Reaper Tournament System

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Abstract. This paper explores a novel way for analyzing tournament structures. Our goal is to find the best suitable tournament under considered purposes. Aside from the number of matches, we address on two other important aspects: competitiveness development and ranking precision. Competitiveness development emphasizes the importance participants' motivation in every match while keeping the matches exciting throughout the tournament. Ranking precision reflects the credibility of tournament results, so that prizes can be distributed with minimum complains and dissatisfaction. To address competitiveness development, this paper proposes a new method which visualizes tournament structures as a tree using graphical model approach, which we call *progress tree*. Considering the similarities of sorting algorithm with the ranking process, ranking precision is discussed based on the quality of algorithm for the ranking task. This paper also analyzes well known tournament structures such as single elimination, double elimination, round robin and Swiss system. The performed analysis reveals the strength and weakness of each tournament structure. Although each tournament has its own pros and cons, none of them can convince the tournament results for all participants while keeping the matches strongly motivating thoroughly. Thus, a new tournament structure called *reaper tournament system* is proposed in this paper to meet those requirements.

Keywords: Tournament structure · Competitiveness development
Stability progressing · Ranking precision

1 Introduction

Competitive games do not just attract players only, but also many spectators who are interested in the game. Tournament is a competitive system to identify the winners. It usually provides some prizes as objectives for participants to compete against each other. It is often used as a formal method to conduct an official game event, to gather players or teams, as well as to attract a large number of spectators. Such large scale events usually receive sponsorship from various companies and organizations. Therefore, it is necessary to be carefully prepared and conducted to be able to avoid disappointments from any party.

Let us discuss three main concerns in tournament systems.

1. The number of matches. This number is crucial for the tournament organizer to calculate the cost of conducting the tournament.
2. Competitiveness development (CD). That is, to avoid the throwaway matches in which participants are not so motivated to play their best. Regarding competitive games, uneven teams tend to make a reduce of interest from the viewers [13,14,18]. However, the structure of the tournament may have great effect on the motivation of the participants. It is important to plan the matches carefully, giving the participants good motivations to play their best in the game.
3. Ranking precision (RP). That is, to make sure the ranking results of a tournament are convincing and reliable. It is important to prove that the prize winners are really worthy.

Regarding the checking of a tournament for whether it can maintain the competitiveness, to the best of our knowledge, there has been until now no study of any method to perform this work. Therefore, we propose a new method to analyze the tournament structures.

The structure of the paper is as follows. Section 2 presents our method for analyzing tournament structures with a focus on competitiveness development and ranking precision. Section 3 shows an analysis of tournament structures including single-elimination, double-elimination, round-robin, and Swiss system. Section 3.6 discusses and analyzes results and evaluation. Section 4 proposes a new tournament system called *reaper tournament*, and analyzes it. Finally, concluding remarks are given in Sect. 5.

2   Analyzing Method

This section presents two important aspects of tournament systems: competitiveness development and ranking precision.

2.1   Competitiveness Development

A competitive match means that the two participants are motivated to compete over the winning outcome. Usually, the desire to win is normal. But, sometimes the benefit of winning could not be so significant, which causes the participants to not yearn for a win. The motivation of a participant consists of many factors, but we restrict ourselves to the tournament structure in this paper. We introduce a notion of "progress tree" to demonstrate the perspective of the participants in a tournament, and then analyze the development of their motivation throughout the tournament.

The progress tree is constructed based on the graphical model approach [17]. A participant's state before or after playing a match is considered as a node. The state in which the participant no longer plays any match is a leaf node. We
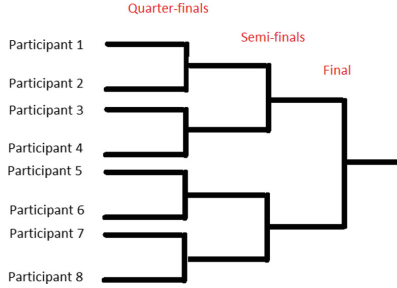
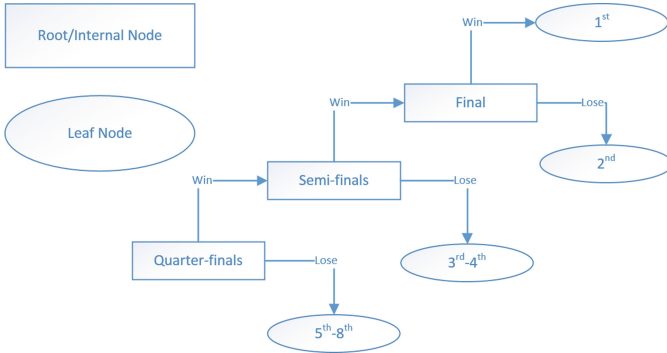**Fig. 1.** Single elimination tournament for 8 participants

Fig. 2. Progress tree of single elimination tournament for 8 participants

show, in Fig. 1, an example of a single elimination tournament for 8 participants, and Fig. 2 shows its progress tree[1].

While "competitive" means having an objective for which participants have to compete against another one, it is common to have more than one prize as objectives in a tournament. Thus, it is necessary to provide prizes that are comparable in order to ensure the consistency in competitiveness. For example, if two winners receive a spoon as the first prize and a pair of chopsticks as the second prize. Each participant may evaluate these prizes differently. Hence, it is possible that a participant would try to lose on purpose in the final match to obtain the pair of chopsticks. This is also the reason why most grand tournaments use money for prizes instead of objects, since the amounts of money are comparable, the consistency between the prizes is ensured.

With consistent prizes in the same unit, we can evaluate nodes in the progress tree. Since we are only considering the structure of the tournament, we evaluate a node as the average value of its direct child nodes. For example, in Fig. 2, let x_1, x_2, x_3 and x_4 be the 1st place prize, 2nd prize, 3rd-4th prize and 5th-8th prize

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[1] In this paper, we assume that a match can only result in a win or a loss.

respectively. Then we have $x_1 \geq x_2 \geq x_3 \geq x_4$. Table 1 shows the evaluation (called the *stability value*) for each node of the progress tree in Fig. 2.

Table 1. Stability values for each node of progress tree in Fig. 2

Node level	Stability value
Final (v)	$\frac{x_1+x_2}{2}$
Semi-final (v_1)	$\frac{v+x_3}{2}$
Quarter-final (v_2)	$\frac{v_1+x_4}{2}$

With the progress tree and having the nodes evaluated, we see that there are two concerns regarding player's motivation or competitiveness development.

Stability progressing. For every node, it is preferable to have the value of the winning outcome larger than the value of the losing outcome. This ensures that the winning outcome has more benefits and is more attractive for the participant.

Possibility of results. Since the prizes serve as an objective to maintain competitiveness, the case in which a prize is no longer able to be achieved also means that a competitive objective is lost. However, in a tournament, to achieve a prize means to give up other prizes (one cannot get the first prize and second prize together). Therefore, it is favorable to have the prizes dropping out eventually in the order of least-valuable first. This practice can also be seen in most prize announcements from lottery prizes to singing/beauty contests.

Aside from those above-mentioned points, there might be a few more interesting observations we can make with the progress tree. For example, if there is a match between two participants who are not on the same node, which means that they are not on an equal footing; the importance of the match, and their motivation of the match are different.

2.2   Ranking Precision

Being a competitive system, the outcome of a tournament should avoid any complaints about its ranking results. This task for giving rankings to the tournament participants is similar to the sorting by comparisons: the input is a list of members to be compared, while the output is a permutation of the input with the member in an order. Although actual sorting algorithms [1–3, 7, 8, 10, 15, 19] may not be suitable to be applied as tournament systems because they do not consider fair treatment to participants with the same performance, it is crucial for a tournament system to maintain the convincement of the rankings to minimize complains from participants and spectators.

We assume that there is a game in which we compare credits, where the participant with higher credits wins. The ranking precision of the tournament is derived from how the tournament can rank participants correctly for such a game. In other words, we consider the tournament as a sorting algorithm, and each match is a comparison between two participants in a game whose outcome is deterministic. Providing all participants with different credits, we run all possible simulations by using permutation. Then, we can see whether or not the tournament can give rankings to participants correctly. However, the method of using permutation simulation is too heavy if the number of participants is too large. In this paper, we therefore conduct experiments with eight participants only.

3   Analysis of Standard Tournament Systems

We analyze several standard tournament systems such as single elimination, double elimination, round-robin and Swiss system. For the purpose of comparison, we consider the example of having eight participants in each case.

3.1   Single Elimination

Single elimination is a type of elimination tournament where the loser of each bracket is immediately eliminated.

Number of Matches: A standard single elimination system with i rounds has $n = 2^i$ participants, and there will be $m = n - 1$ matches conducted. For 8 players single elimination, there would be 7 matches with 3 rounds.

Competitiveness Development: We use the example of 8 participants single elimination, as previously shown in Fig. 1. Assuming that this tournament has comparable prizes distributed in the right order, by observing Fig. 2 and Table 1, we can see that it has no issues regarding *stability progressing* or *possibility of results*. All wins are worth aiming for, and the ranking results are decided from the lowest ranking first.

Ranking Precision: We run the simulations for 8 participants with credits varying from 1 to 8. Table 2 shows the precise ranking of the tournament, while Table 3 shows the actual results counting all $(8! = 40320)$ permutations.

Remark 1. *Among all ranking results, the only 100% correct one is the 1st place. This suggests that single elimination provides the reliable ranking results for the first place only, and other rankings are not really convincing.*

Table 2. The precise ranking of single elimination

Participant	Precise ranking
8	1st place
7	2nd place
6	3–4th place
5	3–4th place
4	5–8th place
3	5–8th place
2	5–8th place
1	5–8th place

Table 3. The results of ranking simulation of single elimination

Participant	1st place	2nd place	3–4th place	5–8th place
1	0 (0%)	0 (0%)	0 (0%)	40320 (100%)
2	0 (0%)	0 (0%)	5760 (14%)	34560 (86%)
3	0 (0%)	0 (0%)	11520 (29%)	28800 (71%)
4	0 (0%)	1152 (3%)	16128 (40%)	23040 (57%)
5	0 (0%)	4608 (11%)	18432 (46%)	17280 (43%)
6	0 (0%)	11520 (29%)	17280 (43%)	11520 (29%)
7	0 (0%)	23040 (57%)	11520 (29%)	5760 (14%)
8	40320 (100%)	0 (0%)	0 (0%)	0 (0%)

3.2 Double Elimination (Classic)

A classic double elimination tournament is designed for at least four participants. At first participants are paired up one on one. The losers will be placed into the lower bracket, whereas the winners will be placed in upper brackets. From this point on, if a participant from the loser's bracket loses a game, the participant is eliminated; if a participant from the winner's bracket loses, the participant will be moved to the loser's bracket. The last participant remaining in the lower bracket will face the last participant standing in the upper bracket in the grand final. This means that after the bracket arranging round at the beginning and before the grand final, for every upper bracket's round, there would be two rounds in the lower bracket.

Number of Matches: A classic double-elimination tournament system for $n = 2^i$ participants (where $1 < i \in \mathbb{N}$) will have $m = 2n - 2$ matches conducted. Thus, we have $m = 14$ when $n = 8$.
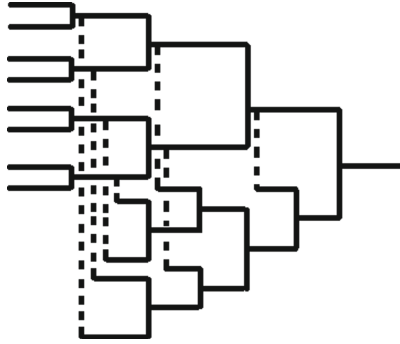
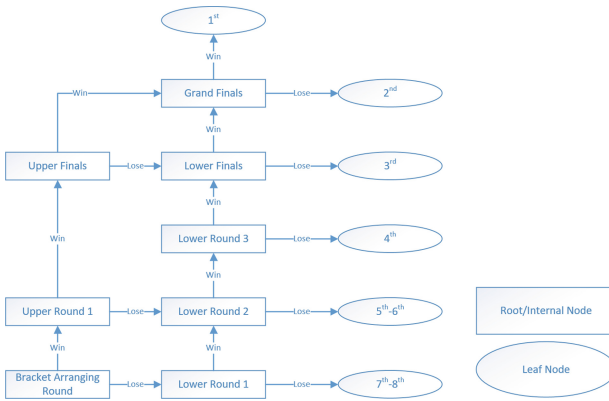Fig. 3. Classic double elimination tournament for 8 participants

Fig. 4. Progress tree of classic double-elimination tournament

Competitiveness Development: We show, in Fig. 3, a classic double-elimination tournament for 8 participants, and Fig. 4 shows its progress tree.

Assuming that this tournament has comparable prizes distributed in the right order, by observing Fig. 6, we can see that it has no issues regarding *stability progressing* or *possibility of results*. Every win has a more favorable value than its loss, and the ranking results are decided from the lowest ranking first.

Ranking Precision: We run the simulations for 8 participants with credits varying from 1 to 8. Table 4 shows the precise ranking of the tournament, while Table 5 shows the actual results counting all 8! = 40320 permutations.

Remark 2. *Our analysis suggests that the classic double-elimination tournament provides reliable ranking result for the first and second place. Still, the other rankings are not really convincing.*

Table 4. The precise ranking of double elimination

Participant	Precise ranking
8	1st place
7	2nd place
6	3rd place
5	4th place
4	5–6th place
3	5–6th place
2	7–8th place
1	7–8th place

Table 5. The results of ranking simulation of classic double elimination

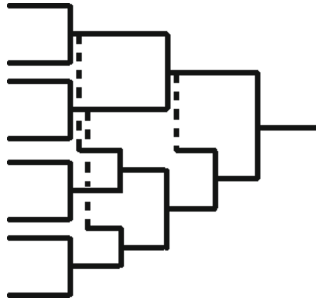| P.	1st place	2nd place	3rd place	4th place	5–6th place	7–8th place
1	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	40320 (100%)
2	0 (0%)	0 (0%)	0 (0%)	0 (0%)	17280 (43%)	23040 (57%)
3	0 (0%)	0 (0%)	0 (0%)	0 (0%)	28800 (71%)	11520 (29%)
4	0 (0%)	0 (0%)	1152 (3%)	9216 (23%)	25344 (63%)	4608 (11%)
5	0 (0%)	0 (0%)	4608 (11%)	25344 (63%)	9216 (23%)	1152 (3%)
6	0 (0%)	0 (0%)	34560 (86%)	5760 (14%)	0 (0%)	0 (0%)
7	0 (0%)	40320 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
8	40320 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)

Fig. 5. Seeded double-elimination tournament for 8 participants

3.3   Double Elimination (Seeded)

In recent double-elimination tournament systems, the bracket arranging round is considered as a pre-stage. This pre-stage can take other forms of tournaments [4,5], or use a rating system [6,9,11,12,16,20] to divide (seed) participants into upper and lower brackets. The rest works the same as in the classic double-elimination tournament.
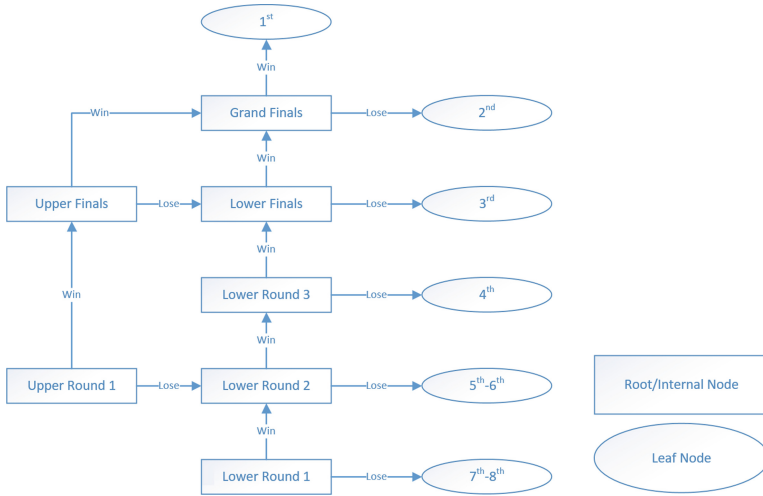
Fig. 6. Progress tree of seeded double-elimination tournament for 8 participants

Number of Matches: A standard seeded double-elimination tournament system with i upper rounds has $n = 2^i$ participants, and there will be $m = \frac{3}{2}n - 2$ matches conducted. Thus, we have $m = 10$ when $n = 8$.

Competitiveness Development: We show, in Fig. 5, a seeded double-elimination tournament for 8 participants, and Fig. 6 shows its progress tree. Assuming that this tournament has comparable prizes distributed in the right order, by observing Fig. 6, we can see that it has no issues regarding *stability progressing* or *possibility of results*. Every win has a more favorable value than its loss, and the ranking results are decided by the lowest ranking first.

Ranking Precision: We run the simulations for 8 participants with credits varying from 1 to 8. Table 4 shows the ranking outcome of the tournament, while Table 6 shows the actual results. Since it is expected that stronger participants and weaker participants will be distributed (seeded) into the upper bracket and the lower bracket properly, There will be $4! \times 4! = 576$ permutations.

Remark 3. *The results (Table 6) of the seeded double-elimination show that it is precise from the 1st to the 4th ranking. This is quite a big improvement compared to the systems we analyzed previously. However, this reliability is heavily based on the seeding system, which may cost many more matches.*

3.4   Round-Robin

In the round-robin tournament system, all participants have to play with each other. In other words, each participant plays with every other participant once. If each participant plays all others twice, the system is called *double round-robin*.

Table 6. Ranking results of seeded double elimination for 8 participants experiment

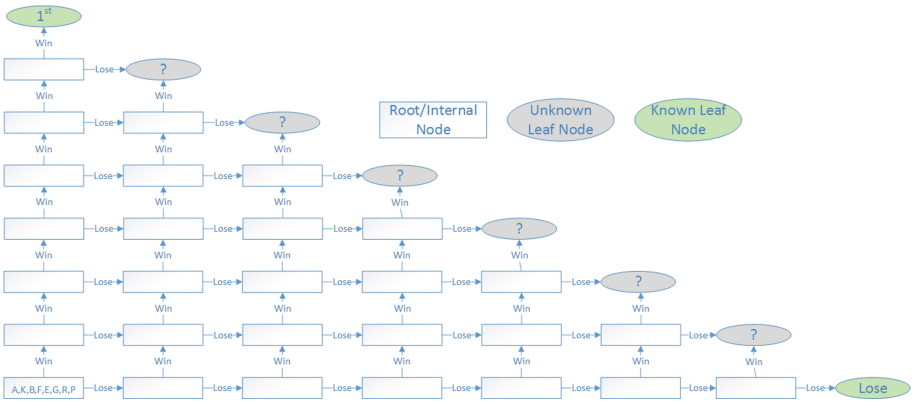| P.	1st place	2nd place	3rd place	4th place	5–6th place	7–8th place
1	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	576 (100%)
2	0 (0%)	0 (0%)	0 (0%)	0 (0%)	192 (33%)	384 (67%)
3	0 (0%)	0 (0%)	0 (0%)	0 (0%)	384 (67%)	192 (33%)
4	0 (0%)	0 (0%)	0 (0%)	0 (0%)	576 (100%)	0 (0%)
5	0 (0%)	0 (0%)	0 (0%)	576 (100%)	0 (0%)	0 (0%)
6	0 (0%)	0 (0%)	576 (100%)	0 (0%)	0 (0%)	0 (0%)
7	0 (0%)	576 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
8	576 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)

Fig. 7. The first round of progress tree of round-robin tournament for 8 participants

Number of Matches: A round-robin system for n participants consists of $m = \frac{n}{2}(n-1)$ matches conducted. Thus for 8 participants, there would be $m = 28$ matches.

Competitiveness Development: We show, in Fig. 7, a progress tree of a round-robin tournament with 8 participants. The big difference from elimination tournaments is that from the beginning, only the leaf from all losses and the leaf from all wins are known. This unstable situation makes us unable to calculate the stability values of the nodes. As the tournament progresses, the unknown leaves will gradually reveal themselves, and the stability values of the nodes would be calculated. Furthermore, unstable situations suggest that it is possible that *stability progressing* and *possibility of results* conditions are not satisfied.

We show, in Table 7, an example situation after 5 rounds, and Fig. 8 shows its progress tree. In this situation, if participant A wins the next match, his victory as the 1st place would be fixed regardless of his last match outcome. This fails to satisfy *stability progressing*. Besides, even the leaves of participants

Table 7. An example of round-robin tournament progress after 5 rounds

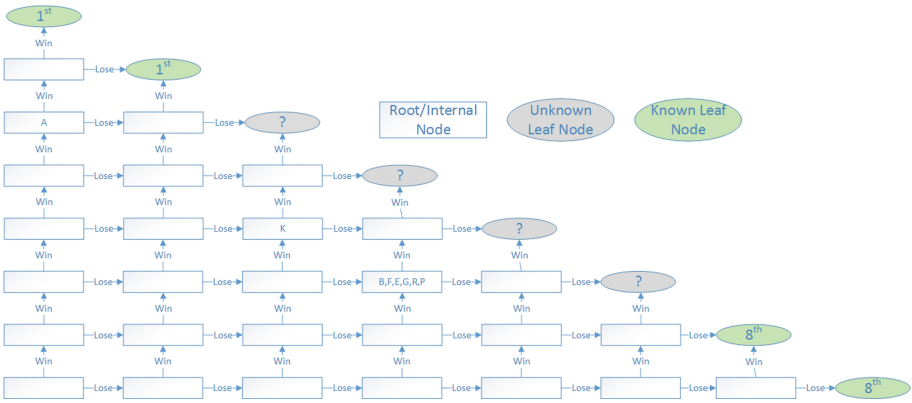| Participant	Wins	Losses
A	5	0
K	3	2
B	2	3
F	2	3
E	2	3
G	2	3
R	2	3
P	2	3

Fig. 8. Progress tree for the round-robin tournament progress presented in Table 7

B, F, E, G, R, and P are unknown, the possibility of 1st place is certainly out of reach. Therefore, this situation does not satisfy the *possibility of results* condition either.

Ranking Precision: We run the simulations for 8 participants with credits varying from 1 to 8. Then, there is only one outcome as shown in Table 8, no matter how the participants are positioned.

Remark 4. *Round-robin tournament gives a really accurate ranking in the simulation. However, the number of matches is high, and the competitiveness development is not good.*

3.5   Swiss System

The Swiss tournament system or the Swiss System is a round based, non-eliminating system that in every round each participant is matched against

Table 8. The result of round-robin tournament

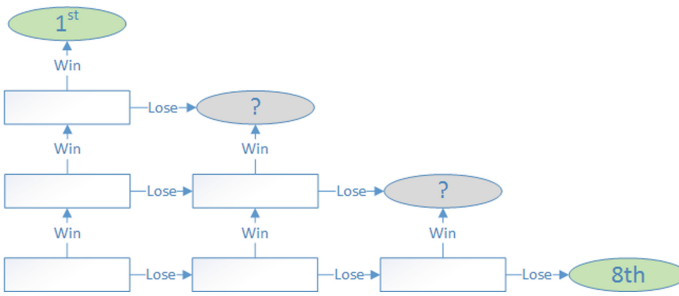| Participant	Wins	Losses	Ranking
8	7	0	1st place
7	6	1	2nd place
6	5	2	3rd place
5	4	3	4th place
4	3	4	5th place
3	2	5	6th place
2	1	6	7th place
1	0	7	8th place

Fig. 9. Progress tree of the Swiss System for 8 participants with 3 rounds

another with a similar score, but not with the same opponent more than once. The number of rounds is considerably less than in a round-robin system. Every participant has to play every round, unless the number of participants is odd. After all the rounds have taken place, if there are participants with the same scores, they will be ranked based on a rating system chosen by the tournament organizer.

We conduct our analysis on an 8 players Swiss System. Assuming that there are no drawn games, and three rounds would be needed.

Number of Matches: A standard Swiss System would require the same number of rounds as a single elimination tournament to determine a clear winner. Thus, for n participants it has $m = \frac{n}{2}(\frac{n}{2} - 1)$ matches conducted. Thus, Swiss System for 8 participants with 3 rounds would consist of $m = 12$ matches.

Competitiveness Development: We show, in Fig. 9, the progress tree of the Swiss System for 8 participants with 3 rounds. The leaf nodes of this system are special. If more than one participant reaches the same leaf node, those participants would be ranked by a rating system chosen by the tournament organizer.

Table 9. The expected and actual ranking results of the Swiss System for 8 participants with 3 rounds

Participant	Expected ranking	Precision
1	8th place	40320 (100%)
2	7th place	23040 (57%)
3	6th place	16128 (40%)
4	5th place	15360 (38%)
5	4th place	13440 (33%)
6	3rd place	16128 (40%)
7	2nd place	25088 (62%)
8	1st place	40320 (100%)

Although the number of rounds is much less compared to the round-robin system, signs of poor competitiveness development already show. A participant with a large lead would be ensured to take first place or second place, while the poor performing ones have no chance of reaching high ranks. If there are more rounds taking place, the worse would be the competitiveness development. For example, the leading participant would have the first place ensured, so his final games are unmotivated; while any of his thrown game would lead to a large change in ranking for other participants because of the rating system.

Ranking Precision: We run the simulations for 8 participants with credits varying from 1 to 8. Table 9 shows the expected precise ranking of the tournament as well as the actual results counting all 8! = 40320 permutations of Swiss System with 3 rounds.

Remark 5. *The ranking precision of the Swiss System is only reliable for the first place and the last place, while the ranking for the other participants is not. Increasing the number of rounds might gradually lead to better results. However, as mentioned in the competitiveness development section, the last games of the top participant might be unmotivated, yet its effects on the ranking of the opponents and other middle ranking participants. This furthermore causes the middle rankings to be unstable.*

3.6   Summary

We show in Table 10 the comparison between the single elimination, double elimination, round-robin and Swiss tournament system. The results show that the single-elimination system has the lowest cost, while its competitiveness development is properly maintained. However, its ranking is only reliable for the top winner. Double-elimination has no problem in competitiveness development either. Its classic style can convincingly qualify the top two winners, while its seeded system can qualify the top four winners. Round-robin on the other hand gives

Table 10. Strength and weakness of the common tournaments compared by the number of matches with n players ($n = 8$), competitiveness development (CD) and ranking precision. Note that the number of matches for the double-elimination (seeded) might be higher when counting the pre-stages.

Tournament system	Matches (for n = 8)	CD	Ranking precision
Single elimination	$n - 1 = 7$	✓	Top 1 winner only
Double elimination (classic)	$2n - 2 = 14$	✓	Top 2 winners
Double elimination (seeded)	$\frac{3}{2}n - 2 = 10$	✓	Top 4 winners
Round robin	$\frac{n}{2}(n - 1) = 28$	✗	All
Swiss System	$\frac{n}{2}(\frac{n}{2} - 1) = 12$	✗	Top 1 winner & last place

convincing ranking on all participants, but it lacks in competitiveness development, and its number of matches is the largest. Swiss system has reliable ranking for the top winner and the last place, whilst the middle rankings are not. The Swiss system also has poor competitive development.

4 Reaper Tournament System

As the results above show, there is no tournament systems which can satisfy both the competitiveness development and the ranking precision for all participants requirement. Thus, we propose a new tournament system called *reaper tournament system*. It assumes the participant number $n = 2^i$ with $1 < i \in \mathbb{N}$.

4.1 The Regulation

Each participant has a list of respected opponents (called respect list) which includes all of the opponents the participant has previously lost to. The reaper tournament system consists of the following steps.

1. **Reaper selection:** All the participants are paired up one on one, the losers will continue to be paired again until there are only two left. These two who have the worst performance will play with each other and the loser will be eliminated as the last place, while the winner will be the reaper. Go to step 2.
2. **Reaper candidates:** The eliminated participants will have their respect list ignored. Aside from the reaper and the eliminated participant(s), all participants who are not in any respect list are placed in a candidate list. If every remaining participant is in a respect list, then the list of candidates will consist of participants which are only respected by the reaper. If there is more than 1 candidate, to step 3. If there is one candidate, to step 4. If there is none, the reaper tournament ends.
3. **Candidates match:** The top two best performance participants in the candidates list will play a match. Of course the winner will be added to the loser's respect list. Go back to step 2.

4. Reaper match: The participant in the candidates list will play against the reaper. The loser from the reaper match will be eliminated and will be ranked just above the previously eliminated participant, while the winner will be the (new) reaper, the system repeatedly finds the weakest player for elimination. Go to step 2.

We show, in Fig. 10, the diagram of the reaper tournament we have just explained.
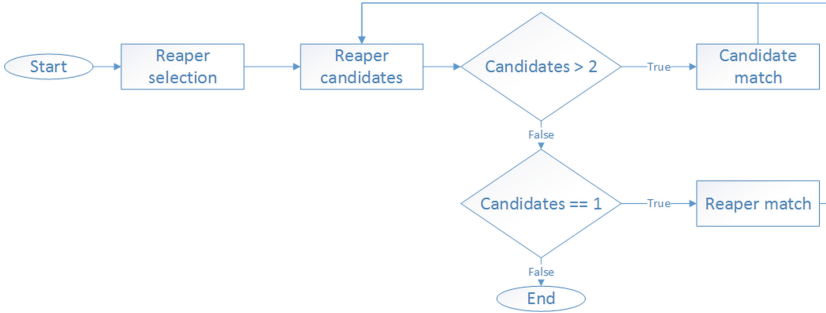

Fig. 10. The diagram of the reaper tournament system

4.2   Analysis of Reaper Tournament

We analyze the reaper tournament as done in the previous section.

Number of Matches: For a reaper tournament with 8 participants, there would be 15 to 17 matches. Since the pairing depends on who among the participants is the reaper, the total number of matches could be 15, 16 or 17. The minimum number of matches per participant is 2, and the maximum is 8.

For the reaper tournament with 4 participants, there would be exactly 5 matches, while for 16 participants it would consists of 39 to 47 matches or could be more. We have not found a general formula for the number of matches in the reaper tournament.

Competitiveness Development: Figure 11 shows the progress tree of the reaper tournament with 8 participants. Although the nodes for the reaper candidate vary depending on the actual progress, it is ensured that every win will lead to a shorter path toward higher value leaf nodes. Furthermore, the prizes are decided in bottom-up way, and all participants who are not eliminated have the chance to be awarded any remaining prize. Thus, the reaper tournament has no problem in competitiveness development.
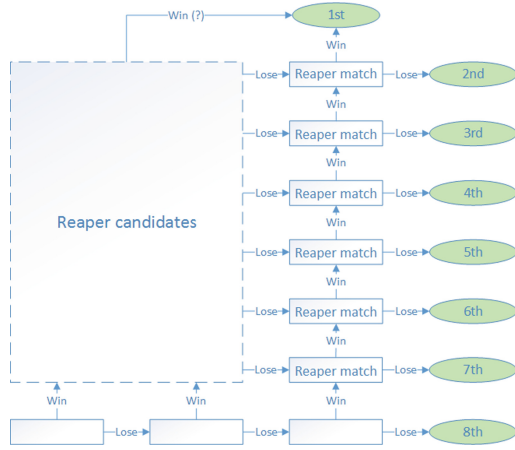
Fig. 11. Progress tree of the reaper tournament for 8 participants

Ranking Precision: We assume that we have 8 participants with credits numbers varying from 1 to 8, and the more credits always win the match. Table 11 shows the expected ranking outcome of the tournament and the actual results counting all $8! = 40320$ permutations.

Table 11. The expected and actual ranking of the reaper tournament for 8 participants

Participant	Expected ranking	Ranking precision
1	8th place	40320 (100%)
2	7th place	40320 (100%)
3	6th place	40320 (100%)
4	5th place	40320 (100%)
5	4th place	40320 (100%)
6	3rd place	40320 (100%)
7	2nd place	40320 (100%)
8	1st place	40320 (100%)

4.3   Evaluation

We show, in Table 12, the extended version of Table 10, with the reaper tournament added to the list. The reaper tournament successfully satisfies competitiveness development and provides convincing rankings for all participants. Furthermore, for 8 participants case, the number of matches required is just slightly larger than the classic double-elimination.

Table 12. Evaluation of the reaper tournament for n participants ($n = 8$)

System	Matches (for $n = 8$)	CD	Ranking precision
Reaper tournament	15–17	✓	All

5   Concluding Remarks

This paper proposed a novel way for analyzing the tournament systems. It focused on three aspects namely the number of total matches in the tournament, competitiveness development and ranking precision. It then proposed a notion of progress tree to detect potential unmotivated matches. The analysis we performed using the proposed method reveals the strength and weakness of each tournament structure. To conclude, single-elimination is best if we want to qualify one winner only. Classic double-elimination is a better choice if we want to qualify two top winners. Round-robin system provides reliable ranking precision for all participants. However, the number of matches is very high, and it fails to maintain competitiveness development. Swiss System can qualify the top winner and the last place, but its competitiveness development is poor.

Realizing that there currently is no tournament systems which could satisfy competitiveness development, we proposed a new tournament system called reaper tournament system. It is able to maintain competitiveness development while providing convincing rankings for all participants. However, we have not yet found a general formula for the number of matches. From our observation, the reaper tournament would have less number of matches than classic double-elimination in case with 4 participants, slightly larger in case with 8 players, and more in case with 16 players.

In future works, we plan to investigate the characteristics of the reaper tournament system. For example, finding out the general formula to calculate the maximum and minimum number of matches for a given number of participants.

References

1. algolist.net. Selection sort (java, c++)—algorithms and data structures (2015). http://www.algolist.net/Algorithms/Sorting/Selection_sort. Accessed 14 Aug 2015
2. Brejov, B.: Analyzing variants of shellsort. Inf. Process. Lett. **79**(5), 223–227 (2001)
3. Cormen, T.H., Leiserson, C.E., Rivest, R.L., Stein, C.: Introduction to Algorithms, 2nd edn. MIT Press, Cambridge (2001)
4. dota2.com. Main event - statitics - asia championships - dota2 (2015). http://dac.dota2.com.cn/statistical/main.htm. Accessed 12 Aug 2015
5. dota2.com. Dota 2 - the international (2016). http://www.dota2.com/international/replays/4/1/. Accessed 1 Feb 2017

6. Elo, A.: The Rating of Chess Players, Past and Present. Arco Publishing, New York (1975)
7. Han, Y.: Deterministic sorting in O (n log log n) time and linear space. J. Algorithms **50**(1), 96–105 (2004)
8. Han, Y., Thorup, M.: Integer sorting in O(n radic;(log log n)) expected time and linear space. In: Proceedings of the 43rd Annual IEEE Symposium on Foundations of Computer Science, pp. 135–144 (2002)
9. Kaiser, E., Feng, W.C.: Playerrating: a reputation system for multiplayer online games. In: 2009 8th Annual Workshop on Network and Systems Support for Games (NetGames), pp. 1–6, November 2009
10. Knuth, D.E.: The Art of Computer Programming: Sorting and Searching, vol. 3, 2nd edn. Addison Wesley Longman Publishing Co., Inc., Redwood City (1998)
11. Graepel, T., Herbrich, R., Minka, T.: Trueskill$^{(TM)}$: a Bayesian skill rating system. In: Advances in Neural Information Processing Systems, vol. 20, pp. 569–576. MIT Press, Cambridge, January 2007
12. Graepel, T., Herbrich, R., Minka, T.: Trueskill through time: revisiting the history of chess. In: Advances in Neural Information Processing Systems, vol. 20, pp. 931–938. MIT Press, Cambridge, January 2008
13. Sanderson, A.R., Siegfried, J.J.: Thinking about competitive balance. J. Sports Econ. **4**, 255–279 (2003)
14. Schmidt, M.B., Berri, D.J.: Competitive balance and attendance: the case of major league baseball. J. Sports Econ. **2**, 145–167 (2001)
15. Sedgewick, R.: Implementing quicksort programs. Commun. ACM **21**(10), 847–857 (1978)
16. Shim, K.J., Ahmad, M.A., Pathak, N., Srivastava, J.: Inferring player rating from performance data in massively multiplayer online role-playing games (MMORPGS). In: International Conference on Computational Science and Engineering, CSE 2009, vol. 4, pp. 1199–1204, August 2009
17. Sucar, L.E.: Graph theory. Probabilistic Graphical Models. ACVPR, pp. 27–38. Springer, London (2015). https://doi.org/10.1007/978-1-4471-6699-3_3
18. Szymanski, S.: Income inequality, competitive balance and the attractiveness of team sports: some evidence and a natural experiment from English soccer. Econ. J. **111**, 69–84 (2001). 108 Cowley, Oxford OX4 IJF, UK and 350 Main Street, Maiden, MA 20148, USA (2001). Blacwell Publisher
19. Thorup, M.: Randomized sorting in O(n log log n) time and linear space using addition, shift, and bit-wise boolean operations. J. Algorithms **42**(2), 205–230 (2002)
20. Zhang, L., Wu, J., Wang, Z.C., Wang, C.J.: A factor-based model for context-sensitive skill rating systems. In: 2010 22nd IEEE International Conference on Tools with Artificial Intelligence, vol. 2, pp. 249–255, October 2010