# 1. Overview

This report discusses both the research and creation of videogame A.I. (artificial intelligence) NPCs (Non-Player characters) through the use of two different A.I creation methods, the former being a BT (Behaviour Tree) and the latter being GOAP (Goal-Oriented Action Planning).

The goal of this project is to use a game engine in conjunction with these two A.I. creation methods to create two identical scenarios which contain NPCs performing specific actions. These scenarios can then be used to get a better comparison between the two A.I. creation methods by looking at how the NPCs behave and by tracking and documenting the creation process of these NPCs.

# 2. Literature Review

## 2.1. Introduction

The aim of this literature review is to examine BTs and GOAP more thoroughly and how they are used in the creation of videogame NPCs. It will discuss how they work, look at their strengths and weakness and compare the two against each other.

## 2.2. Behaviour Tree (BT) System

### 2.2.1. Introduction to Behaviour Trees

A BT is a plan of execution of tasks that was made to shape the behaviour of A.I. NPCs in video games. While it was initially developed for the video game industry it has also seen use in other fields such as robotics and computer science. It has been used in many big games such as Halo and Bioshock. One of the highest profile implementations of BTs currently has been built into Unreal Engine (UE) which is one of the biggest game development engines in the world and this is the implementation that will be referred to a lot throughout this review. A BT is comprised of two components. The first is a graphical representation of a hierarchy of different nodes. These nodes store the logic of the behaviour tree and are connected in a tree like structure, hence the name Behaviour Tree. The second component is a data structure called a Blackboard which is used to store important information the NPC might need to use in its behaviour tree such as player location, health, etc. The tree executes its logic going through the nodes from left-to-right and from top-to-bottom.

**Timeline

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*Figure 1: Behaviour Tree Example* (Haytam, 2020)

BTs are very modular which allow for easy change in the design of AI behaviour in turn allowing the developers to make the NPCs work and compliment the designers works. It allows NPCs to be manually tweaked to fit an area specifically to get the best result out of that area and to make use of the weapons or environment to give the best experience to the user.

### 2.2.2. Nodes

The nodes are split in to three main types, the root node, control flow nodes and execution nodes.

**Root Node -** The root node also sometimes referred to as the start node is a unique node with only one being able to exist in a behaviour tree. It is used as the starting point of a behaviour tree and it can only have one node connected to it.

**Control Flow Nodes -** These nodes control the child nodes under them that they are connected to. There is no limit to how many of these nodes there can be and they can be connected to other control flow nodes. They can decide whether and how to run the child nodes under them based on different conditions such as does the NPC have a weapon and they return a success or failure based on the result of those nodes. There are four main types of control flow nodes but as different behaviour tree implementations are being made and behaviour trees evolve more are being made and the existing ones can change based on which implementation you might look at.

**Sequence Control Flow Node -** Can have an unlimited amount of child nodes and returns success if all its child nodes return success otherwise returns failure if any child node returns failure.

**Fallback/Selector Control Flow Node -** Fallback nodes run their child nodes until they find a child node that returns success then they return success otherwise if all child nodes fail the fallback nodes return failure.

**Parallel Control Flow Node –** This node can only have two child nodes and will run them both constantly at the same time and returns success if one or more of its child nodes returns success.

**Decorator Control Flow Nodes -** Can only have one child node. Works as a conditional node deciding whether its child nodes should be run or whether the tree should continue. It has multiple versions that control then how it runs the nodes and how it handles the return value. Some newer versions exist of decorators such as UEs version which turns the decorator node from a node to a condition that you can add to other control flow nodes to control when they should run.

**Execution Nodes -** Execution nodes also known as task nodes or action nodes carry the main logic of the behaviour tree. They cannot have any child nodes connected to them and they run custom code to execute the specific actions the NPC needs to perform.

### 2.2.3. Blackboard

While blackboards are not necessary most implementations of BTs have them as BTs nowadays and the AI made through them tend to be very complex and blackboards allow for easy storing and sharing of data between the nodes in the tree and each NPC using that BT. At its simplest form the blackboard is a key-value storage system which allows you to store values and assign a name to them such as storing an integer called health which is then used to call them in the BT when required. These values can be easily used and edited by the nodes of the BT and each NPC using that BT.

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*Figure 2: Unreal Engine Blackboard example* (Unreal Engine, 2020)

## 2.3. Goal-Oriented Action Planning (GOAP)

GOAP is a decision-making architecture that takes the next step, and allows characters to decide not only what to do, but how to do it (Orkin, 2002). It is a STRIPS (Stanford Research Institute Problem Solver) architecture used to design the behaviour of NPCs in video games originally created by Jeff Orkin which was first implemented in the game F.E.A.R. (First Encounter Assault Recon) which was published on October 17, 2005.

GOAP allows the NPC to make plans for itself allowing it to adapt to any situation and area it is put in without its behaviour needing to be modified. This makes the NPCs very unpredictable and thus making the game less repetitive and more enjoyable for longer and subsequent playthroughs of it. This also reduces the potential workload on larger games where the NPC would have to be modified to fit each area correctly.

At its base GOAP works like a BT transitioning from one node to another. However, while the BT has all the nodes in a hierarchical structure and defined plan of execution for the tree GOAP instead has a scattering of unconnected nodes containing logic for the actions the NPC can perform and has a cost assigned to them. In comparison the initial implementation of GOAP in F.E.A.R. has a Finite-State Machine (FSM) (which is essentially a BT but with no structure allowing all nodes to be connected to each other) with only three nodes, a Go to, an Animate and Use Smart Object nodes as a base for the NPC used to control the state of the NPC based on the node being run by GOAP with the Use Smart Object node being used to play specific animations essentially working like the Animate node. Jeff Orkin in his paper on F.E.A.R. talks about this stating “As much as we like to pat ourselves on the back, and talk about how smart our A.I. are, the reality is that all A.I. ever do is move around and play animations! Think about it. An A.I. going for cover is just moving to some position, and then playing a duck or lean animation. An A.I. attacking just loops a firing animation”. He says all NPCs do is move and animate which means that you do not need a complex FSM and you just need to pass it the correct animations and values for it to work.

Diagram

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*Figure 3: F.E.A.R. GOAP FSM* (Orkin, Three States and a Plan: The A.I. of F.E.A.R., 2006)

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*Figure 4: regular FSM example* (Owens, 2014)

This is where GOAP differs from BTs. While BTs add more nodes, transitions, and conditions for said transitions GOAP instead make use of a planner, a set of goals, a set of actions and the A\* search algorithm. When BTs get more nodes and the tree grows you have to ensure all nodes can transition to each other without issues and wont impact other nodes which makes the tree increasingly more complex to manage as it grows, while with GOAP you can get rid of the transitions between these nodes altogether. GOAP instead just needs a set of nodes for the actions an NPC needs to perform with costs assigned to them and a set of nodes for the goals an NPC can fulfil. NPCs in the game can then be assigned specific sets of actions and goals that they can do such as walk and shoot. The NPC can make use of the actions in a specific chain to complete the goals but with the goals and actions being unconnected they need to be told which to do. For this the planner and search algorithm are used. First an NPC needs a goal to work towards. Goals usually have a priority assigned to them in the form of a value like an integer or float which get edited based on the state of the world such as a shoot player goal rising if a hostile NPC spots a player. The goal with the highest priority will be then assigned to the NPC. For example, in F.E.A.R. the patrol goal will have a higher priority than the attack enemy goal if the player is not spotted but the if an NPC sees a player then the priority of attack enemy will start rising until it is above patrol at which point it will switch goal to the attack enemy goal and the patrol goal priority will drop significantly.

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*Figure 5: GOAP planning process visualized* (Orkin, Applying Goal-Oriented Action Planning to Games, 2002)

Once an NPC has a goal to work towards it needs to formulate a plan to complete the goal. This is where the planner will come in to play. The planner will look at the list of actions that the NPC can perform such as shoot, move, throw grenade, etc, and it will use their cost values with the A\* search algorithm to create a chain of actions to perform the goal with the lowest cost possible. So, for example if an NPC gets assigned a goal to move to a location. The planner will gather the actions that NPC can make along with their costs. It will check if the location and path to the location is clear then it will plan to move there but say there is a door in the way than it will need to plan to move to the door than open the door and then move to the location again but what if again now there was another path without a door blocking. This is where the scoring system comes in and the A\* search algorithm. The path will be scored based on the actions which in this case will be distance to travel and opening the door. Then the algorithm will go through all choices and pick the least costly one to perform. Then once all actions are picked they get assigned in the correct order working from the end of the goal to the start giving the NPC the plan they need to fulfil their goal.

Once the plan is made each action is gone through one by one through the FSM allowing the NPC to move or play an animation such as opening a door and interacting with that object.

GOAP just like BTs is very modular with how it is made. If the NPCs in the game ever get new content allowing them to perform new actions all that needs to be added for the NPC to work is new actions and goals to their set along with the animation that action performs and cost for the actions for the A\* algorithm to use. Even then this is only required for unique actions as if you were to just add new weapons to the game than all that needs to change is the animation assigned to the shooting action when the NPC has that weapon.

GOAP can also be used very easily between all NPCs in the game as the actions are unconnected they allow all the NPC to just use the same planner with their set of actions. For example, in F.E.A.R. there is mice that use the same planner as regular combat enemies except the set of actions and goals they use only require them to move.

## 2.4. Comparison

### 2.4.1. Advantages of BTs over GOAP

* **Low Complexity –** Easy to start up and use especially with big game engines like Unreal Engine having high-quality built-in implementations that are free to use. Many Blueprints implementations also use visual nodes making them easy to look at and understand with Unreal Engines version being able to be done with their visual scripting so you do not have to even touch code. GOAP on the other hand is more complex to set up and only really benefits the game when the NPC start getting more complex making management of a BT more difficult and if you want the NPC to be more unpredictable making it difficult to set up and not worth using for most smaller games.
* **More Control Over Design of NPCs –** GOAP AI makes the NPCs be able to plan out their own moves and be very unpredictable which while it has its advantages it also makes it so that the NPC may not make full use of the design and environment of the game making those parts feel pointless while with BTs you have full control over what the NPC does and they can be setup to compliment the design of the game and allow the designers to craft the most enjoyable experience possible.
* **Easier Debugging –** GOAP unlike BTs is a lot more difficult to debug because of how unpredictable it is and because of everything being unconnected while BT debugging is a lot easier because of its lower complexity and control the developer has.
* **Smaller Computational Overhead –** GOAP is a lot more computationally expensive as while in BTs you have a defined set of transitions to check and follow, GOAP on the other hand must make plans for every NPC constantly checking over all the possible actions for each NPC and calculating the best one and whenever there is a change to the goal they all must be recalculated again. Nowadays however this is a minor issue with how powerful computers and consoles are nowadays.

### 2.4.2. Advantages of GOAP over BTs

* **Easy Scaling –** While GOAP is more difficult to implement and start up for bigger games it can be used to scale the game easier as when big games are made and have more content added BTs need a lot of reworking for all the transitions to work with each other correctly while with GOAP you would need to just create the appropriate goals and actions with their costs and priorities assigned and the planner will handle it making GOAP work with new content a lot easier because of its adaptability.
* **Adaptability –** GOAP allows NPCs made with it to adapt to most situations. The AI can plan for most changes made and any new areas added to the game that do not make use of new mechanics and can make effective use of the area without needing any changes while BTs will require a lot of extra work for the AI to make use of the new area or mechanics properly. This also allows for user generated content to work with the game better as the user will not have to edit the AI for it to work with what they make and allow them to make more creative content with less restraint.
* **Replay Ability –** The unpredictability of the NPCs as they make their plan and player interaction changing that plan in an infinite number of ways leads to the game being infinitely more replay able than as it would be mathematically impossible to get the same encounter twice while NPCs made with BTs can only have so many ways they can act especially when designed to take the map into account. This make games developed with GOAP able to be played many years and playthroughs down the line and still lead to interesting encounters and can still challenge the player.

## 2.5. Literature Review Conclusion

In conclusion both methods have their strengths however BTs are more common and have become the industry standard because of their modular design, ease of use and low complexity GOAP is a lot more complex, more difficult to use and start up making it a worse choice for small games but very good for giant games where the NPC gets very complex and well-done implementations can make a game endlessly replay able. So, for most games BTs are usually the best option and allow for very creative and designer friendly creation of NPCs but bigger games that can make proper use of GOAP can make for timeless and endlessly replay able games.

Since each method has its own strengths, weaknesses and there is no clear comparison between the methods as the games made using these methods are drastically different and therefore cannot be used to give a clear comparison between, the two methods making the answer as to which is better not clear which is the reason for this project. The project aims to get more clear information by creating a small game and implementing two identical versions of AI NPCs into the game with the use of BTS and GOAP and tracking the process to try to get a better first-hand comparison of the two AI creation methods.

# 3. Design

## 3.1. Scenario Design

This project will contain two scenarios which as mentioned before will be identical with the exception that the NPCs will be made with two different A.I. creation methods but will still ultimately have the same goals to complete. The scenarios themselves will be pretty simple. Each scenario will be a Scene object in the Unity game engine which is essentially a sandbox to put your work in. The scenarios themselves will be simulating a game where there is going to be three NPC workers that will be gathering/storing resources and working based on the type of worker they are and the tool they have.

The initial scenes will be very simplistic in terms of design with all the assets being made in the engine with simple shapes and materials and being static with no animations and no audio. The intention is to replace them with proper assets and animations acquired online once the project is done if there is enough time.

### 3.1.1 Workers

As mentioned there are three workers. These workers are the Miner, the Lumberjack, and the Blacksmith. Each one has a tool with limited durability except the blacksmith which has unlimited durability. Each one will perform their job on an endless loop based on their logic made by the BTs and GOAP. The NPCs themself initially will start out as just a capsule with simple 3D tools attached to their side and a cube protruding from the higher half of the capsule to show which side of the NPC is the front.

Icon

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A picture containing text, windmill, outdoor object

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**Miner/Lumberjack -** The Miner and the Lumberjack are going to work very similarly. They will gather iron and wood until their tool runs out of durability at which point they will go to store the resources they gathered at a storage point. At that point they will go to their corresponding tool station and either take a new tool from the station if there is one available or wait at the station until the blacksmith creates a new tool and deposits it at the station for them.

**Blacksmith –** The blacksmith differs from the other two workers. Unlike the other workers the blacksmiths tool has no durability and he does not harvest any resources. Instead, the blacksmith job is to keep track of the tool stations and make sure there is a tool on them at all times for the other workers to pick up when theirs break. The blacksmith will first go to the storage if there are any resources in there and collect the resources he needs to craft a new tool. Then he will return to his anvil and wait until one of the stations is missing a tool at which point he will use up the resources he gathered at the anvil to make a new tool and go to deposit it at the station.

### 3.1.2 Scene Assets

The scenes themselves will contain multiple simple structures that the NPCs will make use of to complete their jobs. In the end the scenes consist of a floor, a resource storage structure, tool stations, iron deposits, trees, and an anvil.

**Floor -** The floor is currently a flat plane that is coloured green to represent grass with the intent to switch it to actual 3D animated grass and dirt patches.

Shape, background pattern, rectangle

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**Resource Storage -** The resource storage contains and iron and a wood resource deposit with each being surrounded by small walls which is used by the Lumberjack and Miner to store resources in and by the Blacksmith to take resources from to make new tools. It is currently made of simple cubes with the intent once again being to upgrade to proper assets if possible.

A screenshot of a video game

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**Tool Stations -** Each resource storage will have two tool stations attached to it, one by each resource deposit which will hold a corresponding tool based on the deposit for the Lumberjack and the Miner to pick up when their tool breaks. Another tool can then be placed on it by a Blacksmith. Currently it is a half slab with the tool floating above it.

Graphical user interface, application

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**Iron Deposit -** The level will contain iron deposits for the Miner NPC to able to gather iron from it if they have a functioning pickaxe on them. The iron deposit is currently depicted by a set of cubes rotated in different positions.

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**Trees -** There are going to be trees located in the level that the Lumberjack NPC can go to and gather wood from if they have an axe. The tree is currently comprised of a cylinder mesh as the wood base and a set of cones used as the leaves.



**Anvil -** There is an anvil in the world that the Blacksmith NPC can use to make the tools that it deposits at the tool stations for the other worker NPCs. It is currently represented by a black rectangle.

Shape, arrow

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## 3.2. UI and UX

# 4. Scenario Creation

## 4.1. Behaviour Tree Scenario Implementation

### 4.1.1 Behaviour Tree System Setup

Unlike Unreal Engine, the Unity game engine does have not a BT system built into it. Because of a custom BT system had to be built for this project since it was done in Unity. Being that BTs are so popular and that the Unity Engine has a giant community, has a lot of documentation, and uses C# as its coding language which is a lot easier to use than Unreal Engines C++ made it very easy to research and find helpful documentation and tutorials on how to make a BT system in the Unity Engine.

In the end after going through many tutorials and a lot of documentation the BT system for the project was made following two YouTube tutorials on the channel TheKiwiCoder and editing that system afterwards a bit to fit the needs of the project better. TheKiwiCoder has two YouTube tutorials showing how to set up a great BT system but what set his tutorials apart from the others was that he made use of a pretty new Unity Engine tool called UI Builder which allows the user to create custom UI in the editor of the engine. This made it possible to make a good, easy to use and customizable visual representation of the BTs and connect it with the code of the nodes which made it a lot easier to connect the nodes and make the BTs. Also, unlike other tutorials he made blackboard that works with the behaviour trees which was used throughout the project to store the position the NPCs had to move to. The two videos and the channel are named below along with the YouTube link to them.

* Unity | Create Behaviour Trees using UI Builder, GraphView, and Scriptable Objects <https://youtu.be/nKpM98I7PeM>
* Behaviour Tree Editor with UI Builder – Part 2 <https://youtu.be/jhB_GFgS6S0>
* TheKiwiCoder YouTube channel <https://www.youtube.com/channel/UCjszZMwnOW4fO5VIDU_Wh1Q>

Graphical user interface

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### 4.1.2 NPC Logic

## 4.2. GOAP Scenario Implementation

### 4.2.1 GOAP System Setup

### 4.2.2 NPC Logic

## 4.3 Problems Encountered

### 4.3.1. Making GOAP in Unreal Engine

### 4.3.2. Lack of GOAP documentation

### 4.3.3. Making Behaviour Trees in Unreal Engine

# 5. Conclusion