Use of Graph Theory in Video Game Artificial Intelligence for Promoting Replay Value

Case Study: "AI Director" of Valve's Left 4 Dead

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***Abstract*—One of the main factors that makes a video game – as a product – has a long life cycle is its replay value. Replay value describes the 'depth' of an entertainment medium; in this case, a video game. Besides the content of the game, one of the main factors that influences a video game's replay value is the system on which the video game is built upon. This paper will discuss the use of graph theory in explaining Valve's Left 4 Dead artificial intelligence system – the "AI Director" – that promotes its replay value.**

***Index Terms*—Artificial Intelligence, Graph, Left 4 Dead, Replay Value.**

I. Introduction

Left 4 Dead is a first-person shooter (F.P.S.) video game released in 2008. In this video game, the player takes the role as one of the four survivors[1] in a zombie apocalypse scenario. The survivors cooperate to survive while navigating through a series of maps, fighting waves of raging zombies (the "Infected") using found arsenals of weapons and tools (loot), in order to reach an extraction point. Then, the survivors have to hold out until they are extracted from aforementioned place, in which the game ends.

Picture 1. Left 4 Dead game in progress. Source: [1]

The Infected is split to two types, the Normal Infected and the Special Infected. The Normal Infected are zombies that attack at close range. Each has a low pool of health, but they sometimes attack in large mobs. The Special Infected are zombies that have special features which makes them quite deadly to the survivors. For example, the Tank has a monstrous, large body capable of taking large amount of damage, punching cars and throwing a large chunk of rock to the survivors. It also has a deadly punch that can incapacitate a survivor in one hit. Special Infected is further divided to normal and boss infected, based on how frequently they spawn, i.e. generated by the game.

One of the main goals of Left 4 Dead, as stated by Michael Booth, is promoting replayability [1]. It is achieved by dynamically creating the content for the game, based on the players' performance. This system, dubbed by Valve as the "AI Director", makes it possible to achieve a state known as structed unpredictability, in which the author will discuss in-depth, using graph theory.

II. Terms and Definitions

A. First-person Shooter

First-person shooter (F.P.S.) is a video game genre where the player takes the first-person perspective. It is tightly related to three-dimensional video game that contents gun and projectile-based combat.

F.P.S. is further divided to two large subgenres: action, which are fast-paced and concentrates heavily on twitch gameplay, and tactical, which are slower-paced and modeled closer to realistic warfare – more careful planning and cooperation [2].

B. Artificial Intelligence

Artificial intelligence (A.I.) is a field of study that seeks to explain and emulate intelligent behavior in terms of computational processes (Schlakoff in Russel and Norvig, 1995). This relatively new field in science explores about how a 'thinking machine' – either biological or electronic

[1] Besides the Campaign mode (the player takes role as a survivor), there is also a Versus mode (two teams of (maximum) 4 players take role either as survivors or Special Infected). The paper focuses on the Campaign mode of the game.

– perceive, understand, predict, and manipulate a larger world than its own [3].

In the context of video game, AI is often related as a human replacement. It may be used to control non-player characters (NPC) – sometimes referred as bots, particularly in FPS video games, which the human player does not control. These bots control the behavior of the NPCs based on their purpose; they may act as the opposing side, or the helper for the human player; they may also act as individuals or groups, using tactics for and against the player. On the other hand, each bot often have its own pathfinding ability, through the usage of heuristics algorithms. It is used as the means of navigation for the bots in the map it is currently in.

On the other side, an AI may be used to manage some contents of the game, such as static object placements, events, and object properties. The use of AI in this context is known as procedural population/structured unpredictability [1]. Instead of generating contents through prepared scripts or placing them manually (static placement) – which is analogous to a drama – the content of the game is generated through special algorithms that deals with pseudo-randomization techniques. The seed – means of generating the content – is often based on the player statistics, i.e. how well the player is playing the game. However, it may also be based on external data, such as current time, location, and weather of the human player.

C. Replay Value

In terms of video game, replay value may be defined as the ability to sustain player over the course of multiple play-throughs – i.e., how much the player plays the game after he/she finished it. Moreover, replay value can also be defined as the 'depth-to-exhaustibility' ratio of the video game, where 'depth' is the degree of rich interconnection between well-balanced systems inherited by the video game, and 'exhaustibility' the degree of video game's dependence on static content to deliver a message [4].

To illustrate this concept, we will look at two different types of game: a classic board game, chess, and a plot-centric video game, *To the Moon*. Chess contains relatively small amount of static content (the board and the pieces), yet it has a well-balanced, unbiased movement rules – i.e., neither of the two players get unfair advantage, from the gameplay's perspective, over the other – that makes the game generates different gaming experience – the way the player perceives his/her current gaming session – at different play-throughs. Such game is said to have a high replay value. On the other hand, plot-centric video game like *To the Moon* (*Freebird Games*, 2011) often heavily relies on its static contents (music, plot devices, etc.) for its gameplay. This causes its gaming experience to be relatively uniform at different play-throughs. Players will find themselves in a similar situation when they replay the game. Such game is classified to have a small replay value.

Even though research shows that a great many players never finish their games at all [5, pp. 548-549], replay value is still an important aspect to consider in a video game. From a business perspective, the game will have a prolonged life cycle. This is based on a fact that games with high replay value will develop its own community. The community will – especially in games that promotes user-generated content, game content created by the players that adds new gameplay, plot, etc. – add a new gameplay mode using the game. This is true for *Warcraft III*, a strategy-based video game created by *Blizzard Entertainment* in 2002. The community of *Warcraft III* developed one of the custom maps of the game, *Defence of the Ancients* (*DotA*). Due to the popularity of *DotA*, Warcraft III is still being played to this date, with eight million purchases and $230 million revenue generated by 2012 [6].

There are several factors that influences a video game's replay value, such as:

1. *Reward*

Reward is defined as the merits the player gets as the player progresses through the game. As the number of reward increases, the player may see these rewards as a challenge. Therefore, the player will likely to play the game repeatedly to gain these.

2. *Non-linearity*

Non-linearity describes about how the content of the game dynamically changes in different play-throughs. One of the common example of non-linearity is the use of branching plot, in which the plot progression is determined by the player's actions. On the other hand, players may find different objects when they play the game.

3. *Multiplayer*

Even though AI may have the capability to learn, multiple human players in a game increases the number of possibilities that can occur in the game. This is due to the nature of human that can do more unpredictable things than the AI. Furthermore, humans are capable of socializing. As humans are naturally social creatures, playing games with friends tend to be more enjoyable than playing it alone. Besides, every player can try different combinations on how to play the game. Therefore, multiple play-throughs are guaranteed by multiplayer games.

III. Related Theories

A. Graph

Graph is a discrete structure, in which the elements are represented as nodes and their relations are represented as edges. It is defined formally as follows:

DEFINITION 3.1.
Graph G is defined as a pair of sets (V, E), in which:
V is a non-empty set of nodes/vertices (v_1, v_2, v_3, …) and E is a set of arcs/edges (e_1, e_2, e_3, …) that connects a pair of nodes, or written as G = (V, E). [7]

Graphs can be grouped to several types, depending on several factors:

1. *Loop/ring existence*

A graph that does not contain any loop/ring, i.e. the edge has (minimum) two equal elements of (v_i, v_i) and/or (v_i, v_j), where $i \neq j$, is called a *simple graph*. On the other

hand, if the graph contains loop(s)/ring(s), it is called as an *un-simple graph*.

2. Finiteness

A graph that contains finite number of nodes is called a *limited graph*, whereas an *unlimited graph* contains infinite number of nodes.

3. Direction

An *undirected graph* denotes a graph in which the order of the edge is ignored, i.e. $(v_i, v_j) = (v_j, v_i)$. On the other hand, a *directed graph* contains a direction, in which (v_i, v_j) and (v_j, v_i) denotes two different edges. For (v_i, v_j), v_i is called as the *initial vertex*, whereas v_j is called as the *terminal vertex*.

4. Weight

A *weighted graph* has edges that each has its own distinct values, whereas an *un-weighted graph* does not have such value. A common example of weighted graph can be found in maps, in which each node represents cities/locations and the edge represents the distance between each location.

IV. Analysis and Discussion

As stated in section I, one of the goals of Left 4 Dead is to promote replayability [1]. Booth states that replayability promotes long-term engagement with the game, resulting in growth of the game's community (2009). This, in turn, results in ongoing sales and creates exposure opportunities for other related content.

To achieve this goal, Left 4 Dead uses a system called the "AI Director". The "AI Director" (or the Director) handles two major parts of the game. First, it procedurally populates the game environment. This includes the spawning of the infected and placement of loots. In turn, this is achieved by using a set of tools that enables the Director to generate dynamic environment at different play-throughs on the same map. These tools are:

1. Navigation Mesh

The Navigation Mesh represents walkable space of the game's map. It contains spatial information about the game map, e.g. the seen/unseen areas, visible/invisible spots, and visibility of a certain area from another area.

Navigation mesh can be represented as a weighted, undirected graph, with each node containing information about the area. For example:

Information about Area 8	
Visible	No
Visited	Yes
Adjacent Area	5, 7, Safe Room
Survivors inside	Survivor1, Survivor2

Table 1. Sample node information

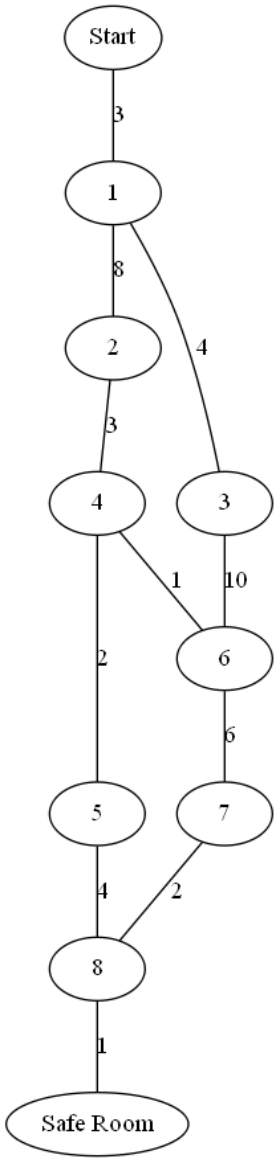

Figure 1. Example of a Navigation Mesh.

2. Flow Distance

Flow Distance shows information about how close the players are to the "Safe Room", i.e. the checkpoints of the game. It is also used to decide whether a spot in the map is currently 'ahead' or 'behind' the survivors.

The Flow Distance operates on the principle of weighted, directed graph. One example is shown as follows:

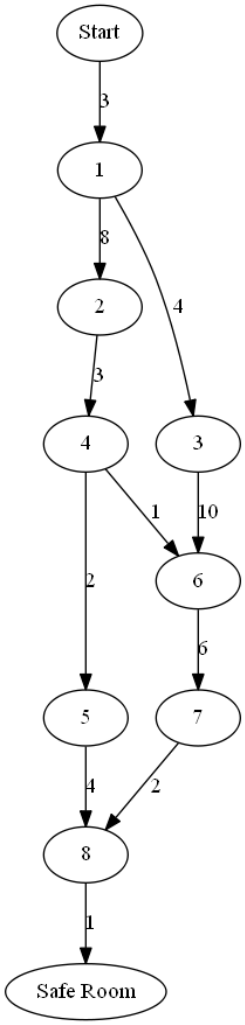

Figure 2. Example of a Flow Distance.

In this graph, each node represents one area that is also a part of the navigation mesh. Each edge represents distance from one area to another area. In order to calculate whether an area is 'ahead' or 'behind' a survivor, the distance between "Start" and the area is calculated. This represents the 'gradient' of the area; the higher the gradient, the closer the area is to the "Safe Room".

It should be noted that, the coloring of this graph does not follow the graph coloring theorem (using chromatic value), since this graph only represents gradients of area, based on their gradient.

From the computational complexity, it is preferred that the gradient values are pre-calculated. This is useful to reduce the amount of computational time needed for the player's computer to recalculate the path distance.

3. Active Area Set

Active Area Set (A.A.S.) denotes the set of Navigation Areas surrounding the Survivor team. In conjunction with the "Flow Distance", the information gathered from the A.A.S. will help the Director in choosing a spawn location for the Infected, spawning the pre-determined loot location, and de-spawning spawned Infected that is located outside the A.A.S.

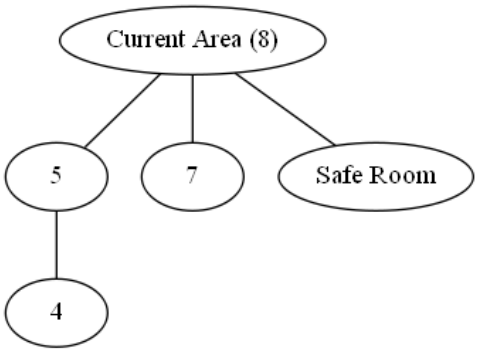

Figure 3. Example of A.A.S.

A.A.S. is determined by using the navigation mesh described earlier. From the survivors' location, a pre-determined value is set to calculate the radius of the A.A.S. Then, all node within the value is added to the A.A.S. From this perspective, adding or deleting an element in the A.A.S. is similar to a linked list with two pointers, i.e. the set can be added from the front (the first area visited) or the back (the last area visited). Therefore, from the time-complexity, adding/deleting elements from/to the A.A.S. will only take O(1).

4. Potential Visibility

Potential Visibility (P.V.) describes about the area in A.A.S. that is potentially visible to the survivor. It is used as a 'block', i.e. preventing unwanted spawns. For example, a zombie suddenly spawning in front of the survivor will make the game look not logical, since the zombie comes out from thin air.

Depending on the map layout, the P.V. may span to several (two or three) adjacent nodes of the A.A.S. Area not covered by the P.V. will be used by the director for spawning the Infected or loot.

From these four tools, the Director will generate different spawning pattern of loot and the infected. The content-generation rules are predetermined as follows [1]:

1. Difficulty affects mob size, spawn frequency, and frequency of loot (Health Kit are rare in Expert, except in Safe Rooms or for poor-performing survivors team [8]).
2. Normal infected are split to two types: wandering and mobs.
3. Wandering normal infected are spawned based on a simple count (N), which is based on the length to the Safe Room/Escape Route and the difficulty. Wanderers may be deleted from an area if it leaves an A.A.S. or a pending mob requires more members.
4. Mobs are created at random intervals (90-180 seconds on Normal difficulty). However, it may be created directly as a result of a Boomer, one of the Special Infected, vomit, which attracts mobs. The mob generation is progressive, i.e. the size of mob grows from the minimum just after spawn to a maximum after a duration.

5. The priority of mob-spawning places is as follows:
    a. Behind the survivors (75%)
    b. Ahead of Survivors (valid area > survivors' "flow" distance)
    c. Near Boomer vomit victim
    d. Anywhere
6. If the Director enters 'relax mode'[2] or the area enters P.V., the wanderer count (N) is zeroed, and no mobs will be spawned.
7. Special infected are split based on their attacks, with the Witch and the Tank categorized as the Boss.
8. Non-boss special infected are created at individually randomized intervals inside a valid A.A.S. Their characteristics will influence the placement of spawn:
    a. Boomers spawn ahead, near the survivors, since they are slow and commonly used for suicide attacks.
    b. Smokers will try its best to be spawned above the survivors.
9. Boss Special Infected spawning is a special case. They are placed about several units before the Safe Room. No same boss can be spawned successively (i.e., no Tank + Tank). The boss events (i.e., which boss is going to be spawned) are dealt as a stack, shuffled and placed at the (re)start of the map.
10. Weapon caches and scavenge items (loot) locations are pre-determined by the map. The Director then chooses which one will be spawned.

From the survivors' perspective, they may be able to find the shortest path from the Start room to the Safe Room through the Navigation Mesh using several methods (example: Djikstra's algorithm). However, due to the unpredictability nature of human players, the addition of certain types of Special Infected capable of disabling a player (Hunters and Smokers), i.e. making them unable to move, the variable number of mobs that the survivors have to fight, and the dynamic nature of the Director, Left 4 Dead creates an unpredictable nature, which influences to its high replay value.

IV. Conclusion

The graph theory can be used to explain the content-generating mechanism used by the AI of a video game. The dynamic nature of the AI can influence a game's content, which in turn will create different gaming experiences for the players in different play-throughs. This can be used to increase the game's replay value.

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Pernyataan

Dengan ini saya menyatakan bahwa makalah yang saya tulis ini adalah tulisan saya sendiri, bukan saduran, atau terjemahan dari makalah orang lain, dan bukan plagiasi.

Bandung, 17 Desember 2013

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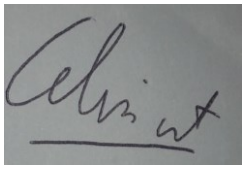

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[2] One of the Director's task is to manage the game's pace [1], which also influences the content generation through the 'modes' of the Director. The modes are influenced directly by the player's performance and difficulty. However, it is beyond the scope of this paper.