Reasoning about interactions when all actions are public

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Based on joint work with
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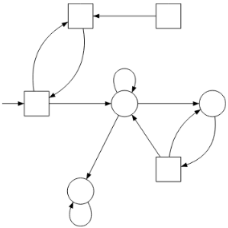
How to algorithmically reason about the behaviour of agents in multi-agent systems?

Algorithmically reason = verification and synthesis

Models



$M = \langle S, Tr, Obs \rangle$ is a transition system modeling dynamics

S	finite set of states
$Tr : S \times Act^{Ag} \to S$	deterministic transition function
$Obs : S \times Ag \to \Omega$	observation function

- Distributed systems
- Multi-player games
- Multi-agent planning domains

Specifications

$$\varphi$$

1. Temporal objectives (LTL, etc.)
   - Achievement: Robot eventually reaches room A.
   - Liveness: Robots deliver packages infinitely often.
   - Safety: Robot’s don’t collide.
2. Properties of agent strategies (ATL, SL, etc.)
   - Winning: strategy guarantees temporal objective.
   - Equilibria: strategies form a Nash equilibrium.
   - Pareto frontier: no agent can improve without harming another.
   - Evolutionary stable strategy: if all agents adopt it, no mutant can invade.

Model-checking problem

- M is a transition system modeling dynamics
- φ is a formula of a strategic logic

Algorithmic problem: given M and φ decide if $M \models \varphi$.

For strategic logics, the techniques also do synthesis.

Partial observation makes things hard

... in a variety of (overlapping) settings:

1. Multiplayer Games — Peterson, Reif 1979
2. Distributed Synthesis — Pnueli, Rosner 1990
3. Model checking ATL — Alur, Henzinger, Kupferman 2002
4. Finite-horizon decentralised POMDPs — Bernstein, Givan, Immerman, Zilberstein 2002
5. Model checking SL and Rational synthesis — Mogavero, Murano, Vardi 2010. Fisman, Kupferman, Lustig 2010. Kupferman, Perelli, Vardi 2014. Gutierrez, Perelli, Wooldridge 2016

E.g., Solving 3-player reachability games: ptime vs. undecidable

How to tame the complexity of reasoning about agents with partial observation?

What is the source of the difficulty?

Seems to be an interplay between...

1. agents having incomparable observations.
2. agents having private communication.

What happens if we drop one of the two?

Drop private communication

- Broadcasting systems (axiomatisation, LTLK synthesis)

  Lomuscio, van der Meyden, Ryan 2000. van der Meyden, Wilke 2005.

- Epistemic planning with public announcements is NP-complete

  Bolander, Holm Jensen, Schwarzentruber 2015 Kominis, Geffner 2015, 2017.

- Game Description Language (II) has “sees” operator

  Schiffel, Thielscher 2014

- In context of multi-agent path finding Nebel (this workshop)

Our contribution

1. Define multi-agent systems with public actions (PubAct-MAS)
2. Define Strategy Logic for imperfect information agents (SLi)
3. Study the complexity of model checking

Public-Action MAS M

M is a PubAct-MAS if the last action of each agent is observable to all agents.

i.e.,

- Each agent has a private component, which it observes, and
- the last action of each agent is stored in the private component of each agent.

SLi Specifications φ

SLi is like FOL (with equality) with variables for strategies.[1]

It can express many solution concepts.

E.g., Say $Goal_i$ is an LTL formula for the objective of agent i.
Nash Equilibrium:

$$(\exists x_i)_i bind(a_i, x_i)_i \bigwedge_i [(\exists y_i bind(a_i, y_i) Goal_i) \to Goal_i]$$

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[1] Strategies are

1. memoryfull,
2. uniform for the agents that use them,
3. quantified using objective $\exists_o x$ or subjective $\exists_s x$ semantics.

Complexity of $M \models \varphi$

Theorem. Model-checking PubAct-MAS against SLi is decidable.

- Complexity for formulas of alternation depth k is $k + O(1)$-ExpTime.
- Complexity for ATL_i^* is 2ExpTime-complete.

Note. Complexity is (roughly) the same as the case of observable states and actions!

Middle ground.

Observable states and actions $<$ PubAct-MAS $<$ MAS

If you remember one fact from this talk...

We now have algorithms that model check (and synthesise) many solution concepts in multi-agent systems assuming all actions are public.

Lots more questions!

- How to deal with stochastic models (Shlomo?)
- How to deal with quantitative objectives (Giuseppe P.?)
- How to engineer practical algorithms (Nello/Moshe?)