2023-Konicki

Exploiting Extensive-Form Structure in Empirical Game-Theoretic Analysis

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- **Date**: 2023-02-02
- **Link:** paper
- **Authors:**
  - Konicki, Christine
  - Chakraborty, Mithun
  - Wellman, Michael
- **Cites:**
- **Cited by:**
- **Keywords:**
- **Collections:**
- **Status:** #in-progress

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0. Abstract

- *Empirical game-theoretic analysis* (EGTA) - general framework for reasoning about complex games using agent-based simulation.

- Approach:
  - Prior EGTA work focuses on normal form game models that lack temporal structure.
  - *Tree-exploiting EGTA* (TE-EGTA) - applying extensive-form game models to EGTA to utilize tree representations as a temporal structure.

    > KEY IDEA - exploit key structure while maintaining tractability. Balance between granularity and model complexity.

- Results:
  - Exploiting some temporal structure can reduce estimation error in strategy-profile payoffs when compared to the normal form model.
  - TE-EGTA improves performance in the iterative setting, when strategy spaces are extended incrementally, as measured by equilibrium approximation.

1. Introduction

- Advantages of EGTA with the normal-form model:
  - Employs agent-based simulation to induce a game model over a restricted set of strategies.
  - This approach is well suited for complex games.
    - Complexity of dynamics and information can be expressed in the simulator, abstracting it from the game model.
  - Associates a payoff vector with each combination of strategies available to the agents.
  - Treat agent strategies as atomic objects.

- Advantages of EGTA with the extensive-form model:
  - Richer model form:
    - Game is expressed as a tree where nodes are game states and edges are agent actions or chance events.
  - Agent strategies are not atomic.
    - Because the tree structure captures fine grained sequences of observations and actions, the model is capable of capturing structures shared across strategies.

> GOAL - take advantage of EFG structure, at flexible granularity, for complex game environments described by agent-based simulation.
>
> Marry the ability to solve complex games via agent-based simulation (provided by NFG expressions) with the rich strategy description (provided by the EFG expression).

- Two modifications to EGTA for EFG:

  1. Methods must estimate the parameters for EFG necessary for describing the imperfect information available to players.
     These include:
     - Payouts - player utilities at terminal nodes.
     - Environment dynamics - probability distribution over successor states for stochastic events (chance nodes).

  2. Methods must extend EFG models as the strategy is expanded, across iterations of the EGTA process.
     - This is done by using a standard approach that incorporates deep RL within EGTA to iteratively augment the EGT model.

- TE-EGTA is tested across three games and measured to outperform previous EGTA models.
- Performance measures:
  1. Average estimation error for true player payoffs for all strategy combinations in the empirical game.
  2. Regret of empirical-game solutions with respect to the full multiagent scenario.

- Paper outline:
  - Section 2 (Preliminaries) - technical background for EFG and EGTA.
  - Section 3 (Tree-Exploiting) - describes TE-EGTA.

- Section 4 (Payoff Estimation Improvement: Theoretical Results) - theoretical results.
- Section 5 (Experiments) - experimental results.

2 - Preliminaries

2.1 - Extensive-Form Games (EFGs)

- *Extensive-form game* (EFG) - model for strategic multi-agent scenarios where agents act sequentially with varying sets of imperfect information about the history of game play.

- History of EFG theory:

  - 1996-Koller - generalized Lemke-Howson method for computing the Nash Equilibria for two-player perfect recall games.

  - 2013-Gatti - replicator dynamics.

  - 2015-Heinrich - fictitious self-play.

  - 2018-Kroer - framework for analyzing abstractions of large-scale EFGs.

  - 2020-Zhang - small certificates carrying proofs of approximate NE.

- This paper assumes agents have perfect recall.

- *Tree structure* - defined as the tuple $G := \langle \, N, \, H, \, V, \, \{I_j\}_{j=1}^{n}, \, \Pi_{j}{}_{j=1}^{n}, \, X, \, P, u \, \rangle$.
  Where:
  - $N = \{0, \, \ldots, \, n\}$ - set of *players*.
    Player 0 represents *Nature* - a non-strategic agent responsible for stochastic events.

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