Game Balance and Game Breaking

A game theory approach

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Motivation & Research Question

What is game balance?

Are games effective for studying system behavior?
Are games important and can they be research surrogates?

Games have moved from arcade machines to consoles to hand-held mobile devices to cloud operations. This indicates that with better computational capabilities – games have increasingly become complex and have higher fidelity.

- Increasing fidelity and realism in games reflects real-world scenarios more authentically and thus creates a potential for serving as surrogates for design.

- Games have also been at the centre of AI and ML innovations over the past two decades. From AlphaGo for Chess to AlphaStar for Starcraft II.

- Agent-based games like Progenitor X, RoboCup Rescue, microRTS and many others have proven that games are effective research models. These are called ‘serious games’ or ‘applied games’.
ROCK, PAPER, SCISSORS

Is a classic example for a balanced-game.

Balanced game is one where all players involved have the same probability to win and the game has no bias over players.

For a game with only three mechanisms, the effort to make a balanced game is very small.

Games of larger scale often struggle with an inherent imbalance when originally designed.

Popular Example: Halo-3 had an overpowered gun that removed the excitement and frustrated game lovers! [10]
Research Question #1

Is game theory a good analytical tool to detect and evaluate game balance?

Subsequent Questions:

• Nash Equilibrium is a weaker solution concept, do we expect it to play a major role over Dominant Strategy Equilibrium?
• How does knowing players’ preferences or rewards provide a commentary on game balance?
• Can game theory be really applied to an RTS game, where the number of decision trees and game states are very large?
Research Question #2

*Is using Mechanism Design as the Design of Experiments approach actually effective?*

Subsequent Questions:

- How are design of experiments and mechanism design related?
- Can mechanism design be applied to finite, zero sum games?
Approach & Setup

*Framework, Model, Design of Experiments, metrics…*
Analysis

Game-balance Assessment

Mechanism Design

New Game Setting

Experiments

Data

(Tournaments for Data Acquisition)

Games

Player 1 vs. Player 2

Bot strategy, Game Mechanics and Game Setup
(Ex: influence of Strategy, Resources, Player position, Unit properties)
microRTS

microRTS is a small implementation of an Real Time Strategy (RTS) game, designed to perform AI research.

The advantage of using microRTS with respect to using a full-fledged game like Wargus or Starcraft 2 is that microRTS is much simpler, and can be used to quickly test theoretical ideas, before moving on to full-fledged RTS games.

Additional Benefits:

- Availability and Ability to create player bots (AI) with a unique set of strategy profiles.
- Completely customizable environment.
- Adding new mechanisms to create a game scenario is possible.
<table>
<thead>
<tr>
<th>Agents</th>
<th>Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>Stores resources and trains workers</td>
</tr>
<tr>
<td>Barracks</td>
<td>Trains attack units (H,L,R)</td>
</tr>
<tr>
<td>Workers</td>
<td>Harvests minerals, construct buildings and basic defense</td>
</tr>
<tr>
<td>Heavy (H)</td>
<td>High attack ability, low speed</td>
</tr>
<tr>
<td>Light (L)</td>
<td>Low attack ability, high speed</td>
</tr>
<tr>
<td>Ranged (R)</td>
<td>Long range attack ability</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Objects</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minerals</td>
<td>Harvested by workers for resources to train and build units</td>
</tr>
<tr>
<td>Terrain</td>
<td>Restricts unit movements (not used)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Actions</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Move</td>
<td>Units navigation on the map</td>
</tr>
<tr>
<td>Attack</td>
<td>Damage enemy units</td>
</tr>
<tr>
<td>Harvest</td>
<td>Gather resources using workers</td>
</tr>
<tr>
<td>Train</td>
<td>Create attack units or workers</td>
</tr>
<tr>
<td>Construct</td>
<td>Build bases or barracks</td>
</tr>
<tr>
<td>Bots</td>
<td>Strategy</td>
</tr>
<tr>
<td>--------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>LightRush</td>
<td>Rushes opponent with Light attack units</td>
</tr>
<tr>
<td>HeavyRush</td>
<td>Rushes opponent with Heavy attack units</td>
</tr>
<tr>
<td>RangedRush</td>
<td>Rushes opponent with Ranged attack units</td>
</tr>
<tr>
<td>WorkerRush</td>
<td>Rushes opponent with Worker units</td>
</tr>
<tr>
<td>LightDefence</td>
<td>Defends using Light attack units</td>
</tr>
<tr>
<td>HeavyDefence</td>
<td>Defends using Heavy attack units</td>
</tr>
<tr>
<td>RangedDefence</td>
<td>Defends using Ranged attack units</td>
</tr>
<tr>
<td>WorkerDefence</td>
<td>Defends using Worker units</td>
</tr>
</tbody>
</table>
How Game Theory is going to be used:

- Game Theory is the study of the strategic interactions of agents that are self-interested within a system or model.
- It deals with the preferences, states, information, decisions, and outcomes of the game.
  - Players – Participants in the game
  - Rules – Guidelines and boundaries of the game
  - Consequences – Negative impacts due to decisions made
  - Payoffs – Rewards for players to motivate them to continue to play

**Best Responses/Replies:**
Best Response or Best Reply is the strategy implemented by a player, conditionally, based on the decisions made by the opponent.
For every strategy in player A’s side, Player B has a best reply. This is generally based on the reward/penalty.

**Nash Equilibrium:** A strategy to maximize agents own utility/reward when the strategy of the other agents are known, and no gains can be made by any player by changing strategy when other remains the same.

**Dominant Strategy Equilibrium:** All agents will follow the same behavior of choosing a reward maximizing strategy irrespective of other player’s information, decisions and strategy.
Revisiting Rock, Paper & Scissors :: Game Balance

<table>
<thead>
<tr>
<th>Row vs Column</th>
<th>Rock</th>
<th>Paper</th>
<th>Scissors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock</td>
<td>Tie</td>
<td>Loss</td>
<td>Win</td>
</tr>
<tr>
<td>Paper</td>
<td>Win</td>
<td>Tie</td>
<td>Loss</td>
</tr>
<tr>
<td>Scissors</td>
<td>Loss</td>
<td>Win</td>
<td>Tie</td>
</tr>
</tbody>
</table>

- Both players have three equally weighted dominant strategies
- This is called a weak Dominant Strategy Equilibrium (DSE)

**Inference:** In balanced game, two possible outcomes. All actions are dominant strategies and/or players have all outcomes as weak DSE.
Role of Mechanism Design:

- Mechanism Design, a sub-field of microeconomics and game theory. It is the design of mechanisms, protocols, and institutions to satisfy certain system-wide objectives.
- It functions under two assumptions:
  - Assumption 1: Agents interacting through such institutions act in a self-interested manner.
  - Assumption 2: Agents may hold private information that is relevant to make decisions.
- Mechanism Design previously has been used in various fields to design protocols and institutions. Ex: Task allocation, network routing, market strategy, healthcare systems, auctions, military operations, etc. [17-24].

Social Objective Function: Define the system-wide objective that all agents involved must work towards/comply.

Player Objective Function: Personal preferences of agents/players.

Grim Trigger: A mechanism designed to trigger game states from their nature of repeatability.
We make use of the **Social Objective Function (SOF)** construct from Mechanism Design. The tests are separated into two categories:

- **Self-Play Games**
  - SOF: Players are restricted institutionally to use similar player strategies (bots)
  - Ex: LightRush vs LightRush, HeavyRush vs HeavyRush

- **Cross-Play Games**
  - SOF: Players are not restricted institutionally to use similar player strategies (bots)
  - Ex: LightRush vs HeavyRush, HeavyRush vs RangedRush
To establish baseline data, the game is run in the form shown in the image.

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Map</td>
<td>16x16</td>
</tr>
<tr>
<td>Resource Quantity</td>
<td>Each player gets 50</td>
</tr>
<tr>
<td>Resource Position</td>
<td>Stacked and cornered</td>
</tr>
<tr>
<td>Starting Resources</td>
<td>None</td>
</tr>
<tr>
<td>Base Positions</td>
<td>Symmetric</td>
</tr>
<tr>
<td>Starting Units</td>
<td>One Worker unit</td>
</tr>
</tbody>
</table>

T: 0, P0: 2 (3.0), P1: 2 (3.0)
### Self-Play Games:

#### Stand-alone Games

<table>
<thead>
<tr>
<th>Tournament Type</th>
<th>Generations (x3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource Quantity (RQ)</td>
<td>30, 40 &amp; 60</td>
</tr>
<tr>
<td>Resource Position (RP)</td>
<td>Displaced by 1, 2 &amp; 3 cells</td>
</tr>
<tr>
<td>Base Position (BP)</td>
<td>Displaced closer, farther &amp; equidistant to resources</td>
</tr>
<tr>
<td>Starting Resources (SR)</td>
<td>2, 4 &amp; 5</td>
</tr>
</tbody>
</table>

#### Asymmetric Games

<table>
<thead>
<tr>
<th>Tournament Type</th>
<th>Generations (x2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(RQ, RP)</td>
<td>(60, closer) &amp; (40, closer)</td>
</tr>
<tr>
<td>(RQ, BP)</td>
<td>(60, closer) &amp; (40, closer)</td>
</tr>
<tr>
<td>(RQ, SR)</td>
<td>(60, 2) &amp; (60, 5)</td>
</tr>
</tbody>
</table>
Cross-Play Games:

<table>
<thead>
<tr>
<th>Tournament Type</th>
<th>Generation - 1</th>
</tr>
</thead>
</table>
Results

*Is microRTS a balanced game?*

*Has game theory aided in understanding game balance?*
## Self-Play Games

### Resource Quantity (RQ)

**Native RQ: 50 for both players**  
**Number of Games: 24**  
**Iterations: 2**

**Dominant Strategies:**  
Player 1 – 1,3,2  
Player 2 – 4,4,5

**Dominant Strategy Equilibrium:** None

**Event:**  
No effect on majority of the strategies;  
*LightDefence* shows RQ does impact the balance in it’s case.  
Shows that it is heavily dependent on RQ when compared to other strategies.

### Inference: RQ controls where game balance lies.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Player 2 changes</th>
<th>RQ-30</th>
<th>RQ-40</th>
<th>RQ-60</th>
</tr>
</thead>
<tbody>
<tr>
<td>LightRush</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>HeavyRush</td>
<td></td>
<td></td>
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<tr>
<td>RangedRush</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WorkerRush</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LightDefence</td>
<td>Player 1 Wins</td>
<td>Tie</td>
<td>Player 2 Wins</td>
<td></td>
</tr>
<tr>
<td>HeavyDefence</td>
<td>Player 2 Wins</td>
<td>Player 2 Wins</td>
<td>Player 2 Wins</td>
<td></td>
</tr>
<tr>
<td>RangedDefence</td>
<td>Tie</td>
<td>Tie</td>
<td>Tie</td>
<td></td>
</tr>
<tr>
<td>WorkerDefence</td>
<td>Tie</td>
<td>Tie</td>
<td>Tie</td>
<td></td>
</tr>
</tbody>
</table>
Self-Play Game DOE inferences:

- **Resource Position (RP)** is a critical mechanism of game balance. The farther it is from a players’ base, the higher the probability of losing.

- **Base Position (BP)** is a sensitive mechanism of game balance. Slightest change can easily modify the probability of win.

- The game run times drastically decreased with increase in **Starting Resources (SR)**. This proves SR is an impactful mechanism too, but no comment can be made on its extent of control on game balance unless the run times are analyzed.
Asymmetric Self-Play Game DOE inference:

- RQ & RP have opposing interdependency, i.e., both increase the win probability for their respective players.
- BP is a stronger contributing mechanism than RQ.
- Defense based strategies are unaffected by BP-RQ variation.
- SR seems to be stronger than RQ.
Cross-Play Games

**Number of Games:** 16 – *in each tournament*

**Iterations:** 2

**Events:**
WorkerDefense has the highest balance based on the number of ties. This is closely followed by RangedDefense for being the second most ties.

This is also very accurate with the nature of results we observed in the self-play games which suggested that RangedDefense and WorkerDefense are the most balanced strategies in the microRTS game play.

HeavyRush, WorkerRush, LightRush and HeavyDefense are the least balanced

**Inference:** Defense strategies are very well balanced.
**Cross-Play Games**

**Dominant Strategies:**
Player 1 – WorkerRush, LightRush
Player 2 – WorkerRush, LightRush

**Dominant Strategy Equilibrium:** 2 (Repeatable zero-sum game, no Nash)

**Inference:** Existence of Dominant Strategy Equilibrium does not point to a balanced game, unless the equilibrium is of weakly strategic dominance and ends in ties. The number of equilibriums do not comment on the extent of balance.

![Payoff Matrix](image)
Is game theory a good analytical tool to detect and evaluate game balance?

Yes, Dominant Strategy Equilibrium helps us detect imbalances!

- Nash Equilibrium is a weaker solution concept, do we expect it to play a major role over Dominant Strategy Equilibrium?
  No, Dominant Strategy Equilibrium is more suitable as the RTS game setting from our perspective; turns out to be a zero-sum game!

- How does knowing players’ preferences or rewards provide a commentary on game balance?
  In zero-sum observable games, this would allow us to point to the best responses of each of the players. With that knowledge it is easy to find Nash and Dominant Strategy Equilibriums.

- Can game theory be really applied to an RTS game, where the number of decision trees and game states are so large?
  Yes, only until the game states can be finite or the perspective is changed from a specific game to player lens (like in our case).
Research Answers #2

Is using Mechanism Design as the DOEs approach actually effective?

Yes, with some precautions and careful modelling!

- How are DOEs and Mechanism Design related?
  Mechanism Design and DOE are not related but complement each other in sequential order. One can easily define the different forms of mechanisms to be tested, and DOE helps in setting up the tests. Another caveat is that imbalances can be in either direction, hence the relation between MD and DOE needs to be completely explored before finalizing experiments.

- Can mechanism design be applied to finite, non-zero sum games?
  Yes, but the finiteness of a game is a huge range. In our case we had 4 mechanisms varied, but microRTS potentially has 9. This further needs to be tested to confidently say that mechanism design is the best approach for finite games.
Future Work

- Full Factorial DOE for complete assessment
- Automated Mechanism Design
- Use game balance knowledge to game break
- Explore additional metrics
Thank You!

Questions?
References


[10] J. Griesemer, “Design in Detail: Changing the Time Between Shots for the Sniper Rifle from 0.5 to 0.7 Seconds for Halo 3,” 2010.
References


References


59


References


Research Publications

At Purdue/CISA:


Accepted:
Prajwal Balasubramani, Cesare Guariniello, Daniel DeLaurentis. “Information fusion architectures to handle emergence in autonomous agent scenarios” For AIAA Scitech 2021 Forum

Prior: