decomposed, this will destroy the item and provide the player with a reduced quantity of resources used in crafting that item. The rate of reduction is influenced by the durability of the item. There are five types of items, Gathering tools, Weapons, Armor, Shield And Consumables.

Gathering tools affects the amount of resources a player can gather. A tool loses durability each time the player gathers resources corresponding to the tool.

The goal of the game is to craft a ship, which is a unique item that needs a great amount of resources. To achieve this goal, the player must utilize all available refining buildings.

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Resource	Gathering tool
Wood	Axe
Stone	Hammer
Iron ore	Pickaxe
Fiber	Sickle
Hide	Knife
Coal	Pickaxe
Herb	-

**Table 2.2:** Basic resources and their corresponding gathering tools

Weapons are used in combat to deal damage to enemies. There are melee and range weapons. A melee weapon loses durability when the player strikes an enemy with it. Range weapons lose durability by firing projectiles. Melee weapons are a sword and spear, and range weapon is a bow. Swords and spears can be either wooden or iron. The bow needs arrows to deal damage. Each time a bow is fired, the arrow it releases is consumed upon impact.

Armor makes player more resilient to enemy attacks by reducing incoming damage by a certain percentage. It gradually loses durability as it absorbs damage. There are three types of armor, cloth, leather, and iron armor.

The shield can be used to completely deflect attacks, but it loses durability with use. There is a wooden shield and an iron shield.

Consumables are crafted using herbs, they can heal the player, and they disappear upon usage.

## 2. ECONOMIC SYSTEM

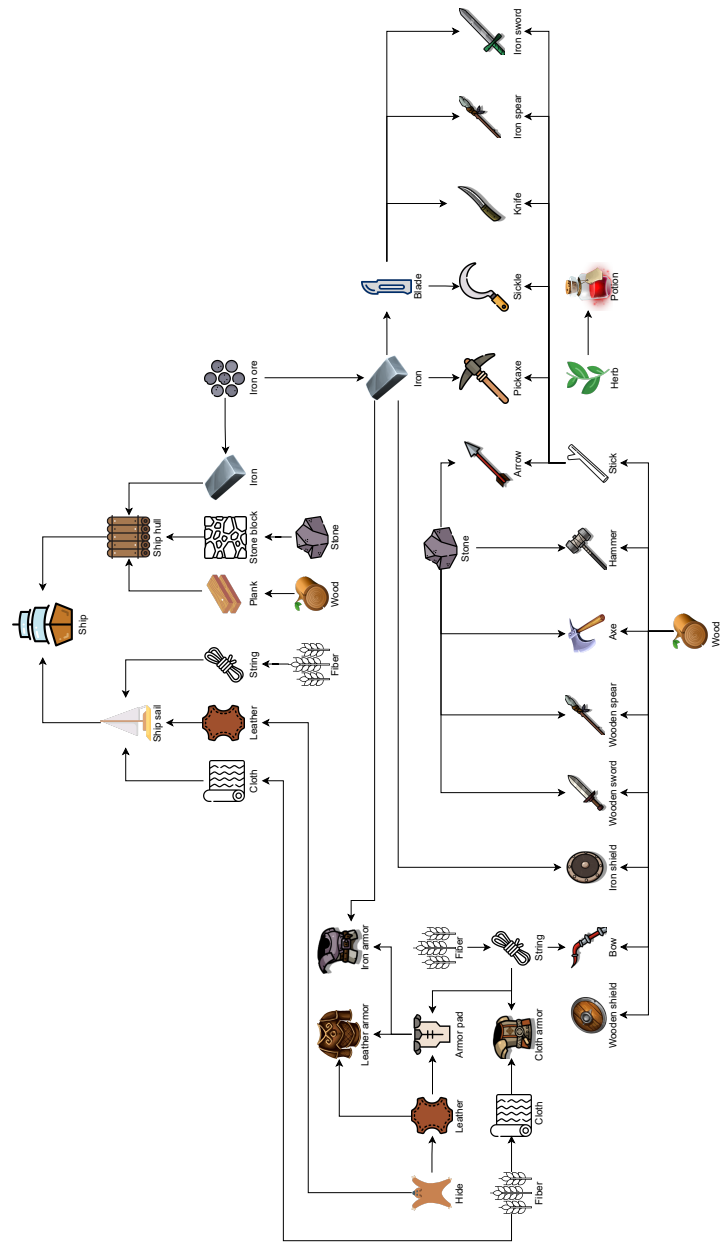


Figure 2.3: Crafting tree

## 2.6 Combat & Trading

Enemies periodically appear and attack the player. If they cannot locate the player, they will attack the nearest structure. Upon defeat, they may drop money and resources. When they defeat the player, the player's corpse will appear at the location of their demise, and the player must wait for some time before respawning. The player's corpse has a predetermined time limit before it disappears, along with everything the player had in their inventory. Money can be used for trading, which lets the player buy base/refined/intermediate resources and items. Trading is not available at all times, a merchant will periodically visit the player, providing an opportunity for trade. The player can also sell their items and resources in exchange for money.

## 2.7 Economy

The player holds every item and resource in their inventory, which has a limited capacity.

Currency enters the economy by defeating enemies and leaves the economy either through the player's corpse vanishing or trading.

Base resources enter the economy via their spawns, by trading, or by defeating enemies. They can be refined into refined resources and crafted into Intermediate resources. They are used to craft items and build buildings. Intermediate and refined resources may also enter the economy through combat and trading. Resources disappear from the economy by refinement, item decomposition, usage as fuel, and the player's corpse vanishing.

Items enter the economy by crafting, trading, and defeating enemies. They are removed from the economy by decaying, decomposing, and the player's corpse vanishing.





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## Non-economic aspects of the game

In this chapter, we define the non-economic systems of the game such as combat, locomotion, distribution of gathering resources, and various mini-games.

### 3.1 Concept

It is a single-player 3D top-down game taking on a deserted island. The goal of the game is to build a ship. The player must gather resources, build structures, refine materials, craft items, trade, and withstand increasingly challenging enemy raids. The game features minimalistic, low-poly, and cartoonish graphics.

### 3.2 Combat

The combat is real-time, meaning that actions, like an attack, are performed in real-time rather than a turn. Each action has an associated execution time and a recharge time. The player must wait for both times to elapse to perform another action. There are two main combat actions: attack with a weapon and defend with a shield. Both player and enemies wielding melee weapons have an attack range in front of them. When they initiate an attack, every entity within that range is affected.

If they have a bow, their attack launches an arrow in a straight line, hitting any entity it collides with. The defence action nullifies all damage received within a brief period immediately after its activation.

## 3.3 Locomotion

The player has only two movement options: walk and dash. Dash is a short and quick burst of movement in a specific direction. It can be used in combat to evade an attack. Dash has a cooldown that prevents the player from using it in quick succession. The player can navigate in all directions. The game can be played on a mouse and keyboard and on a controller.

## 3.4 Distribution of gathering resources

All base resources have their spawn location. When a spawn location is ready, it can be used to gather resources. The amount of resources gathered is affected by the player's gathering tool, and the gathering speed is affected by the player's gathering skill. Spawn locations automatically replenish after a certain amount of time has passed. Base resources can be refined in structures into refined resources. Base and refined resources can be used to craft items, or build structures.

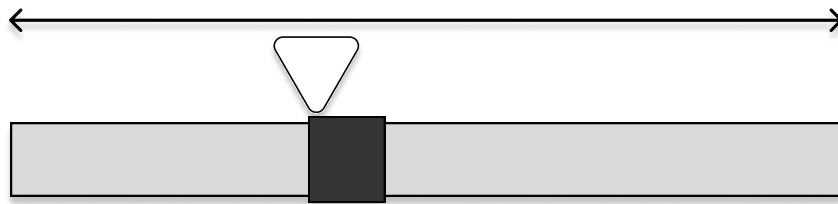
## 3.5 Mini-games

When a player starts to gather base resources, a mini-game starts. Every base resource, except for a herb, has its mini-game that must be completed to gather the resources. The player's gathering skill determines the difficulty of the mini-game. The higher the skill level, the easier the mini-game becomes.

While designing the mini-games, I had to make the goal easily understandable so the player knew what to do and how. The player should also see progress when they do the right thing. Contrary to the unwritten rule that mini-games and puzzles should have increasing difficulty, I implemented the gathering skill system to make the mini-games easier, to reward the player for progressing, and to avoid repetitiveness. (70)

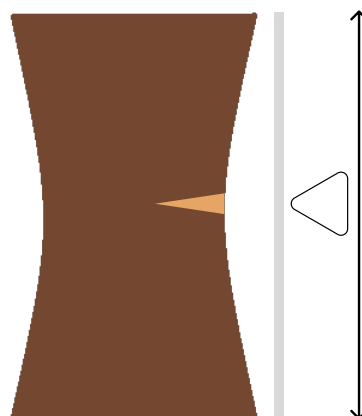
Iron ore and Coal have the same gathering mini-game. A polygon moves along a rectangle from side to side. Somewhere on the rectangle, a small square is positioned. The goal is to press the action button when the polygon is touching

the surface of the square. The required number of successful hits varies based on the player's gathering skill level: three times for an inexperienced level, two times for proficient, and one time for masterful. The square changes its position every time the player fails or succeeds. If the player fails the mini-game, it restarts, resetting the number of successful hits. When a player successfully hits a square, the next square is smaller.



**Figure 3.1:** A visual representation of the mining mini-game

Wood gathering mini-game features a shape representing a trunk of a tree, a rectangle alongside it, and a polygon moving from top to bottom. When the player presses the action button, a cut appears on the tree trunk at the same height as the polygon during the button press. If the action button is pressed at the same position as a cut, the cut grows larger. The goal is to make a cut big enough to cover the width of the tree trunk. The number of hits needed to complete the entire cut varies depending on the player's gathering skill level: four times for an inexperienced level, three times for proficient, and two times for masterful.

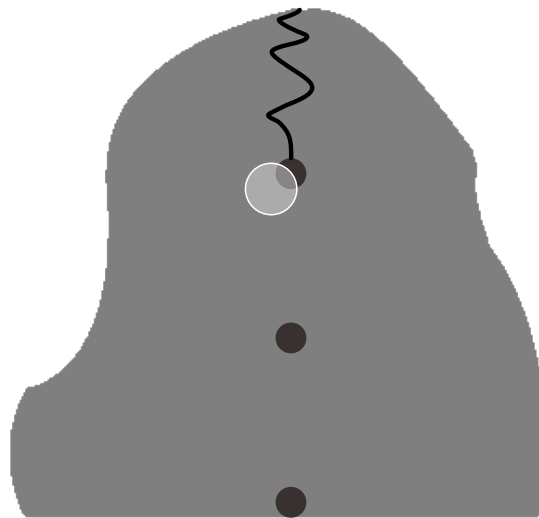


**Figure 3.2:** A visual representation of the wood gathering mini-game

### 3. NON-ECONOMIC ASPECTS OF THE GAME

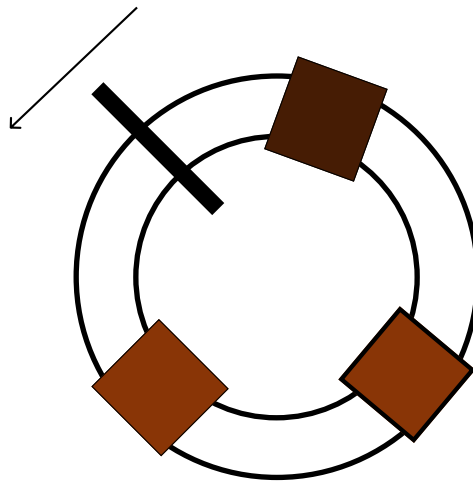
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During the Stone gathering mini-game, there are three chisels placed in a boulder. A white transparent circle, representing a hammer, is controlled with a mouse. The hammer slowly follows the player's mouse and drifts. It never stops moving. Pressing the action button strikes the hammer in the location of the circle. Striking a chisel with a hammer creates a crack that forms from the chisel upwards. The chisel is struck if the circle encompasses any part of the chisel inside it. The strength of a strike depends on how much the circle encompasses the chisel. The goal is to expand the crack to cover the entire height of the boulder. The player must start with the chisel on top and continue downwards. Hitting any part of the boulder without a chisel nearby has no effect. The required number of successful hits on a chisel varies based on the player's gathering skill level and the player's ability to aim the hammer.



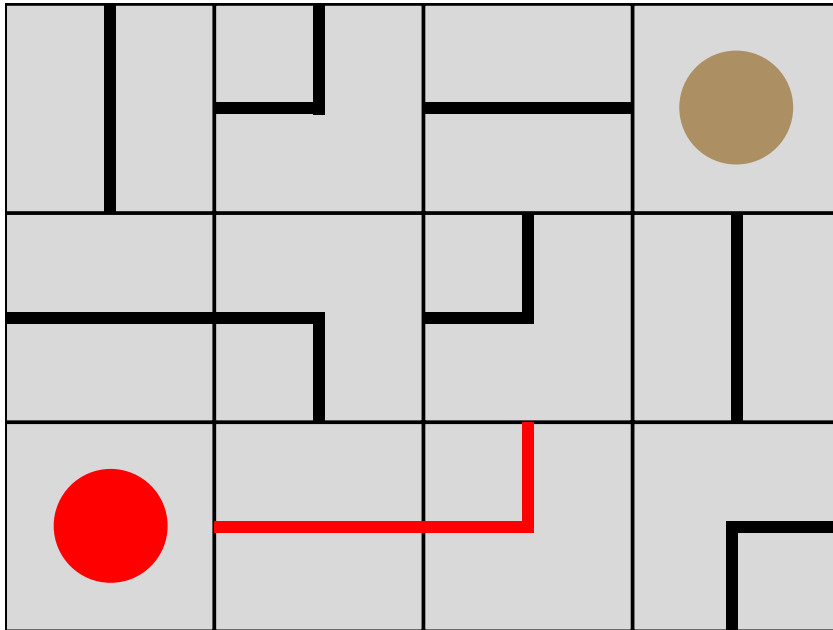
**Figure 3.3:** A visual representation of the stone gathering mini-game

In the Fiber gathering mini-game, there are two concentric circles, a line, and some squares positioned randomly on the circles. The black line quickly moves counterclockwise along the two circles. When the line touches the surface of a square and the action button is pressed, the color of the square dims. The goal is to mark all squares in such a manner. If the action is pressed and the line is not touching any square, all squares that were marked are unmarked. The required number of marked squares varies based on the player's gathering skill level: three for an inexperienced level, two for proficient, and one for masterful.



**Figure 3.4:** A visual representation of the fiber gathering mini-game

The Hide gathering mini-game consists of squares placed on a grid. One of the squares is marked with a red circle, representing the start, and another square is marked with a brown circle, representing the end. Other squares represent various line shapes, that can be rotated by 90 degrees every time the player clicks on them. Every line that is connected to the red circle is colored red. The goal is to connect the two circles using the lines. The size of the grid varies depending on the player's gathering skill level: 4x4 for an inexperienced level, 4x3 for proficient, and 3x3 for masterful.



**Figure 3.5:** A visual representation of the hide gathering mini-game

### 3.6 Sound

The game features a variety of sounds to enhance the gameplay. There are sound effects that represent actions and events in the game, and alert sounds that notify the player of important events, such as the arrival of a trader ship, which is signalled by a whistle sound.

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## Enemy behavior

In this chapter, we will focus on enemy behavior, navigation and spawning logic.

### 4.1 Spawning logic

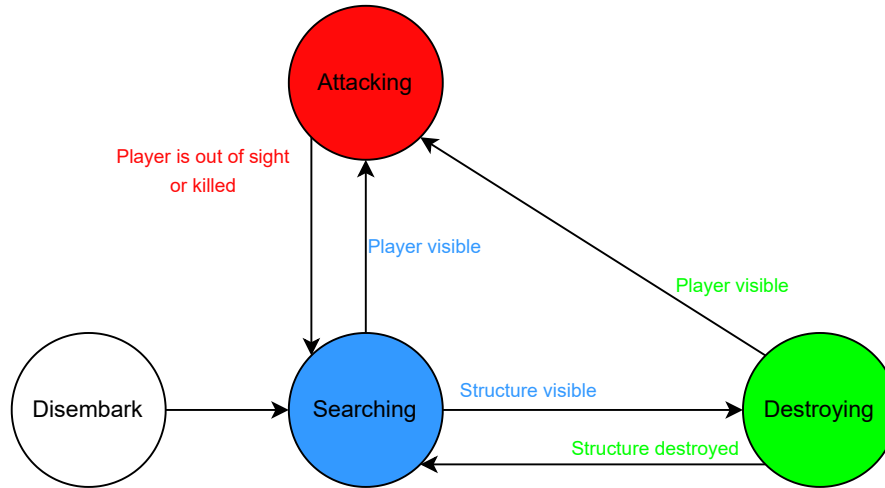
The sea around the player's island is divided into multiple sections. The game keeps track of the overall count of spawned enemy ships and the number of enemy ships spawned inside each section. The spawn point of an enemy ship is selected randomly inside sections that have a low number of spawned ships compared to the overall spawn count. Once an enemy ship spawns, it heads directly in the direction of the island's center. When the ship reaches the island's coast, it stops, several enemies disembark, and the ship leaves.

The number, strength, and HP of the departed enemies increase linearly over time. Thirty percent of the disembarked enemies have ranged weapons, the rest have melee weapons. After enemies have attacked the island, another group can only attack after a certain amount of time has passed.

### 4.2 Behavior

Every enemy periodically checks their distance from all structures and the player. If the player is close enough, the enemy will attack the player. They also have an attack range, that matches the attack range of their weapon, and a small circle encompassing their body used for collision detection.

Enemies have three different states that determine their course of action: searching, attacking, and destroying.



**Figure 4.1:** A state diagram of the enemy behavior

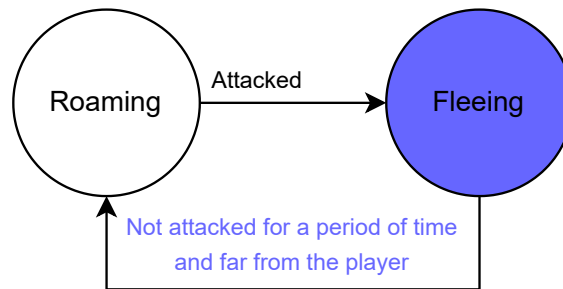
Once enemies disembark from their ship, they enter the searching state. They will each choose the same random direction that would lead them further into the island and start moving in that direction. When they reach the other side of the island, they will once again choose a random direction and head back to the island. If a structure or the player is close to them, they will enter the corresponding state.

Enemies that have the destroying state will move until the structure is in their attack range and attack it. When the structure is destroyed, they go back to the searching state. If they see the player while destroying a structure, they will enter the attacking state.

Enemies with the attacking state move towards the player until he is in their attack range, and then attack the player. If they manage to kill the player, or the player gets out of sight, they will enter the searching state.

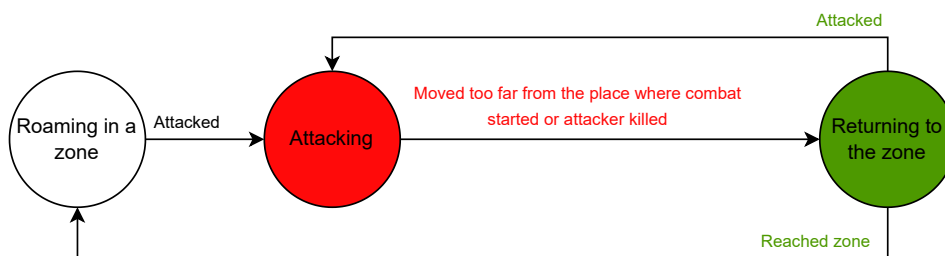


Neutral characters are divided into two groups: natives and animals. Animals roam around the island and start to run away from the player if attacked. Upon escaping the player, they resume their roaming behaviour.



**Figure 4.2:** A state diagram of the animal behavior

Natives also roam in their designated zone and respond defensively when attacked by both the player and enemies. They return to their zone after either defeating the attacker or moving too far from the place where combat started or attacker killed. If they are attacked while returning, they will engage in combat. Wounded native will regain HP while in their zone.



**Figure 4.3:** A state diagram of the native behavior

## 4.3 Navigation

Every non-player entity in the game moves using a Navigation Mesh, a Unity built-in system that represents the walkable areas of the game environment. A NavMesh is created through a process called NavMesh baking, which involves collecting meshes from all non-moving game objects. These meshes, along with the entity size, are used to generate the NavMesh. Unity also provides built-in components like NavMeshAgent to navigate an entity across the scene. The NavMesh ensures that the entity avoids obstacles and moves only where it should.

---

## Procedural generation

This chapter focuses on procedural generation of resource spawn points and environmental objects.

### 5.1 Resource spawn points

The island is separated into four zones: beach, grass, dirt, and yellow grass zone. Every zone has some probability of a resource spawn point spawning into them. Once a zone is selected, the spawn point is placed randomly inside the zone.

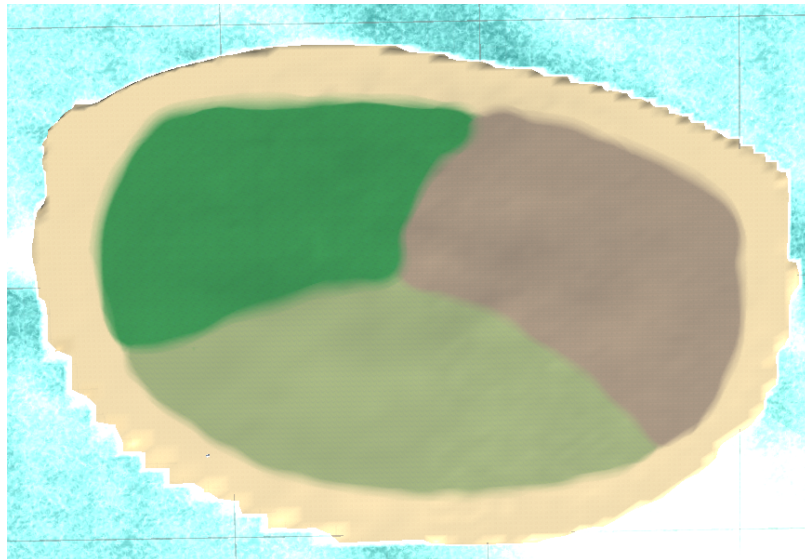


Figure 5.1: Island zones

## 5. PROCEDURAL GENERATION

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There is a set amount of each spawn point that gets placed using the probabilities.

Spawn	Beach zone	Grass zone	Dirt zone	Yellow grass zone
Tree	10%	50%	20%	20%
Boulder	70%	10%	10%	10%
Iron stone	40%	15%	20%	25%
Fiber crop	5%	15%	70%	10%
Animal	10%	10%	10%	70%
Coal stone	10%	10%	40%	40%
Bush	10%	70%	10%	10%

**Table 5.1:** Zone probabilities of a resource spawn

### 5.2 Environmental objects

Environmental objects are placed after resource spawn points. Native zone with natives is placed randomly. The placement of grass is determined by a noise map. A noise map is a type of procedural texture or height map generated using mathematical functions to create patterns that appear random or natural. Rocks are placed randomly while keeping some distance from each other.

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## User interface

In this chapter, we will design a user interface that allows the player to organize their inventory and craft or refine items.

In designing the user interface for a game, it is beneficial to draw inspiration from existing games within the same genre and change it to suit the game.  
(70)

### 6.1 Inventory

The inventory contains everything the player picked up. It has two sections: a grid of squares and an equip section. Each square in the grid can store a limited amount of one item type. The player can move stored items between squares at will. The number of items in a square is displayed in the bottom left corner of each square. In the top right corner, there is a sorting combo box with two options, A-Z and type. The A-Z option sorts the items alphabetically, and the type option sorts the items in this order: Base resource, Refined resource, Intermediate resource, Gathering tool, and Usable item. When a mouse hovers over an item, a window appears with additional information, including the item's name, type, and the item statistics if it is a weapon, tool, shield, or armor. The left side of the inventory lets the player equip items by moving them to the corresponding square. The best available gathering tool is automatically equipped once it is in the inventory.

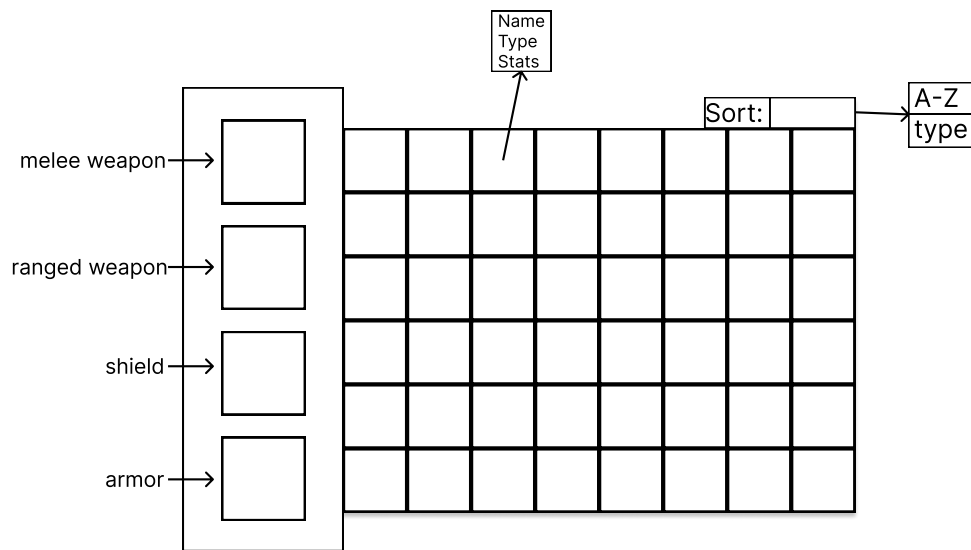


Figure 6.1: Inventory design

## 6.2 Crafting menu

The crafting menu contains a list of items that can be crafted. Upon selecting an item to craft, a crafting tree is displayed. The crafting tree displays all resources along with the required amount. If there is an intermediate product in the crafting recipe, it is displayed as a child node of the final item. If the player has enough resources, the craft button at the bottom becomes available. The resources are removed from the inventory, and the crafted item is transferred into the inventory.

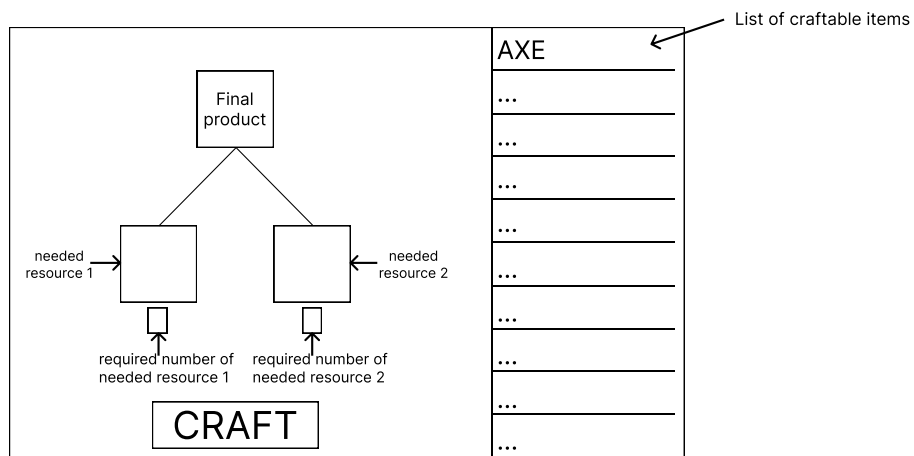


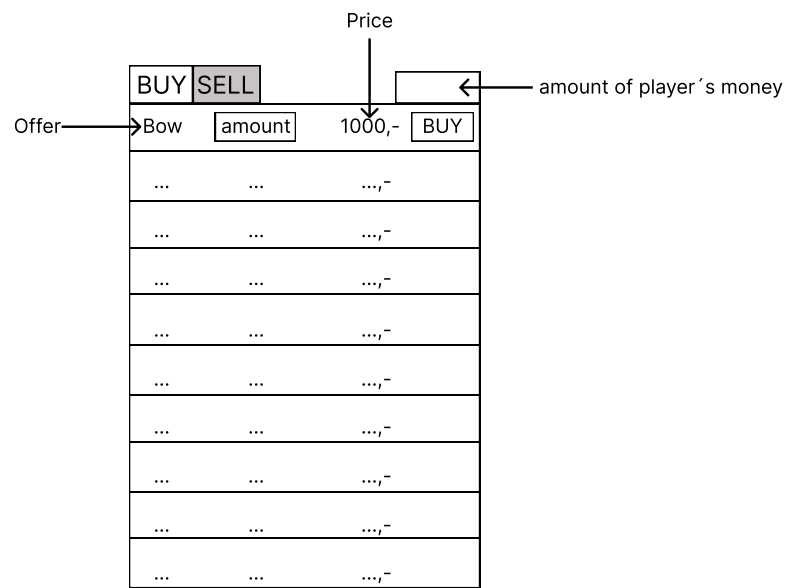
Figure 6.2: Crafting menu design

## 6.3 Trading menu

The trading menu has two sections and each of them consists of a list. There is a trading section and a selling section. The player's current amount of money can be viewed in the top right corner in both sections. Player can set the amount of items and resources they will buy or sell. If the player has enough funds and buys the item, the item is transferred into his inventory, and the cost is subtracted from their money count. If the player sells an item, the item is deleted from his inventory and the cash is added to the player's funds.

## 6. USER INTERFACE

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**Figure 6.3:** Trading menu buying section design

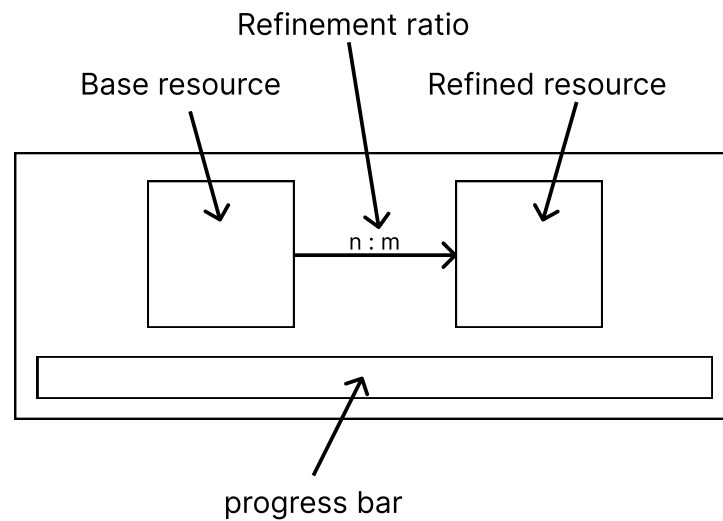


**Figure 6.4:** Trading menu selling section design



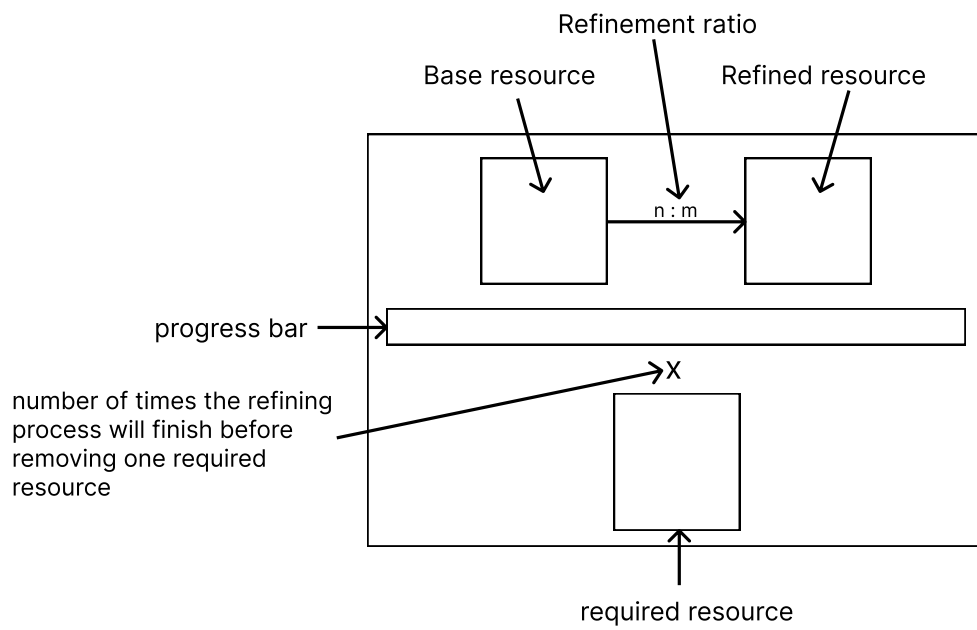
## 6.4 Resource refinement menu

The resource refinement menu has two squares and a progress bar. Player can put their resources in the square on the left and get the corresponding refined resources from the square on the right. Every refining process has its ratio. With a ratio  $n:m$ ,  $n$  resources are removed and  $m$  refined resources are generated. Player has to wait for the progress bar to finish in order to refine resources.



**Figure 6.5:** Refinement menu section design version one

If the refining process requires another resource to complete, the menu will include an additional square for the required resource. For example, the furnace will require both iron ore and coal to make iron. Below the progress bar, there is a number indicating how many refining processes are executed before the required resource count is decreased by one.



**Figure 6.6:** Refinement menu section design version two

## 6.5 Heads-up display

The left down corner of the display is dedicated to a control scheme that shows controls such as attack, defense, and heal. When an enemy attacks, the merchant arrives, or a resource refining process ends, an icon will appear in the direction of the event at the corner of the screen.

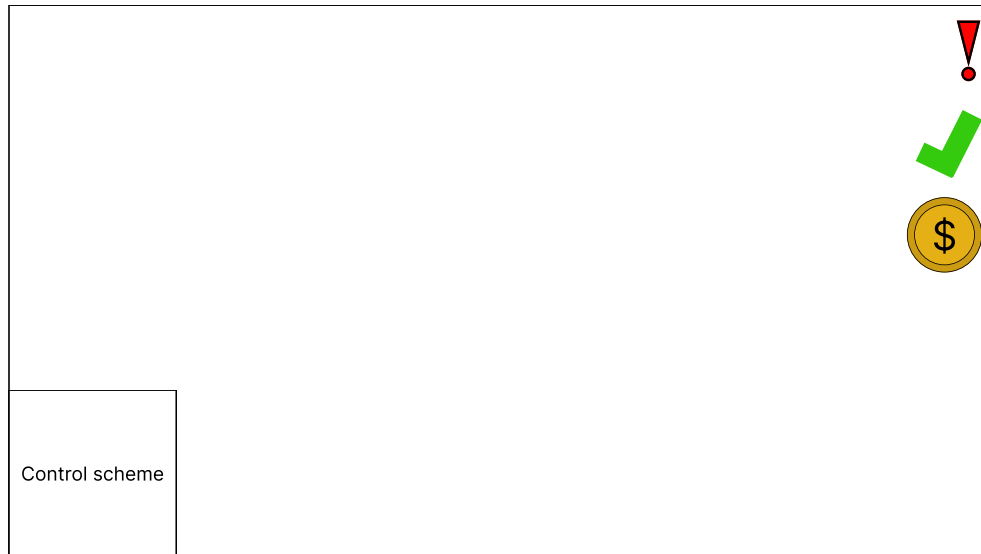


Figure 6.7: HUD design



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## Technology used

This chapter includes technologies used during the development of the game.

### 7.1 Unity

Unity (81) was chosen as the development platform. Unity is a cross-platform game engine developed by Unity Technologies. It has a robust rendering engine, physics simulation, a comprehensive asset pipeline, and a user-friendly integrated development environment. Unity supports a vast ecosystem of plugins and assets, enabling developers to enhance their projects with additional functionalities and resources. (87)

### 7.2 Figma

Figma (35) was used for designing all UI elements, mini-games, and recipe images. It is a browser-based user interface design tool developed by Figma, Inc. It allows multiple users to work on the same design project simultaneously and provides users with the ability to add functionalities including text manipulation, color changes, image adjustments, and animation to their interface assets. (36)

### 7.3 Git

Git (45) was used as the version control system for the game. It is a distributed version control system that is widely used for tracking changes in source code during software development. It was developed by Linus Torvalds in 2005. (86)

### 7.4 Mixamo

Mixamo (2) was used for rigging<sup>2</sup> and animating characters. It is an online platform owned by Adobe that provides 3D characters, automatic rigging tools, and an animation library.

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<sup>2</sup>Rigging is the process of creating a digital skeleton for a 3D model, which allows the model to be animated.

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## Implementation

This chapter depicts some interesting implementations of various game mechanics.

### 8.1 Enemy AI logic

The enemy AI is implemented by using a state machine structure. A state machine consists of a finite number of states, that determine the machine's behaviour. Based on the current state and a provided input, the machine generates output and may transition between states. (3)

Coroutines were used for tasks like periodically checking surroundings, damaging a building, or recharging the enemy's attack. Coroutine allows a program to pause its execution and yield control back to the calling code, while potentially resuming its operation later. (82)

### 8.2 Items and recipes

Items and various crafting recipes are represented by scriptable objects. Scriptable object is a data container that is independent of class instances. This allows for easy creation, modification, and reuse of objects across different parts of the game without directly modifying the code. Scriptable objects can be configured directly through Unity's Inspector and help separate data from the logic.

## 8. IMPLEMENTATION

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Changes to items or recipes can be made at runtime without recompiling the code, which enables dynamic adjustments during gameplay testing. Scriptable objects are also serializable, allowing for easy saving and loading of game data.

(83)



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# Optimization

Adding environmental objects heavily impacted the game's frame rate. To ensure that it runs smoothly, I looked into several optimization techniques within Unity. (69)

## 9.1 Draw call

A draw call tells the graphics API what to draw and how to draw it. Each draw call contains all the information the graphics API needs, such as information about textures, shaders, and buffers. Preparing draw calls is very costly, so the goal is to have as little as possible. (80)

## 9.2 Batching

Batching enables to group objects with the same material<sup>3</sup> into one object and display them with one draw call. Unity merges the different meshes into a single mesh that uses the common material. If the materials do not match but are similar, they can be manually merged into a single one.

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<sup>3</sup>Material is a data structure with information about how to draw an object. It contains a shader with all its parameters, plus information about how to set the GPU render state.

## **9.3 Batching techniques**

### **9.3.1 Static Batching**

It is automatically applied to all static objects in the scene that share the same material and have a batching static flag enabled. Static Batching creates a single mesh containing all the individual meshes. The main limit to static batching is the number of vertices and indices each batch can have. The main downside is increased memory usage.

### **9.3.2 GPU Instancing**

GPU Instancing can work with non-static objects. Unity passes a list of transforms (position, rotation, and scale). The memory usage is not increased as much as with Static Batching. However, there's a performance cost of creating and updating the list of transforms. The performance cost is much bigger when the object is non-static. This is also the optimization technique that worked for me the best.

### **9.3.3 Dynamic Batching**

Dynamic Batching allows batching dynamic objects with different meshes but is heavily limited and highly unpredictable. There is a great CPU performance cost of creating batches in run-time and results often differ from frame to frame.

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## User testing

This chapter provides a summary of the user testing conducted. The game prototype was tested with six participants. The main focus was on finding bugs and testing the comprehensibility of game mechanics. The average length of a test session was 46 minutes. Every tester managed to complete the game.

### 10.1 Performance

Testing was conducted on six different machines with various operating systems: Windows 10, Windows 11, and macOS 14. The game ran smoothly across all devices ranging from legacy laptops to high-performance models.

### 10.2 User experience

- One tester did not notice a notification text while gathering resources.
- Three testers did not realize their item was crafted after clicking the *craft* button. The game should notify of the event.
- Most of the testers struggled to consistently succeed in the mining mini-game. The speed of the mini-game was reduced.
- Four participants did not notice the icon representing the merchant's location, leaving them confused after hearing a sound effect announcing the merchant's arrival.

- All testers have repeatedly throughout the entire session attempted to close all UI elements using the Esc key.
- Some participants managed to get out of the game map. To prevent this, an invisible wall was placed around the island.
- A Few testers had trouble distinguishing between iron ore spawn and stone spawn.
- Four participants had trouble navigating between multiple user interfaces at the beginning of the sessions.
- Testers with 4k screens or screens with aspect ratios other than 16:9 encountered a bug where the stone mini-game cursor would not follow their mouse correctly.
- Most participants died in the second encounter, difficulty scaling was reduced.

### 10.3 Critical bugs

- When player died, they could not attack anymore. This was a major problem because fighting animals is essential for completing the game. The problem was temporarily resolved by quitting and reloading the game.
- The crafting components for the ship did not save and would disappear upon loading the game.
- Occasionally, defending caused the player to get stuck, preventing them from attacking.

### 10.4 Minor bugs

- The trading menu did not show the player's money count.
- Collecting items from the player's corpse would duplicate them.
- Quitting and reloading the game destroys enemies, which allows players to cheat by avoiding combat.

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## User testing template

Name:

Hardware specs:

Overview:

- You are on an island, the goal is to build a ship, you can collect basic resources, build buildings, craft and refine resources in the buildings.

Tasks:

1. Build the Sawmill structure
  - Gather Wood
  - Gather Stone
  - Craft a weapon
2. Build the Stonecutter structure
  - Refine Plank
  - Gather Stone
3. Build the Furnace
  - Refine Plank
  - Refine Stone block

4. Build the Weaving machine

- Gather Stone
- Refine Iron

5. Build the Tanning rack

- Refine Cloth
- Refine Plank

6. Build The Shipyard

- Refine Plank
- Refine Iron
- Refine Stone block

7. Finish the game

- Craft a ship

Events:

- Merchant arrival
  - Ask if they know what happened
  - Ask them to go trading
- Enemy arrival
  - Ask if they know what happened
  - Ask them to go fight the enemy
- See Natives
  - Ask what they think



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## Assets used

This chapter includes assets used during the development of the game.

### **B.1 Texture assets**

- FREE Stylized PBR Textures Pack (61)

### **B.2 Model assets**

- Graveyard Kit (55)
- Pirate Kit (56)
- Survival Kit (58)
- Fantasy Town Kit (54)
- LowPoly Water (25)
- Low Poly RPG Fantasy Weapons Lite (52)
- Lowpoly Environment - Nature Free - MEDIEVAL FANTASY SERIES (65)
- Boar model (50)
- Sword model (62)
- Spear model (71)

- Bow model (79)

### **B.3 Animation assets**

- Rigify Animbox (85)

### **B.4 UI assets**

- Buttons pack (46)
- UI Essential Pack (22)
- Pixel UI Pack (57)
- UI Pack (RPG Expansion) (59)
- Buttons pack (46)
- Fantasy Inventory Icons [Free] (51)
- Resource Icons (84)
- RPG inventory icons (67)
- Hide item icon (72)
- Coal item icon (37)
- Cloth item icon (38)
- Fiber item icon (66)
- Stone item icon (39)
- Iron ore item icon (40)
- Leather item icon (73)
- Herb item icon (49)
- Pickaxe item icon (41)
- Sickle item icon (44)
- Stick item icon (89)

- Stone block item icon (74)
- String item icon (23)
- Plank item icon (75)
- Blade item icon (17)
- Armor pad item icon (4)
- Ship sail item icon (43)
- Ship hull icon (42)
- Ship icon (53)

## **B.5 Sound assets**

- Arrow strike (64) (68)
- Sword hit (21) (20)
- Boar (76)
- Death (78) (77)
- Pain (1)
- Punch (24)
- Enemy ship (19)
- Merchant arrival (63)
- Player ship (18)



## Abbreviations

MMO - massively multiplayer online game

MMORPG - massively multiplayer online role-playing game

PoE - pieces of eight

NPC - non-player character

PvP - player versus player

HP - hit points

LTD - limited liability

UI - user interface

AI - artificial intelligence

API - application programming interface

GPU - graphics processing unit

CPU - central processing unit

PBR - physically based rendering

RPG - role-playing game