From Rock, Paper, Scissors to Street Fighter II: Proof by Construction

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Abstract

Competitive fighting games, where players choose a rapid sequence of actions designed to trump an opponent's simultaneous actions, are more complex, real-time adaptations of the well-known game *Rock, Paper, Scissors*. We present an analysis of Rock, Paper, Scissors's gameplay, as well as real-time variations. These variations comprise a constructive argument that competitive fighting games, such as Capcom's *Street Fighter II*, are indeed also variants of Rock, Paper, Scissors.

CR Categories: I.3.6 [Computer Graphics]: Methodology and Techniques—Interaction techniques

Keywords: game design, game genres, Rock, Paper, Scissors, Roshambo, Street Fighter II

1 Introduction

In *Rock, Paper, Scissors* (RPS), two players choose, in secret, one of three options (rock, paper, or scissors) and then simultaneously present, or throw, their choices to each other. The outcome is then scored. The choices are ordered cyclically: paper beats rock, scissors beat paper, and rock beats scissors. Each presentation is a complete game [Juul 2005]. The game can be extended to a series of matches, where the winner is whoever wins a majority of matches (for example, best 2 out of 3). In this paper, we refer to a single, scored, synchronous pair of throws as a match and to a series of matches as a series.

Often used casually as a tie-breaking scheme, RPS has an annual world championship [World RPS Society 2006], has been the subject of two computer tournaments [Billings 1999], [Billings 2001], and has been the subject of scholarly articles on game strategy [Billings 2000b] and its applications in other fields (e.g. [Sinervo and Lively 1996] and [Tainaka 2000]).

2 Previous work

A survey of RPS variants, increasing the number of throws and allowing additional players, is presented in [Wikipedia 2006b]. Notably, [Lovelace 2005] introduced variants with up to 25 throws, while Garfield introduced a particularly scalable variant for many players (see [Wikipedia 2006a]). [Wikipedia 2006b] describes a number of games that employ a cyclic orderings of pieces.

[Crawford 1984] discussed the intransitive nature of RPS, using the term *triangular* as an informal descriptor for intransitive relationships in game design. Recent works in game analysis propose formal definitions and design patterns (e.g. [Church 1999], [Falstein 2002], [Kreimeier 2002], [Björk et al. 2003], [Salen and Zimmerman 2003], [Zagal et al. 2005], [Juul 2005]).

[Friedman 1995] introduced the first RPS-playing computer program. The ICGA maintains a topic page on the game [Haworth 2005]. [Billings 2000b] and [Billings 2000a] present the results and findings of the First International RoShamBo Programming Competition, including game strategies. Two such tournaments were held [Billings 1999], [Billings 2001]. [Egnor 2000] presents an explanation of the winning RPS-playing program from the first tournament.

[World RPS Society 2006] describe a detailed rule set for human-played RPS games and a discussion of strategy, such as memorizing patterns of throws, opponent pattern prediction, and human psychology. [Walker and Walker 2004] discuss human RPS strategies in greater depth.

3 Analysis

Although RPS has a simpler cousin, called Matching Pennies or Odds and Evens, RPS remains better known and scores matches with an intuitive cyclic ordering. A number of less-well-known variations increasing the number of throws also exist (see [Wikipedia 2006b]); all of these games scale the complexity of the rules but change nothing fundamental about gameplay. The optimal (game theoretic) strategy for all of these games—at least, those with balanced play—is to choose randomly; this guarantees a tie on average. (This is shown for Matching Pennies in [Fudenberg and Tirole 1991]. Similar reasoning can be applied to RPS and the other variants with a balanced scoring system.) Thus, at its core, RPS is a sequence of competitive decisions with no consistently successful strategy.

The lack of a repeatably successful RPS strategy also makes it an interesting game. For every decision, both players have access to a choice capable of trumping the opponent's choice. There is no resource or position to be held or accrued. In fact, every choice is available at every decision.

In this work we focus on the choices presented to players by the game and not on how players arrive at their decisions. As such, we avoid overt discussion of player psychology. RPS-playing computer programs demonstrate the strategic depth available when predicting opponents' decisions using only the history of past decisions, and, similarly, in arcades in Japan *Street Fighter II* is played with no visual contact between players.

3.1 Must player choices be cyclic?

A reasonable question to ask is whether the ordering of player choices must be cyclic if we wish there to be no universally undefeatable choice. The answer is yes. To see this, consider choices to be nodes of a directed graph, where there is an edge from node a

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to b if b trumps a. In such a graph an undefeatable choice is represented by a node with no outgoing edges, also called a *sink*. (We are assuming that the graph is finite.) Thus, to guarantee the absence of undefeatable choices, we desire a graph with no sinks. We prove that directed, acyclic graphs must have at least one sink. Let G be a directed, acyclic graph. Because G is acyclic, there must be a finite longest path p. (If there are multiple paths of equal length, choose any.) Let v be the last node on the path. Either v is a sink, and we are done, or else v has an outgoing edge to some other vertex w. Because G is acyclic, w cannot already lie on the path, or else we would have found a cycle. Then w does not lie on the path p, and p can extended along the edge from v to w, contradicting p the longest path. Therefore, v must be a sink and the proof is complete. To guarantee no undefeatable player choices, the graph of choices must be cyclic.

For the purposes of this article, we define the class of RPS-style games as those in which players make a series of competitive decisions with no long-term advantage accumulation and access at every decision to a set of moves that includes trumps of opponents' moves.

3.2 Poker

Although we focus on real-time variants of RPS, it is instructive to point out similarities with other turn-based games.

In RPS, a match is resolved instantaneously the moment any information is shared between players. The outcome of a match is determined as soon as it has begun. In contrast, a poker match is drawn out. Players are randomly assigned a "choice," and player control is limited to information release. Moreover, these choices are totally ordered, so one player unambiguously holds a superior choice. In Poker, just as in RPS, successful players are those able to accurately predict an opponent's secret choice (whether assigned or genuinely chosen).

However, we do not consider Poker to be in the class of RPS-style games due to its lack of player choice in general and lack of trump choices in specific.

3.3 Long-term strategy games

The lack of advantage accumulation in RPS stands in marked contrast to a long-term strategy game such as chess or turn-based or real-time strategy games (e.g. [Harris 1984] or [Blizzard Entertainment 1998]). In such games, strategy consists of planning a long-term series of decisions designed to increase one's position relative to one's opponent. Better strategies predict opponents' moves farther into the future. Strategy in RPS, however, consists of predicting the opponent's next throw based upon his or her previous throws.

4 Real-time variations

We consider several real-time variants of RPS. Here, real-time refers to the time granularity of player actions (on a computer, user input). A human-scored game is limited by our human ability to score rapid, unpredictable events, whereas computer-scoring has no such limitation.

With each additional RPS variant, we move closer to competitive fighting games like *Street Fighter II* [Capcom 1991], while simultaneously arguing that the variant is still a member of the class of RPS-style games.

Variant 1 In our first and simplest real-time RPS variation, we reduce the time between throws to zero so that players are always in a state of either rock, paper, or scissors. Players can change their throw at any moment, asynchronously. The score is evaluated continuously and measured in time-points. For every millisecond that player one is showing a throw that trumps player two's throw, player one gains one millisecond in time-points (Figure 1). In this variant, a *round* lasts for 30 seconds. At the end of the round, the player with the most time-points wins. It is worth noting that this design scales to an arbitrary number of players at once; a player gains time-points for every other player he is beating at any millisecond. Observe that our only change from RPS itself is the removal of synchrony, a gameplay element present in RPS but absent from our definition of the class of RPS-style games. Clearly this variant is still a member of that class.

Variant 2 Whereas in our first variant each player is constantly showing his throw, in our second variant a throw lasts for a fixed duration. Players still throw asynchronously, however. A throw takes time until impact, at which point it is scored against an opponent's current state (perhaps also throwing), and time to retract. Before and after throwing, a player is in an idle state. In addition to predicting what an opponent will throw, players must also predict *when* an opponent will throw. A mistimed throw opens a player to his opponent counter-throwing a guaranteed trump (Figure 2). Just as variant 1 is in the class of RPS-style games, so is variant 2; we have again only removed the synchrony present in turn-based RPS.

Variant 3 Next, we experiment with throw timings. We present a third variant (based on variant 2) where rock's throw duration, the time until impact plus time to retract, is twice as long as scissors' throw time, while paper's is half as long. To preserve balance, rock scores 4 points against scissors, scissors 2 points against paper, and paper 1 point against rock.

Variant 4 We introduce additional throws to our third variant to arrive at the fourth. These additional throws provide new time and score risk and reward choices. First, we add *strong* throws that double throw duration but score twice the points, awarded to whichever player throws the trump. Strong throws double the risk and the reward.

In addition to strong throws, we introduce *gambits*, which are special throws activated by more complex input sequences. For example, pressing the button for rock three times rapidly throws an *Avalanche* gambit. If thrown against scissors, Avalanche scores [rock rock rock] against the sequence [scissors $opponent.history(1)$ $opponent.history(2)$], where $opponent.history(n)$ is the opponent's n-th previous throw. If thrown against an opponent's paper or rock, Avalanche is scored as a regular rock throw (losing or drawing). Figure 3 depicts a successful *Sharp Knives* gambit ([rock scissors scissors]). Gambits take triple the duration to retract, leaving the throwing player especially vulnerable to a trump throw. Similar gambits exist for all triplets of throws.

For each new throw, the opposing player also holds a trump. For this reason, variant 4 remains in the class of RPS-style games, having changed the scoring and variety of throws but continuing to offer players a trump for every throw.

Final variant: Street Fighter II We present the fifth and final variant of RPS, expanding on variant 4. In this variant, players have a visible avatar and an additional joystick controlling the avatar's

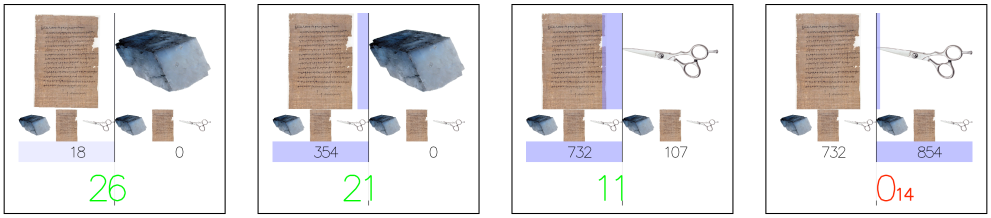

Figure 1: A 30 second round of variant 1. From left: player one throws paper, and player two throws rock; player one accumulates five seconds of time-points; player two changes his throw to scissors; eleven seconds later, player two is set to win by a slim margin.

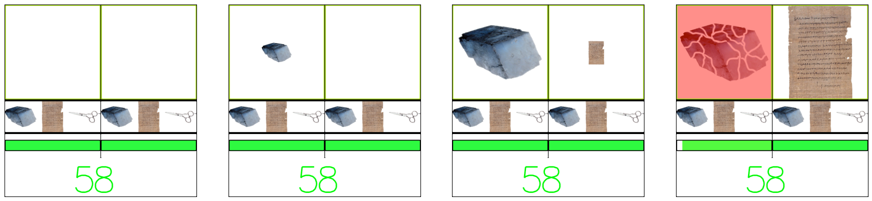

Figure 2: Variants 2 and 3. From left: both players are in the idle state; player one throws rock; player two throws paper, the trump; player two scores.

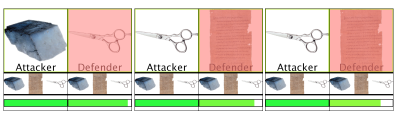

Figure 3: Variant 4. Having noticed that his opponent threw paper twice followed by scissors, player one throws the Sharp Knives gambit ([rock scissors scissors]). From left: the three stages of the gambit.

position. The number of different throws and gambits are greatly expanded. Furthermore, certain throws are only available from certain positions and only score if the opponent is in a vulnerable position. Available positions are standing, crouched, and jumping, as well as relative proximity (Figure 4, rows 1-3). Generally, a standing position is vulnerable to a crouched throw, a crouched position is vulnerable to a jumping throw, and a jumping position is vulnerable to a standing throw (Figure 4, row 4). (However, the plenitude of throws in this variation provides choices that trump even from a vulnerable position. See, for example, Figure 4, row 6, center.) With n throws, we have n^2 possible scoring decisions. Fortunately for players, there are two special throws, called *blocks*, that force a draw against $\frac{2}{3}$ of an opponent's throws. A block from a standing position results in a draw against any of an opponent's jumping or crouching throws, while a block from a crouching position results in a draw against any of an opponent's standing or crouching throws (Figure 4, row 5). Finally, there is a throw which trumps even a block, though it is available only when the avatars are in very close proximity. This throw is depicted in Figure 4, row 6 right.

In this variation gambits do not operate on an opponent's history. Instead, they have unique properties and long retract times. One gambit succeeds even when avatars are far apart (Figure 4, row 7 left). Another gambit throws in rapid succession (Figure 4, row 7 center). A third gambit scores greater points (Figure 4, row 7 right).

Position can be thought of as multiplying the number of throws, by way of the Cartesian product. That is, if there are m positions, each throw can now be thought of as m different throws, one in each position. Viewed this way, we see that the fifth variant has deviated none at all from our definition of RPS-style games.

This variant is famously represented by Street Fighter II. At this point, we have reached the gameplay and complexity of well-known competitive fighting video games.

5 Conclusions

It is worth noting that a physical fight between two opponents of equal strength, perhaps in a martial arts school and especially as depicted in choreographed scenes in martial arts movies, also bears a strong resemblance to RPS, so it should come as no surprise that the video game adaptation does, too. While no longer a game—the consequences are real—a physical fight is a sequence of short-term, asynchronous decisions made by "players," where each is capable of choosing an option that trumps the opponents coincident throw.

By better understanding the class of RPS-style video games and RPS itself, designers gain a more detailed map of games and game genres. This allows them to predict which games a design decision will bring them closer to, which is useful for studying prior work and foreseeing gameplay changes prior to prototyping.

Finally, it is important to note that some competitive fighting games include short-term advantage accumulation and that Street Fighter II is complex enough to have an unbalanced set of throws.

We close with several remarks on the strategy of *button mashing*, or pressing input buttons randomly, in competitive fighting games. Given a uniform distribution of equally-valued throws and trumps, button mashing would be the optimal (game-theoretic) strategy, always guaranteeing a tie. Alas, Street Fighter II has a biased distribution, so a strong player is able to defeat a naive button masher. (Here we are considering position as a throw modifier, by the Cartesian product. We conjecture that much of the non-uniformity is due to position.) However, it should not surprise a strong player to find that if he or she engages a naive button masher in the subset of throws the button masher does manage to uniformly sample, the result is often a tie. And button mashers need not despair; by biasing their random selection to match each throw's expected cost and outcome, by sampling from a more uniform subset of throws, or by judicious use of non-random throws, button mashers can continue to frustrate strong players by guaranteeing a draw.

Figure 4: Row 1: Standing (left), crouching (center), jumping (right). Rows 2-3: Various throws from a standing position (left), crouching position (center), jumping position (right). Row 4: White player scores with a proximate throw while standing (left), crouching (center), jumping (right). Row 5: Red player blocks white player's standing throw (left), crouching throw (center), jumping throw (right). Row 6: White player's crouching throw trumps red player's standing throw (left); white player uses an exceptional crouching throw that trumps red player's jumping throw (center); in very close proximity, white player uses the throw that trumps red player's block (right). Row 7: A gambit effective at a distance (left), that throws in rapid succession (center), that scores greater points (right).

6 Future work

Although we can guess at its structure, the directed graph of *Street Fighter II* throws remains to be drawn. In addition, games with real-time decisions, such as the variants presented, are amenable to a different sort of game theoretic analysis than the one referenced here for turn-based RPS.

The method of gameplay analysis presented in this work can be applied to any two games where one is archetypical and the other is a hypothesized member of its game class—for example, Space Invaders and first-person shooters. The hypothesis is verified if the variants do not eliminate some essential aspect of the game class.

References

BILLINGS, D., 1999. The First International RoShamBo Programming Competition. [Online; accessed 2-May-2006].

BILLINGS, D. 2000. The First International RoShamBo Programming Competition. *ICGA Journal 23*, 1, 42–50.

BILLINGS, D. 2000. Thoughts on RoShamBo. *ICGA Journal 23*, 1, 3–8.

BILLINGS, D., 2001. The Second International RoShamBo Programming Competition. [Online; accessed 2-May-2006].

BJÖRK, S., LUNDGREN, S., AND HOLOPAINEN, J. 2003. Game design patterns. In *Level Up: Digital Games Research Conference*, 180–193.

BLIZZARD ENTERTAINMENT, 1998. Starcraft. PC Game.

CAPCOM, 1991. Street Fighter II: The World Warrior. Arcade Game.

CHURCH, D. 1999. Formal abstract design tools. *Gamasutra* (July).

CRAWFORD, C. 1984. *The Art of Computer Game Design*. Osborne/McGraw-Hill, Berkeley, CA, USA.

EGNOR, D. 2000. Iocaine Powder. *ICGA Journal 23*, 1, 33–35.

FALSTEIN, N. 2002. Better by design: The 400 project. *Game Developer Magazine 9*, 3 (March).

FRIEDMAN, P., 1995. Roshambot. [Online; accessed 2-May-2006].

FUDENBERG, D., AND TIROLE, J. 1991. *Game Theory*. MIT Press, Cambridge, MA, USA.

HARRIS, L., 1984. Axis and Allies. Board Game.

HAWORTH, G., 2005. Roshambo. [Online; accessed 2-May-2006].

JUUL, J. 2005. *Half-Real: Video Games Between Real Rules and Fictional Worlds*. MIT Press, Cambridge, MA, USA.

KREIMEIER, B. 2002. The case for game design patterns. *Gamasutra* (March).

LOVELACE, D. C., 2005. Rock-paper-scissors variants. [Online; accessed 2-May-2006].

SALEN, K., AND ZIMMERMAN, E. 2003. *Rules of Play : Game Design Fundamentals*. MIT Press, Cambridge, MA, USA.

SINERVO, B., AND LIVELY, C. M. 1996. The rock-paper-scissors game and the evolution of alternative male strategies. *Nature 380* (March), 240–243.

TAINAKA, K. 2000. Physics and ecology of rock-paper-scissors game. In *Computers and Games*, Springer, T. A. Marsland and I. Frank, Eds., vol. 2063 of *Lecture Notes in Computer Science*, 384–395.

WALKER, D., AND WALKER, G. 2004. *The Official Rock Paper Scissors Strategy Guide*. Fireside, New York, NY, USA.

WIKIPEDIA, 2006. Ready, Aim, Fire — Wikipedia, The Free Encyclopedia. [Online; accessed 2-May-2006].

WIKIPEDIA, 2006. Rock, Paper, Scissors variations — Wikipedia, The Free Encyclopedia. [Online; accessed 2-May-2006].

WORLD RPS SOCIETY, 2006. World RPS Society. [Online; accessed 2-May-2006].

ZAGAL, J., MATEAS, M., FERNÁNDEZ-VARA, C., HOCHHALTER, B., AND LICHTI, N. 2005. Towards an ontological language for game analysis. In *DIGRA Conference*.