The Current State of Video Game AI

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***Abstract*—Nearly every video game production studio utilizes some form of AI in their games to enhance the player experience and make their products more enjoyable. The earliest video games did not have AI in them because they were relatively basic and were initially designed for actual humans to play against each other within the game itself [1]. Early games like Pong used "basic decision trees" for their algorithms [2]. Another algorithm technique that was used in early game AI was the "finite state machine" algorithm which was first widely adopted in the 1990s [3]. C++, Java, and Javascript are all used in the video game industry, but each language has its own purpose. Many different game genres utilize a form of AI called dialogue-based NPCs. Video games that have AI that you can attack or damage, have what's called enemy AI or hostile AI. This shape of game AI usually employs the finite state machine (FSM) algorithm. Friendly AI makes use of the parallel task algorithm [4]. A more advanced form of game AI is procedurally generated content. This form of game AI does all of the work for you as long as you keep playing the game that has this system. A popular video game franchise that has started to use modern AI and machine learning technologies in their video game AI is EA Sports' FC games. A specific subset of AI that is currently receiving an abundant amount of research is reinforcement learning and deep learning. Eventually, game AI will benefit from this research to make the player experience better than it is currently [1].**

Keywords—Game AI; Machine Learning; Algorithms; Decision Tree; Finite State Machine; C++; Java; Javascript; Enemy AI; Friendly AI; Modern AI; Reinforcement Learning; Neural Networks; Deep Reinforcement Learning.

I. Introduction

AI (Artificial Intelligence) has been an integral part of the video game development process for decades. Nearly every video game production studio utilizes some form of AI in their games to enhance the player experience and make their products more enjoyable. Video games are even being used to currently train general AI algorithms to further advance that area of research. Many video game enthusiasts and beginner game developers are not familiar with the processes and algorithms that go behind making game AI. So, this paper's goal is to investigate the origins of game AI, how it works, and how it has advanced over the years up until recent times. More specifically, this paper will identify and discuss how the very first implementations of game AI were done in the 20th century leading up to cutting-edge technologies that are being used right now. The future of game AI will also be discussed. The technicalities of various types of game AI and their respective algorithms will also be discussed. Other topics include the use of modern AI algorithms in video game development. With this in mind, the paper will provide readers with a holistic and up-to-date background on game AI and what it has to offer in the future. The paper discusses four different conference papers published in the IEEE that contribute advanced knowledge to the subject matter. Additional outside articles and papers are included as an aid to the knowledge presented in this paper.

II. Background on Game AI

A. General Background

The very first applications of artificial intelligence were done by Alan Turing in 1950 [5]. Thanks to this discovery, AI would later be introduced into the video game industry to provide new experiences for players. Video games have been around for a very long time now, and undoubtedly, the systems that powered the game AI in early video games were very basic compared to today's standards.

This is due to the limitations that early computers had like small amounts of storage, memory, and overall processing power which limited the complexity of the algorithms that could be used for game AI. In fact, the earliest video games did not have AI in them because they were relatively basic and were initially designed for actual humans to play against each other within the game itself [1]. From this, we can assume that the initial purpose of game AI was to provide a solo player with an artificial opponent to play against and to make the game very replayable since another real-life opponent is not required to play the game [1]. Early video game culture named it "AI" only because it simulated playing against a real-life human player.

B. General Algorithms

The first games to implement AI in their systems were Pong and Space Invaders which came out in 1972 and 1978 respectively [1], [6], [7]. The AI algorithm in Pong was relatively simple because it only involved some simple conditional statements in the game's code to run the AI and help it decide whether to move the paddle to the right or the left. More specifically, these systems are composed of "basic decision trees"[2]. A figure that displays this very rudimentary algorithm is shown below.

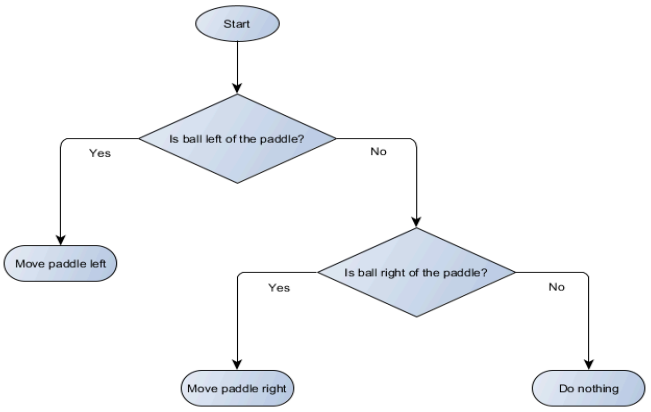

Fig. 1. Pong AI Algorithm. Adapted from [2]

Another algorithm technique that was used in early game AI was the "finite state machine" algorithm which was first widely adopted in the 1990s [3]. An example of an early video game that adopted the finite state machine algorithm for its AI was Super Mario Bros [3]. Modern games like Call of Duty and Battlefield also employ this algorithm for their enemy AI which are found in their non-multiplayer game modes that only involve playing with bots. In some online game modes, AI bots can co-exist with online players. The finite state machine algorithm can be viewed as a more complex structure of conditional statements compared to the simpler decision tree algorithm used in Pong. A figure displaying this algorithm is shown below.

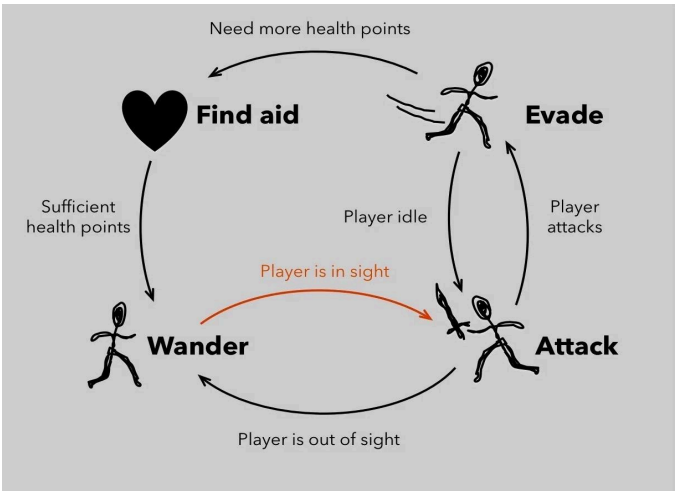

Fig. 2. Simplified Finite State Machine Algorithm. Adapted from [3]

C. Programming Languages Used For Game AI

The most popular programming languages that are used in the computer science world are also used for the development of video game AI. That is, C++, Java, and Javascript are all used in the video game industry, but each language has its own purpose.

1) C and C++

For example, in AAA (triple A) games, developers typically use C++ because it lets developers maximize the performance of the game in general, which also includes the AI [8]. C and C++ are considered to be an intermediate-level language, meaning that programmers are able to access low-level computer hardware with a language that is human-readable. Due to this fact, these languages are widely known for giving programmers the ability to efficiently manage the amount of memory used in their video games and thus produce a smooth-running game. Also, most triple AAA games require a vast amount of storage and memory to play, which means that it is crucial to be able to efficiently handle all processes that are using the computer memory.

2) Java

An example of a great video game that uses Java for its various forms of AI is Minecraft Java Edition. The entirety of the game is programmed in Java, as the title suggests. The reason why Java is a popular choice among game developers is due to the fact that it's an "object-oriented programming language" which lets developers quickly implement complex AI [8]. Due to its modularity, object-oriented programming is good for managing game AI subsystems, like managing individual AI types in a game.

3) Javascript

Javascript is a programming language that is mostly used to create internet websites. Many popular video games also exist in this realm, but they aren't as sophisticated as AAA games or Minecraft. For browser-based game AI development, Javascript is paired up with "frameworks" like "Phaser" to create these more simple games [8].

Overall, the systems and programming languages that power the AI in current games are much more advanced compared to those of early game AI due to the drastic technological advancements in overall computing power that have happened over the last century. Despite this, most modern game developers continue to use the same fundamental techniques like the decision tree and finite state machine algorithms to create the AI in their games. Except for the fact that the implementations of these algorithms in game AI are more complex than their 20th-century counterparts. Some are using more advanced methods that are more related to the current research that is being done with general artificial intelligence, which will be discussed later in the paper.

We have known to call the NPCs and bots that we play within our favorite games as "game AI." But, are they really considered true artificial intelligence? Video game "AI" is not true artificial intelligence because it doesn't learn and make human-like decisions like modern AI and machine learning implementations. But, that doesn't necessarily mean that the current research surrounding modern AI won't be used for video game AI in the future.

III. Different Forms of Game AI

A. Dialogue-Based AI (NPCs)

Many different game genres utilize a form of AI called dialogue-based NPCs. This form of game AI is very rudimentary and is a great example of a system that has been extensively pre-programmed by the developer to react to the player's responses. The algorithm it uses is similar to the decision making tree algorithm that was used by Pong back in 1972. The difference is that these decision trees are called "dialogue trees" [9].

These dialogue trees are much more complex and branch out more compared to Pong's simple decision making tree. It is widely used in adventure-based fantasy games, where the player runs into an NPC that starts asking you questions and you respond with either a manually written text answer or a predetermined selection of responses

that the game provides for you. But, it is also sometimes used in other game genres like first-person shooters. A figure of a complex dialogue tree for a fantasy game is shown below.

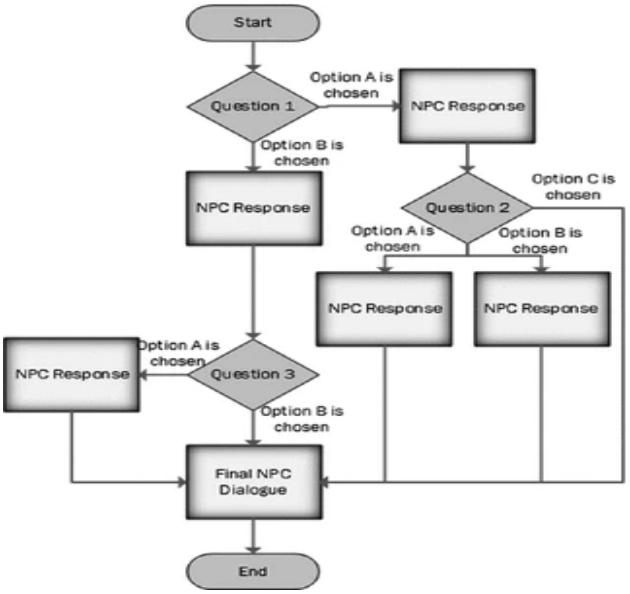

Fig. 3. Example of a Dialogue Tree for a Fantasy Game. Adapted from [9]

Some games have dialogue-based NPCs that can change the whole course of the gameplay through the storyline. An example of this is in the campaign for Call of Duty: Black Ops Cold War where in the mission "Identity Crisis" you have the option to either lie or tell the truth during an interrogation scene which determines whether you will later betray and kill your allies, or fight alongside them, with both scenarios happening in separate missions [10]. So, we can firmly conclude that these dialogue trees are definitely more complex than Pong's decision tree because as we saw that in Black Ops Cold War, there were whole game-altering effects with its dialogue tree algorithm.

B. Enemy AI

Video games that have AI that you can attack or damage, have what's called enemy AI or hostile AI. This shape of game AI usually employs the finite state machine (FSM) algorithm and is present in many first-person shooter games like Call of Duty or fighting games like Street Fighter and Mortal Kombat. The FSM algorithm uses automata theory to determine the next course of action that the AI will take based on its current situation. The computer, or in this situation, the enemy AI will switch from various states depending on the actions of the player. The possible states that an AI can switch between in a first-person shooter are patrol, attack, run away, and regenerate health. For example, if you enter a room with an enemy AI that is patrolling the area and it spots you, it will switch from the patrol state to the attack state. If you shoot it back and lower its health, it will switch from the attack state to the runaway state. Once the AI perhaps finds cover from you, it will switch from the runaway state to the regenerate health state. Finally, once it regenerates health it will switch to the patrol state to start looking for you again. Figure 2 displays this process.

This is just an example run, as each state is capable of choosing more than one path that can be completely different from the example run that was described.

C. Friendly AI

There exists another form of game AI, but in this case instead of playing against you, the AI serves as a companion and helps you reach the goal that you are trying to reach in the game. One method that developers use to program friendly AI is through the use of "parallel tasks" which is very similar to decision-making trees and finite state machines [4]. For example, in a crime-based video game, a friendly AI that is helping you rob a bank will only use its special door-hacking abilities only if you defend the area while it hacks the door [4]. Here, this friendly AI makes use of the parallel task algorithm, where it continuously checks the condition if the player is defending the area with the "until fail decorator" function, which determines if the AI will continue hacking the door or not [4]. A figure of this algorithm in action is shown on the next page below.

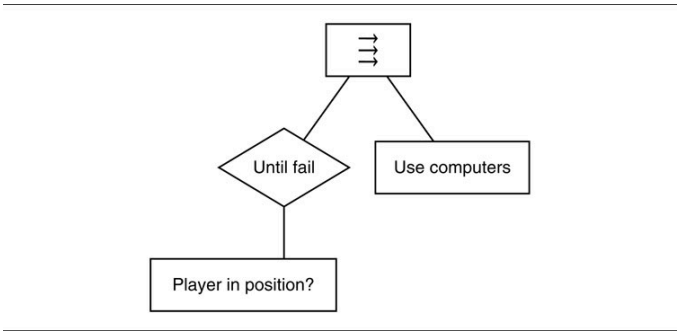

Fig. 4. Parallel Task Algorithm in Action. Adapted from [4]

Friendly AI can have many different roles in video games. They exist in many popular game genres like first-person shooters, crime games like Grand Theft Auto, sports games, adventure games, and more. Some are fairly intelligent and actually help you a lot in-game like the previous example of the bank robbery AI. But, sometimes friendly AI are entirely scripted and only serves to help carry out a scene in a game. For example, in many Call of Duty campaign modes some of the AI soldiers that fight alongside you will fire their weapon at seemingly nothing or their bullets will do very little damage to the enemy, leaving you to do almost all of the work yourself. Luckily, this isn't always the case for friendly game AI, and there exist many other game AI systems that do all of the work for you.

D. Procedurally Generated Content AI Systems

A more advanced form of game AI is procedurally generated content. This form of game AI does all of the work for you as long as you keep playing the game that has this system. Procedural generation is an advanced form of game AI that uses complex algorithms that involve randomization to generate many sorts of content like maps, "textures," and "3-D models" [11]. A very famous example of a video game that uses this configuration of AI is Minecraft [11]. The game randomly generates everything in its worlds, which helps players have a fresh experience every time they load up a new world [11]. This makes players get hooked on the game due to its great replayability. From this, we can assume that this form of AI is much more complex than the rest of the algorithms this paper has discussed since it usually needs to create large amounts of content in a short amount of time.

Although the algorithms used for procedural content generation are very advanced, developers are making some progress with using modern AI techniques for their game AI.

IV. Modern Game AI

A. Advanced AI Algorithms In EA Sports FC 24

A popular video game franchise that has started to use modern AI and machine learning technologies in their video game AI is EA Sports' FC games. The developers of the famous soccer-based video game use camera-recorded data from real-life soccer matches to train their exclusive machine learning models to imitate the movements of real-life professional soccer players in FC 24's gameplay [12]. Additionally, the developers have also taken advantage of modern AI models to help make ball movements in the game to follow the laws of physics better than in previous installments of the franchise [12]. From this, we can assume that the game developers' goal is to give the player a more realistic gaming experience that will make them feel as if they were playing on the field. Ultimately, they developed these technologies in the game to increase player interest and retention in the game.

This also suggests that game developers are starting to get a sense of how they can employ modern AI algorithms in their games, but there is still a long way ahead for other popular AAA franchises to start doing this as well.

V. The Future of AI and Game AI

A. Current AI and Its Future Influence in Games

Although the game AI that we usually interact with like NPCs, enemy, and allied bots has not advanced much, there may be some advancements coming in the near future thanks to the help of the current research being done in other areas of machine learning and AI. There is much research surrounding machine learning as of now and there continue to be advancements in the field. A specific subset of AI that is currently receiving an abundant amount of research is reinforcement learning and deep learning. Eventually, game AI will benefit

from this research to make the player experience better than it is currently [1].

B. Reinforcement Learning and Deep Learning Techniques

Reinforcement learning is a form of machine learning, which is a part of the overarching topic of artificial intelligence. More specifically, reinforcement learning simply operates by considering all possible options to ultimately find the best one through "trial and error" [13]. One can think of reinforcement learning simply as a machine that learns and grows through the things it has been exposed to which "reinforces" its understanding of the topic. The things that these machines are exposed to are called training data.

To fully understand how reinforcement learning algorithms work, we need to explore the mathematics that goes into powering them. The basic statistics topic that is used in reinforcement learning is called the "Markov decision process" or MDP for short [14]. The mathematics involved in the Markov decision process involves advanced statistical analysis with an emphasis on making complex, probabilistic computations to allow reinforcement learning algorithms to choose the most optimal path for their situation [14].

On the other hand, deep reinforcement learning is an even more advanced system that takes the principles of general reinforcement learning and includes the use of neural networks [13]. Neural networks are such an advanced piece of artificial intelligence that they even imitate how the neurons in our brains work [1].

Due to the sophistication and practicality of neural networks, it is widely used in various difficult computational problems that can be solved in a very short amount of time [15].

Some examples of modern uses of neural networks that are not directly related to game AI are "computer vision" and "natural language processing" [15].

In an ever-growing technology and artificial intelligence industry, it is almost inevitable that these methods will also be implemented in video game AI.

C. Deep Reinforcement Learning for Game AI

As of right now, video games are being used by researchers to train general deep learning models, which has been shown to be a very useful tool for the advancement of these algorithms.

Researchers involved with deep reinforcement learning algorithms create AI "agents" that are able to intelligently play various types of video games. Researchers use the collected data to study their decisions and overall performance in the game [16]. From there, researchers set up this algorithm to analyze how their "agents" learn with a failure and "reward" mechanism [16]. The mechanism works by "rewarding" the "agent" when it does something beneficial for itself in the game, like successfully landing a hit on the enemy, or a "penalty" when it loses health due to the enemy's attacks [16]. Every time the "agent" performs an action that results in a "reward," the "agent" receives a cue that it has just learned something new from a situation [16]. From this, we can assume that the reason why researchers find that video games are such a powerful tool to train their reinforcement learning models is due to the fact that most games allow you to make a vast amount of different decisions in a scenario which allows the researchers to analyze if their "agents" are making the most optimal decisions in these various games.

A popular game genre that is currently used by researchers to train this AI technology is fighting games. Due to the complexity of fighting games in general, researchers have extensively used this genre for their "agents" when working to further advance the field of deep learning algorithms [14]. A figure of how these algorithms work alongside a fighting game is shown on the next page below.

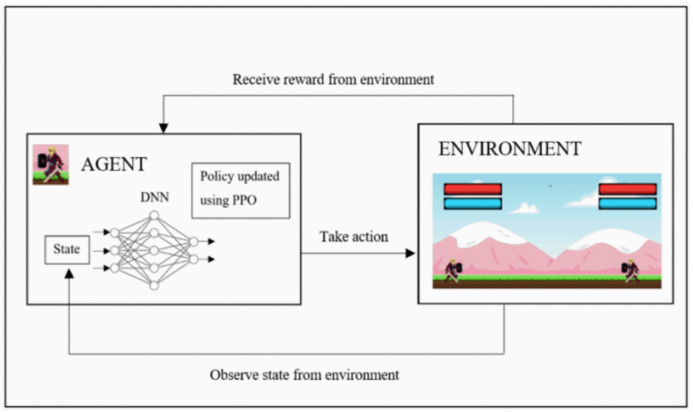

Fig. 5. Demonstration of Deep Learning Algorithm Trained With a Fighting Game. Adapted from [16]

The complexity of fighting games is especially evident in modern games like Super Smash Bros Ultimate and the more recent Mortal Kombat 1 because there are hundreds, if not thousands of different attacking and defensive moves that a player can take against their opponent with all of the different character options that the games have to offer.

From this, we can assume that AI agents can be effectively trained to be incredibly intelligent with these types of games because there are many different variables that can stimulate the complex system of neural networks within the agents' deep learning systems.

Fighting games are just one of the many video game genres that researchers have at their disposal to train their AI agents which can therefore allow them to create more holistic AI models [16].

Although this current research in deep reinforcement learning is being used more for the general advancement of the subject matter, the fact that video games are being used to train these agents to become more intelligent suggests that perhaps these advancements will eventually become part of game AI in modern games.

Most modern game developers are still fixed to using the old finite state machine algorithm to develop their game AI [16]. The issue with these methods is that the game AI can become very predictable over time for the player, which may make the player get bored with the game in a fairly short amount of time [16].

Granted that most video game developers design their game AI with the intent for them to be beatable by the player, another path they can take to make the interactions between the player and the game AI more varied is to start implementing some of the methods that have been discovered through all of this research that has been done with deep reinforcement learning.

The authors of [16] and [14] predict that the results of the research surrounding the use of video games to train deep reinforcement learning models will ultimately be applied to the everyday AI that players interact with in their favorite upcoming video games.

VI. Discussion

It seems that EA Sports has started to borrow ideas from the modern AI and machine learning algorithm research that is going on right now. EA Sports labeled these algorithms as "proprietary," meaning that they are company secrets and are probably patented. At the very least, this means that game developers are starting to question whether or not to continue using the same old game AI algorithms that have been used for years and are starting to implement more modern approaches to their AI. The current research that's being done is very promising and has a strong outlook on being implemented in game AI.

But, it will be quite some time before more game developers start implementing these more advanced algorithms into their game AI. The main reason why most companies haven't started adopting these new frameworks is because they know that the current systems they have in place make lots of profits. A major overhaul in the video game industry would need to happen for companies to start applying advanced AI and machine learning methods for their bots. Another possible scenario would be if consumers simply start getting bored of the current game AI systems that are currently in place for their favorite game franchises.

As more people around the globe start to learn more about artificial intelligence and the current research that is being done in the field, more people will be intrigued about how it can apply to more

things in the technology sector. Video game AI belongs to the technology sector and as more consumers start to know the prevalence of AI, they will start to question why more game developers aren't applying it to their game AI. This will put pressure on large companies to probably start thinking more seriously about using advanced machine learning algorithms for their game AI. The pressure will be more immense if companies see other companies implementing fully-functioning modern AI algorithms in their game AI.

If more modern game developers start implementing these new techniques for their game AI, they will need to be able to strike the right balance between developing a game AI that is both beatable and refreshing to the player every time they interact with the AI.

Considering the immense amount of wealth of the video game industry, more major video game developing companies should be able to apply these new methods to their games. Also, given that EA Sports was able to implement these modern technologies in FC 24, this should indicate to other AAA game developers that it is possible for them to do it too. This will be dependent on whether or not the companies deem these methods to be financially feasible.

If more game development companies are successful with implementing modern AI algorithms in their game AI, they can use it as a marketing technique to attract more customers and thus make more profits.

VII. Conclusion

For now, modern video games keep improving every single day in other areas like graphics and overall performance, which are both of course integral aspects of the player experience. Improving video game graphics has been one of the main priorities for developers when making games in order to keep up with the industry and player expectations of having near-realistic graphics [1]. We can assume that the reason why developers currently put a lot more effort into making games with high-definition graphics is because it makes games more immersive, which in turn makes the game more enjoyable for players. This will in turn boost player interest and retention which drives up sales for the company.

All in all, the AI that players interact with is also an integral part of the player experience because, without it, video games would be extremely boring and would lack merit. The current research surrounding AI and machine learning suggests that eventually all of the fruits of the research will make their way into game AI. Given this, it would be natural for the video game industry to make improvements in game AI as well, given how much credibility general AI has gotten in recent days.

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