Attractiveness of Real Time Strategy Games

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***Abstract*—Game refinement idea is a unique theory that has been proposed based on the uncertainty of game outcome. A game refinement measure was derived from the game information progress model and has been applied in the domains such as board games and sports games. The present challenge is to apply the game refinement theory in the domain of RTS games. To do so, we use StarCraft II as a testbed and introduce a concept of strategy tree in order to construct a game tree of a RTS game. Then, game refinement values are calculated and compared with other type of games. It is found that StarCraft II has a zone value of game refinement.**
Keywords: Game refinement theory, StarCraft II, real time strategy game, game progress, strategy tree

I. Introduction

Video games grow more popular every year and Real Time Strategy (RTS) is a sub-genre of strategy video games which does not progress incrementally in turns [3][2]. Our research interest is to know a theoretical aspect of attractiveness of such popular video games. However, any method or approach to quantify the engagement of target games is strictly limited. In other words, no mathematical theory has been established in this direction. The present study is the first attempt to explore the attractiveness of RTS using a new game theory which focuses on the game sophistication.

Many efforts have been devoted to the study of strategic decision making in the framework of game theory with focus on mathematical models of conflict and cooperation between intelligent rational decision-makers or game-players. Game theory originated in the idea regarding the existence of mixed-strategy equilibrium in two-person zero-sum games [6], which has been widely recognized as a useful tool in many fields such as economics, political science, psychology, logic and biology.

However, little is known about mathematical theory from the game creator's point of view. An early work in this direction has been done by Iida *et al.* [4][5], in which a measure of game refinement was proposed based on the concept of game outcome uncertainty. A logistic model was constructed in the framework of game-refinement theory and applied to many board games including chess variants. Recently a general model of game refinement was proposed based on the concept of game progress and game information progress [8]. It bridges a gap between board games such as chess and sports games such as soccer. The next challenge is to apply the game refinement theory to RTS games.

In this study we have chosen the domain of StarCraft II, which is one of the most popular RTS games. We analyze the attractiveness of StarCraft II based on the game refinement theory. In typical RTS games like StarCraft II, players build armies and vie for control of the battlefield. The armies in play can be as small as a single squad of Marines or as large as a full-blown planetary invasion force. As commander, one observes the battlefield from a top-down perspective and issue orders to one's own units in real time. Strategic thinking is key to success. Players need to gather information about the opponents, anticipate their moves, outflank their attacks, and formulate a winning strategy. StarCraft II features three distinct races whose armies comprise entirely unique units and structures. Each race has its own strengths and weaknesses, and knowing their tactical profiles can mean the difference between glorious victory or crushing defeat.

To our best knowledge, no one published any successful application of the game refinement theory to RTS games. The main reason is that a RTS game is basically time-continuous, so any method to determine the game progress has not yet been established. In this study we propose an idea to determine the game progress of RTS games bases on a concept of strategy tree.

In Section II we present the game refinement theory. Then, a concept of strategy tree will be described in Section III while showing how to apply the strategy tree to StarCraft II. Section IV presents an application of game refinement theory to StarCraft II. Finally, concluding remarks are given in Section V.

II. Game Refinement Theory

We give a short sketch of the basic idea of game refinement theory from [8]. The "game progress" is twofold. One is game speed or scoring rate, while another one is game information progress with focus on the game outcome. In sports games such as soccer and basketball, the scoring rate is calculated by two factors: (1) goal, i.e., total score and (2) time or steps to achieve the goal. Thus, the game speed is given by average number of successful shoots divided by average number of shoot attempts. For other score-limited sports games such as Volleyball and Tennis in which the goal (i.e., score to win) is set in advance, the average number of total points per game may correspond to the steps to achieve the goal [9].

Game information progress presents the degree of certainty of a games results in time or in steps. Let G and T be the average number of successful shots and the average number of shots per game, respectively. Having full information of the game progress, i.e. after its conclusion, game progress $x(t)$ will be given as a linear function of time t with $0 \leq t \leq T$ and $0 \leq x(t) \leq G$, as shown in Equation (1).

$$x(t) = \frac{G}{T}\,t \tag{1}$$

However, the game information progress given by Equation (1) is unknown during the in-game period. The presence of uncertainty during the game, often until the final moments of a game, reasonably renders game progress as exponential. Hence, a realistic model of game information progress is given by Equation (2).

$$x(t) = G(\frac{t}{T})^n \tag{2}$$

Here n stands for a constant parameter which is given based on the perspective of an observer in the game considered. Then acceleration of game information progress is obtained by deriving Equation (2) twice. Solving it at $t = T$, the equation becomes

$$x''(T) = \frac{Gn(n-1)}{T^n}t^{n-2} = \frac{G}{T^2}n(n-1)$$

It is assumed in the current model that game information progress in any type of game is encoded and transported in our brains. We do not yet know about the physics of information in the brain, but it is likely that the acceleration of information progress is related to the forces and laws of physics. Hence, it is reasonably expected that the larger the value $\frac{G}{T^2}$ is, the more the game becomes exciting due to the uncertainty of game outcome. Thus, we use its root square, $\frac{\sqrt{G}}{T}$, as a game refinement measure for the game under consideration. We can call it R value for short.

Here we consider the gap between board games and sports games by deriving a formula to calculate the game information progress of board games. Let B and D be average branching factor (number of possible options) and game length (depth of whole game tree), respectively. One round in board games can be illustrated as decision tree. At each depth of the game tree, one will choose a move and the game will progress. Figure 1 illustrates one level of game tree. The distance d, which has been shown in Figure 1, can be found by using simple Pythagoras theorem, thus resulting in $d = \sqrt{\Delta l^2 + 1}$.

Assuming that the approximate value of horizontal difference between nodes is $\frac{B}{2}$, then we can make a substitution and get $d = \sqrt{(\frac{B}{2})^2 + 1}$. The game progress for one game is the total level of game tree times d. For the meantime, we do not consider Δt^2 because the value ($\Delta t^2 = 1$) is assumed to be much smaller compared to B. The game length will be normalized by the average game length D, then the game progress $x(t)$ is given by $x(t) = \frac{t}{D} \cdot d = \frac{t}{D}\sqrt{(\frac{B}{2})^2} = \frac{Bt}{2D}$.

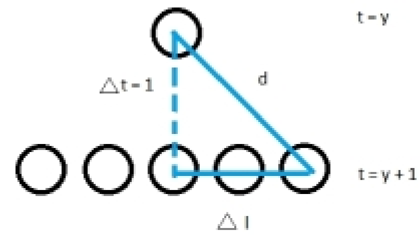

Fig. 1. Illustration of one level of game tree

TABLE I
MEASURES OF GAME REFINEMENT FOR BOARD GAMES AND SPORTS GAMES

Game	B or G	D or T	R
Chess	35	80	0.074
Go	250	208	0.076
Basketball	36.38	82.01	0.073
Soccer	2.64	22	0.073

Then, in general we have, $x(t) = c\frac{B}{D}t$, where c is a different constant which depends on the game considered. However, we manage to explain how to obtain the game information progress value itself. The game progress in the domain of board games forms a linear graph with the maximum value $x(t)$ of B. Assuming $c = 1$, then we have a realistic game progress model for board games, which is given by

$$x(t) = B(\frac{t}{D})^n. \tag{3}$$

Equation (3) shows that the game progress in board games corresponds to that of sports games as shown in Equation (2).

To support the effectiveness of proposed game refinement measures, some data of games such as Chess and Go [4] from board games and two sports games [8] are compared. We show, in Table I, a comparison of game refinement measures for various type of games. From Table I, we see that sophisticated games have a common factor (i.e., same degree of acceleration value) to feel engagement or excitement regardless of different type of games.

III. STRATEGY TREE AND RTS

Our present study focuses on StarCraft II which is a RTS game where the player's goal is to destroy their enemy's base by developing their own base and an army. In StarCraft II players cannot see their opponent's situation and they have the same power, StarCraft II does not rely on any chance. Therefore, in a sense this game is similar with board games such as chess. It means that we can use some similar tools or methods to analyze the game of StarCraft II.

A. Basic Idea of Strategy Tree

Minimax strategy is a decision rule used in decision theory, game theory, statistics and philosophy for minimizing the possible loss for a worst case (maximum loss) scenario [7]. Alternatively, it can be thought of as maximizing the minimum gain (maximin or MaxMin). Originally formulated for two-player zero-sum game theory, covering both the cases where players take alternate moves and those where they make simultaneous moves. It has also been extended to more complex games and to general decision making in the presence of uncertainty. The traditional minimax tree is illustrated in Figure 2. Because StarCraft II is an incomplete information game, neither player A or player B do not know opponent's condition, so they only consider about their own tree. Our idea is to combine the search tree of both players. Then we can establish a strategy tree of StarCraft II.

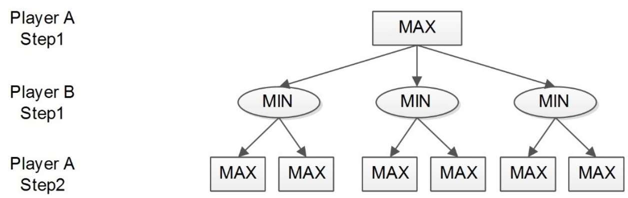

Fig. 2. The traditional minimax tree

B. *Strategy Tree of StarCraft II*

StarCraft II is a RTS game where players have the goal to destroy their enemy by building a base and an army. Players can choose 1 out of 3 races to play with. These races are: Terran, Protoss, and Zerg. Terran are humans, Protoss are alien humanoids with highly advanced technology, and Zerg are a collection of assimilated creatures who use biological adaptation instead of technology [1].

For anything a player builds, he needs to gather 2 types of resources: minerals and gas. These resources are used to construct buildings which in turn can be used to produce units. At the start of the game, no all units and buildings are available. New construction options can be unlocked by making certain buildings. This means that some units and buildings are available at the start of the game while others become available later in the game. This is also called tier: the point in time that certain units and buildings become available.

In order to play the game well, one must engage in strategy, macro-management and micro-operation. Strategy determines whether player can establish the strategic superiority. Macro-management determines the economic strength of a player. This is determined by the construction of buildings, the gathering of resources and the composition of units. Micro-operation determines how well a player is able to locally control small groups and individual units. It includes movements and attacks that are issued by the player [10].

Macro-management of a player heavily depends on the strategy the player has chosen to follow. For example, if a player chooses to rush his opponent by making fighting units at the very early stage in the game, his economy will suffer. On the other hand, if a player chooses to focus on having a strong economy before building an adequate-size army, he would take the risk of being overrun by his opponent.

1) Opening stage of StarCraft II: According to the game features of StarCraft II, we should divide the game into four parts: Opening, Mid-prophase, Mid-anaphase and Endgame. The game could finish in any time domain. For example, while players choose supervise attack or extremely rush strategy, the game must finish in 7 or 8 minutes or before; Normally, the average game time is 15 to 20 minutes (it means that most games will not enter into Mid-anaphase or Endgame time domain). As our experience, we find the game in different time domain, the **main elements** are completely disparate.

TABLE II
FEATURE OF STARCRAFT II IN EVERY PROCESS

Domain	Timing	Character
Opening	0 to 10 minutes	Strategy
Mid-prophase	10 to 20 minutes	Economy and Management
Mid-anaphase	20 to 30 minutes	Economy and Operation
Endgame	Over 30 minutes	operation

In the opening, the StarCraft II is similar to real war or traditional board games. In other words, only in the opening time domain, StarCraft II is an intellectual game. While a game enters into Mid-prophase or Mid-anaphase, the main elements are economy, management and operation. It means that in mid-game, the StarCraft II is similar to the simulation game. As we know, a good chess player not always can be a good manager, a strategy genius does not mean that he could be a nice executive.

For the endgame, the operation element will be more and more important, even occupy all the StarCraft II process. It means that on that time StarCraft II is similar to Super Mario. When we watch somebody playing Super Mario, we rarely focus on his intellectual strategy, we only focus on whether or not his operation skill is proficient. In this situation, StarCraft II is like sports games such as soccer and basketball.

Fig. 3. Feature of StarCraft II

According to the above, only in the opening stage, we have the strategy tree, and then find the B and D. Also in the opening stage, the game is highly similar to traditional board games or brain sports, we can take example by game tree model to establish new mathematical model. If we want to research mid-game or end game, we must find other model or method. At least, the meaning of B and D must be changed. Actually, the completion between profession players, the most exciting and wonderful part is mid-game. It is likely that body sports are more suitable than brain sports to watch. However for AI research, apparently opening part seems more valuable. Also the opening stage is worth to establish opening book or do other related research in the future. So these are the reasons why we only focus on the opening stage.

2) Strategy Tree – The Tree with Unbalanced Children Nodes: In StarCraft II, there are three races. Every race has their own particular strategy tree. Here we analyze the Protoss strategy tree. We enumerate all the opening strategies existed, which are commonly used in High Ladder system. Professional players have validated their rationality through experience and experiments.

In the following strategy tree, the content is denoted as "4BG" or "BF" which means a strategy name or code name. These strategies would be used in the opening stage, i.e., within 10 minutes after starting a game. Then we get the strategy tree as shown in Figure 4.

Since StarCraft II is a RTS game, its minimax tree cannot be built in a normal way. For example, the depth of tree is defined by each step or turn, while in Starcraft II, the depth might be given by time evolution. We show, in Figure 5, such an example. In Figure 5, we notice that the child node "BCrush" and child node "BF 2BN" have the different depth. This situation would never happen in traditional board games to build a minimax search tree. So we consider one method to solve it, while changing an unbalance depth tree into a balance tree. While adding the temporary node, then we get another strategy tree of Protoss as shown in Figure 6.

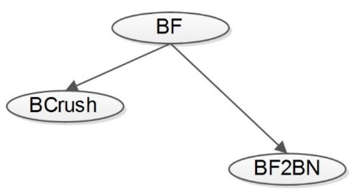

Fig. 5. An example of strategy tree with two unbalanced child nodes

IV. ANALYSIS OF ATTRACTIVENESS OF STARCRAFT II

A. Applying Game Refinement Measure

The game of StarCraft II can be divided into four parts. For the artificial intelligence, the most important part is the opening domain where players have to focus on their strategies. In this area, the weaker player would have a little chance to win. Now we can draw the figure of Terran and Zerg as follows.

In Figure 6, the Protoss tree's depth is 9. In this tree, the total branching factor is 116 and we have 74 parent nodes, so average branching factor is $B = \frac{116}{74} = 1.57$. However, until now we cannot calculate the game refinement value directly. Because in the real game, two players cannot maintain playing game independently at anytime. Sometimes, they will use spy and predict their opponent's choice to modify their strategy. So we can combine two trees into one tree, as shown in the following figure.

For the combined strategy tree, player A's choice and Player B's choice are all happened in the same time. No matter player A choose A1 or A2, it will not affect player B to decide B1, B2 or B3, combine the two trees together, can analyze the game refinement value more accurately. While player A uses

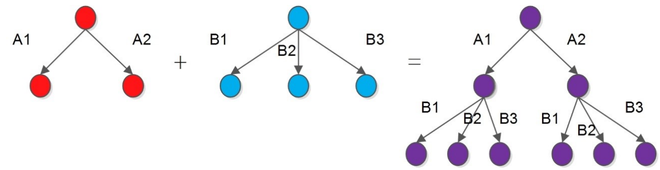

Fig. 9. Combination of two strategy trees

spy then realize player B will choose "some strategy", he can modify his next path based on player B's parent node.

In minimax tree, the whole tree size is estimated by B^D, and the game refinement formula equal to $\frac{\sqrt{B}}{D}$, while in the combined strategy tree, the tree size is $(B^2)^D$, so the game refinement value should be given by $\frac{\sqrt{B}}{2D}$. Then the game refinement value of Protoss in the opening time domain is given by

$$R = \frac{\sqrt{B}}{2D} = \frac{\sqrt{1.57}}{2*9} = 0.0695.$$

Similarly, race Terran and Zerg also have their own strategy tree, then the game refinement value is calculated, as shown in Table III. In this table, we notice that Zerg has two game refinement values.

TABLE III
MEASURE OF GAME REFINEMENT FOR THREE RACES IN STARCRAFT II

Race	all nodes	all parent nodes	B	D	R-value
Terran	126	76	1.64	16	0.0805
Zerg	219	141	1.54	18	0.0692
Zerg*	564	210	1.61	20	0.0819
Protoss	116	74	1.55	18	0.0691

The R-value not only means the property of every race, but also means the competition between same race such as Terran versus Terran or Zerg versus Zerg. We evolve the mathematical formula in Equation (4).

$$R = \frac{\sqrt[4]{\frac{AllBranchFact_1}{AllFatherNode_1} * \frac{AllBranchFact_2}{AllFatherNode_2}}}{\log_{Avg.depth}(depth_1 * depth_2) * Avg.depth} \tag{4}$$

Then we have the full data of every race's competition in Table IV:

TABLE IV
MEASURE OF GAME REFINEMENT FOR EVERY COMPETITION IN STARCRAFT II

	Terran	Zerg	Zerg*	Protoss	Average
Terran	0.0805	0.0746	0.0809	0.0747	0.07675
Zerg	0.0746	0.0692	None	0.0694	0.07107
Zerg*	0.0809	None	0.0819	0.0754	0.07940
Protoss	0.0747	0.0694	0.0754	0.0691	0.72150

Compared with other traditional board games, the result are closed, as Table V shows:

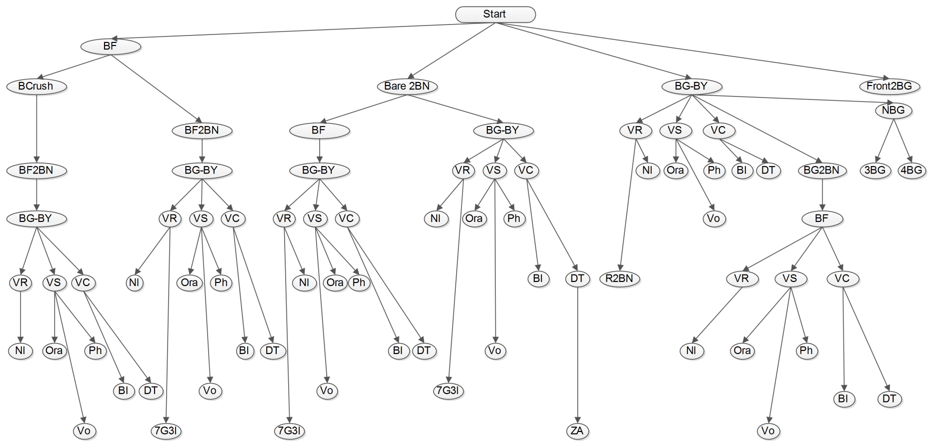

Fig. 4. The opening strategy tree of Protoss

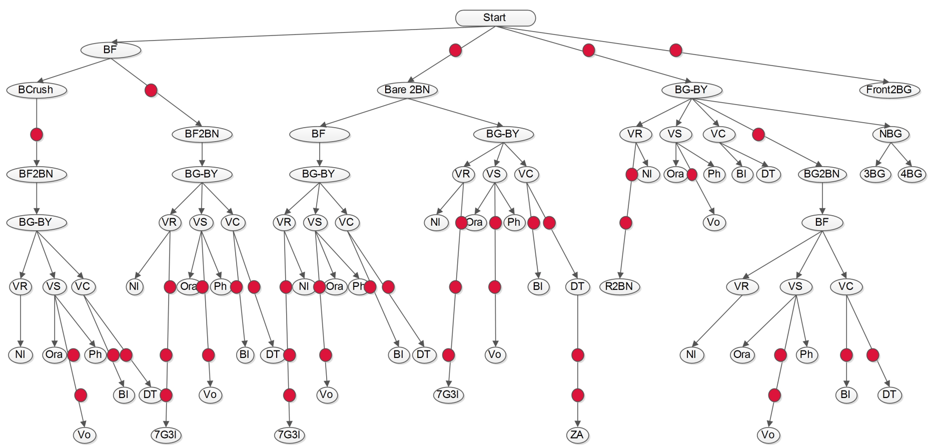

Fig. 6. The new opening strategy tree of Protoss with temporary node

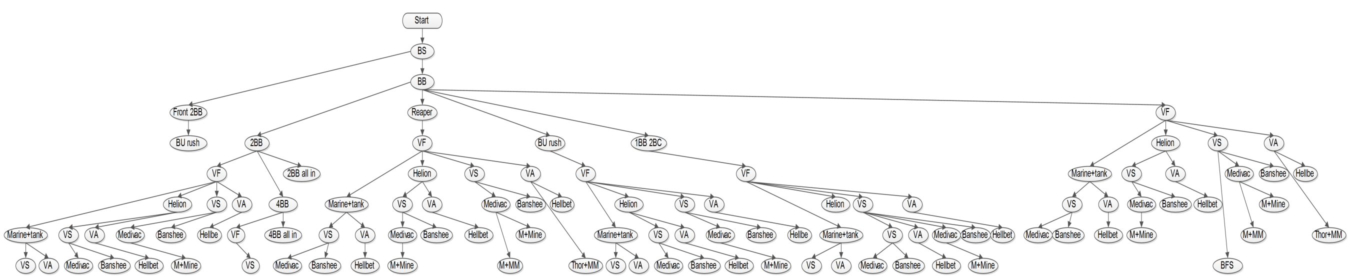

Fig. 7. The opening strategy tree of Terran

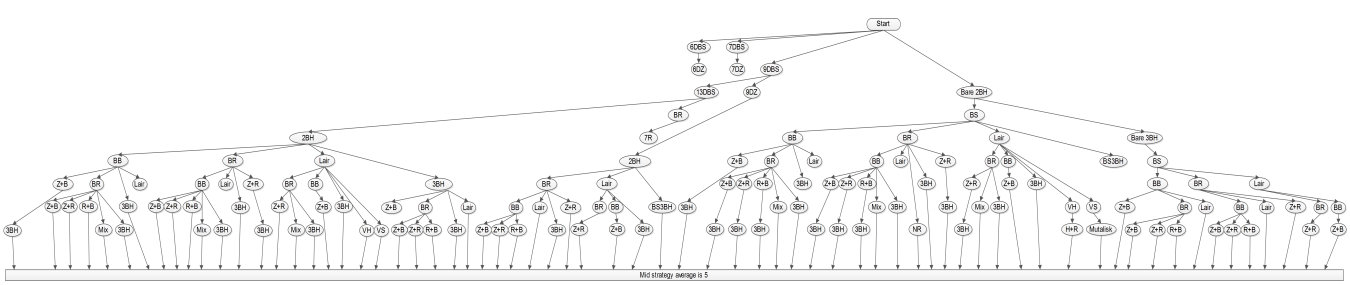

Fig. 8. The opening strategy tree of Zerg

TABLE V
GAME REFINEMENT VALUES FOR STARCRAFT II AND BOARD GAMES

Game	$\frac{\sqrt{B}}{D}$
Chess	0.074
Go	0.076
Terran	0.07675
Zerg	0.07107 to 0.07940
Protoss	0.72150

B. Discussion

As shown in Figure 7 and Figure 8, strategy trees of Terran and Zerg are more complex than Protoss. In particular Zerg's strategy tree has critical points, as shown in Figure 8. This means that game refinement value will change after crossing the critical point [10].

Below we show the illustration of tech tree structures of three different races. Figure 10 shows that Protoss tech tree is a branch tree. Terran tech tree is basic divergence linear, as shown in Figure 11. Moreover, Zerg tech tree is a disperse tree, as shown in Figure 12. Thus the different structures determine that Zerg has a strategy critical point in the opening stage, but Terran and Protoss have no such point.

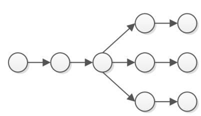

Fig. 10. Protoss's tech tree structure

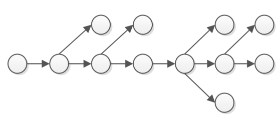

Fig. 11. Terran's tech tree structure

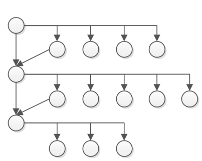

Fig. 12. Zerg's tech tree structure

TABLE VI
STARCRAFT II LADDER RACE RATIO OF GRANDMASTER GROUP

Server	Terran	Zerg	Protoss	Random
US	23.5%	38%	36.5%	2%
EU	23.8%	40.5%	34.7%	1%
China	25.5%	35.8%	34.3%	4.4%
Korea & Taiwan	30.1%	32.5%	32.5%	4.9%

Compared with the StarCraft II ladder race ratio in Table VI, it is found that the race Zerg has been selected with highest percentage in every local server. Behind that, the second popular race is Protoss. Consider the operation difficulty, the results mainly fit the research result. In addition, as shown in Figure 13 [11], we notice that the wining percentage of Terran is lower than Protoss. Actually, Protoss is much easier to control, while Terran and Protoss's player has the same APM(Actions Per Minute), Terran's player has less chance to win. According to the nature of StarCraft II, many players play the game not only for fun, but also for winning the competition, even though Terran is more interesting than Protoss, they prefer to choose the latter.

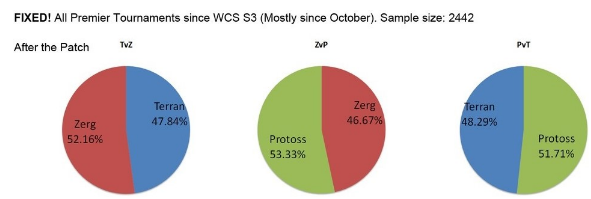

Fig. 13. wining percentage of three races

V. CONCLUSION

While introducing the concept of strategy tree, the game refinement measure has been calculated for three different races in the opening game of StarCraft II. Thus, it is possible to compare the degree of game refinement or engagement of RTS games with other type of gamers such as board games and sports games. We conclude that the resulting game refinement values of StarCraft II, as measured by game refinement theory, support the previous assumptions of a balanced window of game sophistication around 0.07-0.08.

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