Implementation of Graph and Trees in Video Games Generally

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***Abstract*—Video games has been existing in our daily lives for quite some time. Besides playing them in our personal computers and game consoles, we could also play them in smartphones. It's like they have become parts of our lives. However, little did we know that the design of games generally utilizes graph and trees. This paper will be elaborating the application of graph theory in various video game genres that adopt it.**

***Keywords*—Edge, Graph, Node, Tree**

I. INTRODUCTION

Here is an example :

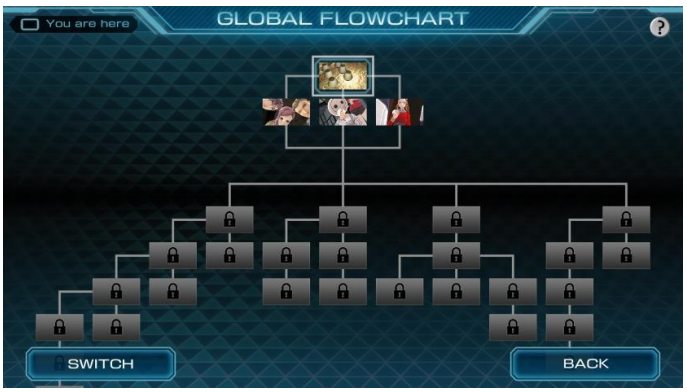

Fig 1.1 - Zero Time Dilemma Story Global Flowchart, Source:http://thevitalounge.net

This is an in-game screenshot of one the best visual novel games ever made, Zero Time Dilemma. This game was developed by Spike Chunsoft and was the third installment of the Zero Escape series. This game is a mix of psychological horror, mystery, suspense and thriller. The core gameplay of the series are puzzle that must be solved escape-room style. There are several elements related to science that aren't real. One of the recurring elements are the abilities to warp your consciousness in the present to the past of the future. The term "SHIFT" is used for the act of "warping". The story is about a group of people seeking to prevent a world crisis caused by a virus called Radical-6. These people are the ones who can SHIFT. They had just warped from the future because their future self realizes that the Earth is dying due to Radical-6. This virus is capable of making its victims suicidal. In other words, billions of people will die if no prevention measure is taken.

The antagonist in this game is Zero, a mysterious figure dressed as a plague doctor. There are 9 people confined in a room and are forced to play a game. The game's objective is to kill six out of nine people and escape through a certain door that unlocks after those six have been killed. There are three teams playing the game, three participants in each team.

In this game, you take control of three main characters Carlos, Diana, and Q, the team leaders. With them, you are constantly given situations that forces you to make difficult decisions depending on the situation. Different choices yield different outcomes, which lead you to a variety of endings. Going through particular scenarios makes you come across various puzzles as well. The gameplay only cycles between room escape puzzles and decision making scenarios.

Fig 1.1 shows a flowchart containing plot fragments of the game. If you look carefully, the flowchart has the form of a graph, with the boxes as the nodes (vertices) and the gray lines as the edges. The term "nodes" and "edges" would be covered in the following section.

II. THEORY

A. Graph

Graph G is defined as a tuple (V, E), such that G = (V, E)

V → non-empty set of vertices (nodes)
{ *a, b, c, d, e* }

E → set of edges
{ *E1, E2, E3, …, E7*}

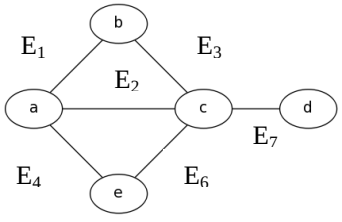

Fig 2.1 – Graph, Source**:**http://graphs.grevian.org

Based on the orientation of the edges, graph is divided into two types :

a. Undirected graph

Undirected graph is graph that doesn't have directed edges.

b. Directed graph/ Digraph

Directed graph is a graph that has directed edges.

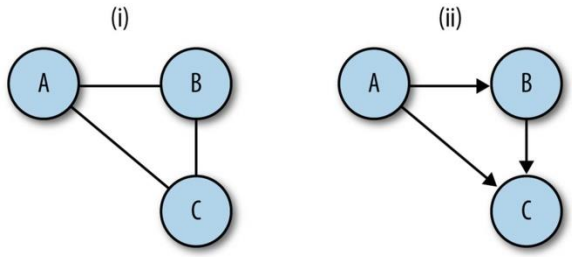

Fig 2.2 - (i) Undirected Graph, (ii) Directed Graph, Source:http://apprize.info

B. Tree

A tree is defined as an undirected graph which doesn't form a circuit. A circuit is a set of vertices and edges which form a closure in a graph.

Let G = (V, E) be a simple undirected graph with *n* vertices, then :

a. G is a tree

b. Every pair of vertices is connected with a single edge

c. G has *n*-1 edges

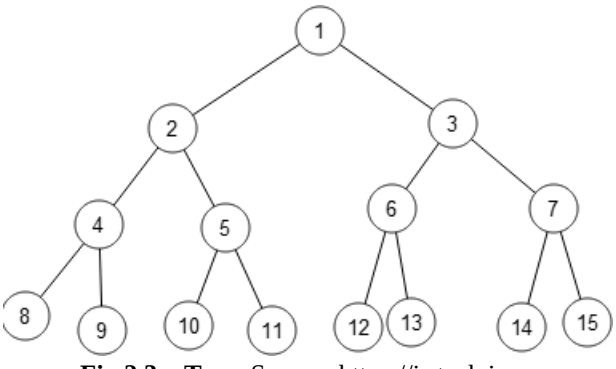

Fig 2.3 – Tree, Source: https://i.stack.imgur.com

Node 1 would be the *root*, while node 2 and 3 are the *children* of node 1. Node 1 is the *parent* of node 2 and 3, and so on.

III. Application of Graph in Video Games

A. Artifial Intelligence (AI)

Artificial Intelligence is defined as the ability of an object not controlled by human to think for itself and act according to its will. Before artificial intelligence came to be. Non-human object are hard-coded. We could look at a game titled "Space Invaders" as an example. In Space Invaders, the player's objective is to shoot down the aliens that constantly comes down to the bottom of the screen. The player must shoot them before they reach the bottom. All the movements of those aliens were scripted and didn't show any sign of intelligence. This is due to the fact that the aliens didn't have the will to react to any behavior of the player. Therefore, the so-called artificial intelligence didn't seem to be an artificial intelligence at all.

The earliest true artificial intelligence to exist in video game history is the computer opponent in the game "Pong". Pong is a game where two sides compete with each other, deflecting a ball back and forth. The objective of the game is to deflect as many balls into one of the player's "goal" as they could.

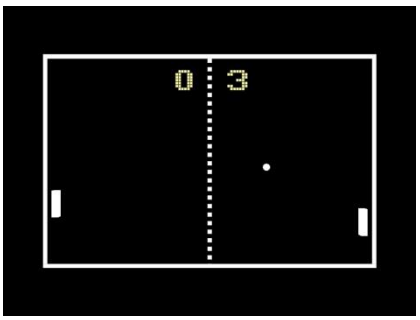

Fig 3.1 – Pong, Source: https://ucarecdn.com

Where the computer opponent would move the paddle is determined by a simple equation that calculates at what height would the ball cross the goal line. After the calculation was complete, the opponent would move the paddle to the calculated position as fast as it could. This could be illustrated with a graph where there are only two nodes, node A for the state of being idle and node B for the state of being mobile after receiving the signal to move. Those two nodes are connected with an edge which go both ways. In short, the graph is a directed graph where state A could go to state B and vice versa.

The more complex example of this would be guard sentries going on patrol, like the ones in Hideo Kojima's *Metal Gear Solid*. In the beginning of the game. The player was situated in a warehouse where two guards were patrolling. Each guard follow distinct patterns of walking. One of them goes back and forth along a straight line, while the other could turn left and right around the warehouse. Both of the guards are in their initial state, let's call it "Patrol". If, unfortunately, the player came into the guards' field of vision, they would enter another state, let's call it "Alert". In this state, they would use any means to get rid of the player until the player dies or hide long enough and result in their states changing into "Caution". During this state, the sentries would cease their pursuit of the player, but still continues to investigate the environment to confirm the player's location.

From this scenario, we could form a directed graph to illustrate the behavior of the patrol guard. The states "Patrol",

”Alert”, and “Caution” would be the nodes. “Patrol” is connected to “Alert” and “Caution”. The reason why sentries could change states from “Patrol” to “Caution” is that on some occasions, the player might do something to trigger the guards without coming into contact with them. Things such as stepping on a puddle, which produces a *splash* noise, would make the guards aware of an intruder in the area. They would go into “Caution” state because of this. On the other hand, “Alert” is also connected to “Patrol” and “Caution”.

Today, AI in video games has grown significantly. It is getting smarter and smarter. Its intelligence has grown almost as close as a human’s. Their reactions to player actions have been very extensive. The concrete evidence for this is the difference between AI in *Metal Gear Solid* and *Metal Gear Solid V : The Phantom Pain.* Guard sentries are not as dumb as they used to be, they are able to react differently in different situations. As evidence, paraphrasing from [11], enemies are now able to adapt to the players tactics. If the player often launch attacks on enemy camps at night, the next thing they are going to do is start carrying flashlights and go on night patrol.

Along with the growth of AI, there is one component of AI that has also developed. The said component, primarily implemented in games with AI is, pathfinding. It is a very important part of articial intelligence. It is how units in Warcraft or zombies in Left 4 Dead move to a certain assigned point while avoiding hazards and obstacles. This feature uses the nodes and edges in the graph theory in its implementation. It makes the AI’s behavior more realistic and makes it seem like they could find their own way in traversing the environment in the game. Pathfinding is mainly found in real-time strategy games such as *Warcraft, Starcraft, Command and Conquer,* or games with mobile NPCs like *Resident Evil: Outbreak.*

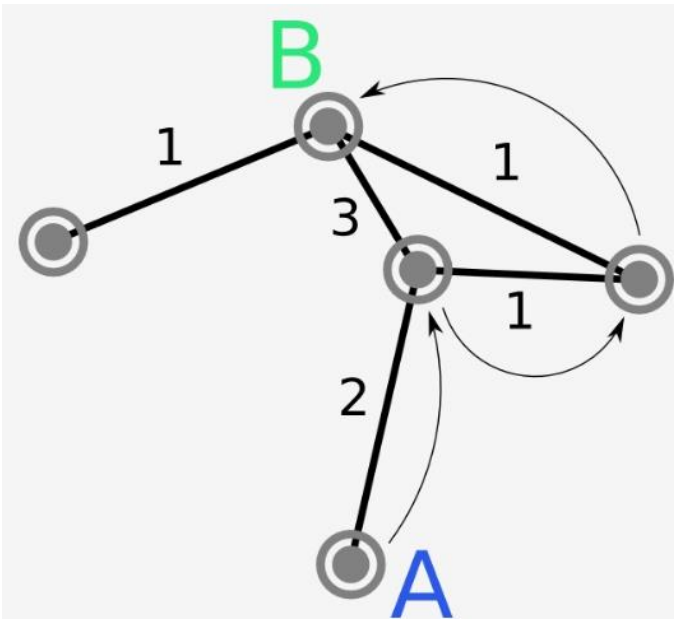

Fig 3.2 – Pathfinding using waypoints
Source:http://jceipek.com

How pathfinding works could be simply explained using this figure above. The numbers in the graph represent the cost for moving. Let’s say an NPC (NPC stands for Non-playable Character, which are characters not controlled by the players.) would like to move from node A to node B. It would first calculate the cost of each route available and chooses the route with the least cost. From this graph, we could conclude that the NPC would take the longer, but less costly, route to reach its destination, which is the forward-right-left route. As simple as that.

However, even though this concept is straightforward and uses less memory, the results were unrealistic and inefficient. Imagine a human walking in an extremely straight line through a jagged path. The movements could be interpreted as unrealistic. Therefore, more algorithms are used for pathfindings in AI these days, including the A* algorithm which will not be discussed in this paper.

B. Environment/ Level Design

Levels are environments where the players’ character roams. Levels can be found mostly in platformer or open-world games. They are the spaces where human-controlled character can jump, run, or interact with NPCs. These levels give the players something to explore as a form of fun experience besides playing the game itself. In some games, the stages or area might also have their own beauty, which on some occasions might be appreciated as a form of art.

The levels that would be discussed in this section are the ones in open-world genre games. Open-world games are the ones that allow us to seamlessly traverse through the world. There are no loading screens that separate one area from another, after all it’s seamless. However, some game designers often design their games in such a way that the player would have to go through certain parts of the game world before going to the next one. Usually this is done by placing obstacles in the entrance of the area that would be visited late in the game, or maybe give the player penalty for entering the certain area too early. By doing this, the player would play the way the designers desired. This method had been implemented in games, such as, *Grand Theft Auto, Pokemon*, etc.

Let’s take *Grand Theft Auto : Liberty City Stories* as an example :

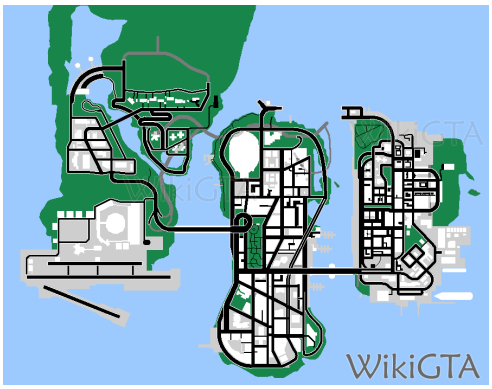

Fig 3.3 – GTA Liberty City Map, Source: http://nl.wikigta.org

The figure above is an overhead map of Liberty City, a fictional city modeled after the real world's New York City. Liberty City is divided into three areas : (from east to west) Portland, Staunton Island, and Shoreside Vale. Each of them are based on areas in New York City. Portland is heavily modeled after the areas in Brooklyn and Queens, with Staunton Island being the adaptation of New York's Manhattan Island. Shoreside Vale seems to be modeled after New Jersey because it has several landmarks from there, such as The Bronx and Westchester County, that can be located in New Jersey.

Now, to simplify the map. We could draw a graph with the three distinct areas as the nodes.

Fig 3.4 - Graph Form of Liberty City Map(Before)

The figure above is drawn based on Fig 3.3. If we look at it, the graph only has nodes, there aren't any edges to be found. This is because the graph above illustrates the state where the player begins a new game. The first city the player would be in is Portland. The connection of Portland to other areas has not been opened yet. The player must complete all the missions available in Portland to proceed to the next area, Staunton Island. The game was designed to force the player to play certain parts of the game to proceed. This is implemented by placing the bridge between Portland and Staunton island under construction for a certain reason. The player would have no other means of travelling to Staunton Island. This is due to the fact that the player has no access to air and water transportation at the time. In addition to that, the character controlled by the player cannot swim. If the character jumps into the water, his life would be drained to zero and then he would lose consciousness, which is a smart method for keeping the player in Portland before progressing any further.

Upon completing the last mission in Portland. The bridge connecting Portland and Staunton Island would be open that instant. The graph of the current state would look as follows :

Fig 3.5 - Graph Form of Liberty City Map(After)

The same would happen if all the missions in Staunton Island has been completed. Then, the path between Staunton Island and Shoreside Vale would open.

IV. Application of Trees in Video Games

A. Plot Branch

Plot branch, or widely known as story branch, a term for a certain type of storytelling in video games that has several branches, meaning several paths of story progression. To illustrate this, imagine a scenario where you are with a friend in the forest and suddenly you encounter a bear. The outcome of this scenario would be: a. You and your friend run away from the bear and be safe, b. You and your friend are wounded by the bear, or c. You and your friend kill the bear. By imagining this there are already three branches of a single scenario, which would be the point of this section.

We could almost always find this in any story-driven game. The application of trees are very common in visual novel games that offer different endings. Several scenarios lead to several path, resulting in various outcomes. Looking at Fig 1.1 the fact become more obvious to us that the Global Flowchart is indeed a tree (except there are 2 circuits there). Games like *Zero Time Dilemma* heavily relies on this in the making of the game, which makes the game have some depth in the plot and keeps players in suspense and excited due to the abundance of plot points. Story branch can be one of the most interesting element in video games because it keeps the player guessing until they find out the truth behind everything and also curious about the "what ifs" in the story. Some visual novel games leave a cliffhanger ending, which doesn't conclude the whole story and instead leave it without any conclusion. In any case, a story with branches always starts with a root. From there the story will start to branch, affected by the players actions or decisions. In some cases, some plot branch would eventually converge in the same node, as if the difference in action choices do not impact the story at all. This kind of plot design is quite rare though.

B. Dialog Tree/ Conversation Branch

Dialog is one of many gameplay mechanics used in video games. This feature is adopted mostly in adventure games, where player have the freedom to converse with NPCs. These characters may be common pedestrians in the streets, shopkeepers, or eccentric people who possess abilities to help the players out. Mostly in adventure game, players are allowed to talk to them. In some games like *The Elder Scrolls : Skyrim*, player are allowed to choose what to answer in a dialog between them and the NPCs. Those choices affect what answers the NPCs might give. If the player chose an answer that offends the NPCs, then they might become aggressive or even attack the player if they had a weapon in hand. In most games, the choices players make when conversing with the NPC usually don't affect the story whatsoever. However, in some games like *Mass Effect*, dialog choices alter the progression of the story and eventually alters the ending of the game. For example, the player would be able to have a romantic relationship with some NPCs depending on the choice of words they make when having a chat with them.

There are several purposes of implementing branching conversations in video games. This gameplay mechanic gives players a sense of control, which makes the player more attached to the protagonist controlled by them. It also makes them feel more meaningful to the game, because they could influence the outcome of the game. This makes them feel in charge. In addition to that, branching conversations also make players able to feel for the protagonist and the NPCs and relate

to them. That is one feature of many story-heavy video games until today.

Normally, in JRPG or Japanese role-playing games, the dialog trees are not as complicated as you might expect. There are slim chances that the choice of sentences have any impact to the story. The dialog tree is there only for extra content related to the story, nothing more. There are cases where whatever choice you make, it only adds more dialog and eventually you will come to the key dialog, which is mandatory in the game.

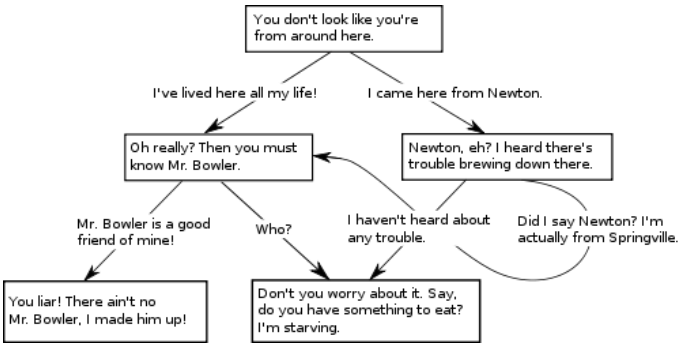

Fig 4.1 – Dialog tree, Source: https://camo.githubusercontent.com

The figure above shows how branching conversations in video games are implemented. Of course, any conversation starts with the initial sentences spoken by the player or the NPC with only one possibility. Subsequently, the conversation might be directed differently according to the choices the players make. At some point, there might be a choice that will move the conversation backwards, as shown above. This is implemented that way to make the communication more realistic and less unusual.

C. Weapon Tree

Weapon crafting tree or weapon tree is defined as a tree containing all possible products of weapon crafting. Different base weapons have different weapon trees and different products means different statistics of the weapons. Trees like this are the main feature of *Monster Hunter* games. Players have to be aware of what path of the tree should they take to craft their desired weapon, otherwise it is not guaranteed that they would come across their weapon of choice.

Monster Hunter is a game where players take on the role of a hunter, whose appearance is customized by the players in the beginning of the game. The core gameplay of this game is hunting monsters and gathering materials to craft more powerful weapons. There is not any major objective to accomplish. Players are just living the life of a hunter, hunting monsters day and night and struggling to become stronger every day. The gameplay itself is a loop. Players hunt, they craft weapons when they have enough materials, and then they get back to hunting.

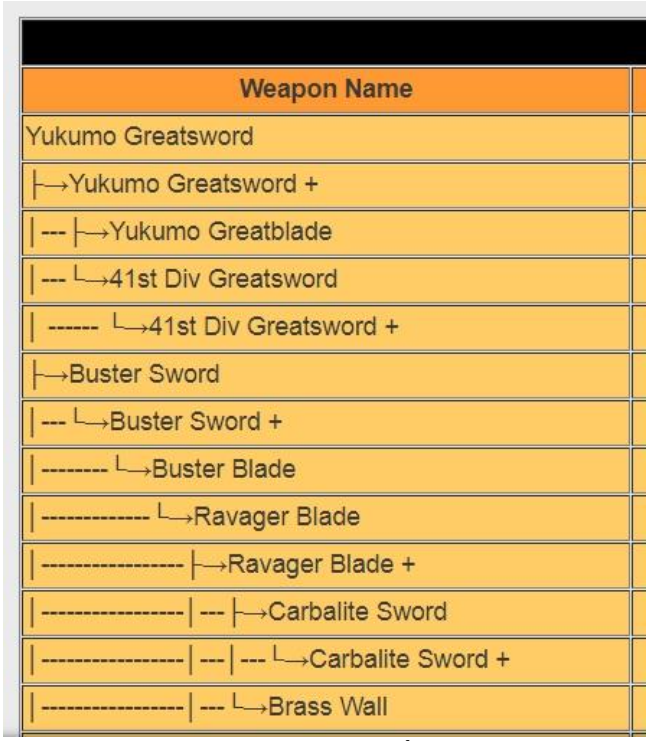

Fig 4.2 – Monster Hunter Portable 3rd Greatsword Weapon Tree, Source: http://monsterhunter.wikia.com

This figure shows the possible product of the Yukumo Greatsword, which acts as the root/base of the weapon tree. From Yukumo Greatsword, we could possibly upgrade it to two other swords. We could upgrade the sword into Yukumo Greatsword+ or we could change the appearance and add more statistics to the weapon by crafting it into Buster Sword. Supposedly we chose the Buster Sword, then we could craft all the way to Ravager Blade and come across another branch. We could choose between Ravager Blade+ or Brass Wall. This weapon upgrading/ crafting system heavily utilized the tree concept.

D. Skill Tree

According to [10], skill tree is a term for a certain set of skills and abilities arranged in a form of a tree. This mechanic is found in open-world games nowadays. Those games include, *Assasins Creed : Origins*, *Farcry 3*, *Watch Dogs 2*. It is the most implemented features, starting from games on the Playstation 3 platform until now. It has been an important part of these games to mark the progress of players. Usually the system is integrated with the leveling system if available. If players level up, they gain a certain number of skill points. Those points will then be used to "purchase" skills they desire. Various paths give distincts skill/ abilities. With different combinations of learnt skills, the playstyle of players might differ.

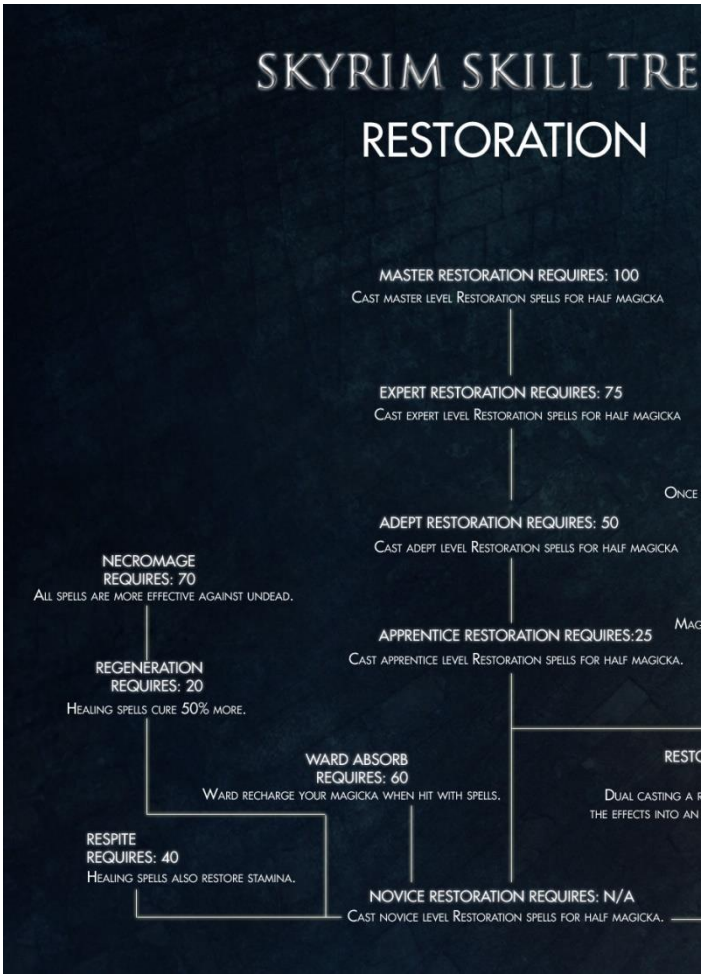

Fig 4.3 – The Elder Scrolls : Skyrim Restoration Skill Tree, Source: http://gameranx.com

The skill tree in the figure above goes bottom-up. To put it in other words, the root is at the bottom. In the beginning, players will always start from "Novice Restoration". As they progresses, defeated enemies and level up, they will have had enough points to move up the skill tree. They may choose to allocate the points to the leftmost branch, which would be "Respite", or if they really want to, they could gather more points to move up the middle path, which would lead them to more branches. The purpose of this skill tree is to give player freedom in forming their character with their own unique skills and statistics. This features is prevalent in most Western role-playing games like *Skryim.* Even first-person shooters like *Call of Duty* adopts this system. Skill tree has been an important part of games today, and might always be. With the skill tree the growth of characters controlled by players could be visually seen through unique actions performed after obtaining certain skills. It also give players more advantages in facing the threats available in the game, more skills means more power, and more power means easier time in defeating enemies and make progress in the game.

V. Conclusion

From this paper, we can conclude that graph theory is inseparable from video game production. Many aspects of a video game depend on graphs in their implementation. The mentioned aspect includes plot, artificial intelligence, environment design, branching dialogues, weapon tree, and skill tree in games. Hopefully, the application of graph theory in video games persist on growing and make future games with more engaging experience to be expected, fresh ideas, and high quality.

VII. Acknowledgment

The author thanks Mr. Rinaldi Munir for the opportunity to express his opinion about the relation between discrete mathematics and video games through this paper. By taking this opportunity, the author has gained more insight about the the math behind video games.

References

[1] http://informatika.stei.itb.ac.id/~rinaldi.munir/Matdis/2015-2016/Graf%20(2015).pdf, accessed: December 1st, 2017.
[2] http://informatika.stei.itb.ac.id/~rinaldi.munir/Matdis/2013-2014/Pohon%20(2013).pdf, accessed: December 1st, 2017.
[3] J. Wexler, "Artificial Intelligence in Games", 2002, http://www.cs.rochester.edu/~brown/242/assts/termprojs/games.pdf, accessed: December 1st, 2017.
[4] A. Freed, "Branching Conversation Systems and the Working Writer", 2014,https://www.gamasutra.com/blogs/AlexanderFreed/20140902/224609/Branching_Conversation_Systems_and_the_Working_Writer_Part_1_Introduction.php, accessed: December 2nd, 2017.
[5] C. Ma, "Game Level Layout from Design Specification", Published in *Computer Graphics Forum, Volume 33, Issue 2 (Eurographics 2014 Papers)*, *http://www.cs.ubc.ca/~chyma/publications/gl/index.html*, accessed: December 2nd, 2017.
[6] http://zeroescape.wikia.com/wiki/Zero_Escape:_Zero_Time_Dilemma, accessed: December 2nd, 2017.
[7] http://gta.wikia.com/wiki/Liberty_City_(3D_Universe), accessed: December 2nd, 2017
[8] http://monsterhunter.wikia.com/wiki/MHP3rd_Great_Sword_Weapon_Tree, accessed: December 2nd, 2017.
[9] Julian Ceipek, "Game Path Planning", http://jceipek.com/Olin-Coding-Tutorials/pathing.html. accessed: December 2nd, 2017
[10] https://www.giantbomb.com/skill-tree/3015-382/, accessed: December 2nd, 2017
[11] Erik Kain, "12 Incredible Things About 'Metal Gear Solid V: The Phantom Pain'", https://www.forbes.com/sites/erikkain/2015/09/03/12-incredible-things-about-metal-gear-solid-v-the-phantom-pain/#444628ab52df, accessed December 2nd, 2017.

Declaration

I hereby declare that this paper is of original work, neither an adaptation, nor a translation of any existing paper, and not an act of plagiarism

Bandung, December 3th 2017

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