Strategic Abilities of Asynchronous Agents: Semantic Side Effects


ABSTRACT

Recently, we have proposed a framework for verification of agents’ abilities in asynchronous multi-agent systems, together with an algorithm for automated reduction of models [14, 16]. The semantics was built on the modeling tradition of distributed systems. As we show here, this can sometimes lead to counterintuitive interpretation of formulas when reasoning about the outcome of strategies.

KEYWORDS

Alternating-time temporal logic; asynchronous systems; semantics

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1 INTRODUCTION

Alternating-time temporal logic ATL* [3, 4, 28] allows to express important functionality and safety requirements in a simple and intuitive way. Moreover, algorithms and tools for verification of strategic abilities have been in constant development for almost 20 years [1, 2, 5–10, 12, 13, 17–19, 21–23, 25, 26]. It has been recently proposed how to adapt the semantics of ATL* to asynchronous models [14, 16]. We show that the semantics leads to counterintuitive interpretation of strategic properties [15]. First, the semantics disregards finite paths. In consequence, it evaluates some intuitively non-intuitive interpretation of strategic properties [15].

2 MODELS OF MULTI-AGENT SYSTEMS

We first recall the models of asynchronous interaction in MAS, proposed in [14] and inspired by [11, 20, 27].

Definition 2.1 (Asynchronous MAS). An asynchronous multi-agent system (AMAS) S consists of n agents Agt = {1, . . . , n}, each associated with a tuple Ai = (Li, i, Etvi, Ri, Ti) including a set of local states Li = {l1i, l2i, . . . , lmi}, an initial state i ∈ Li, and a set of events Etvi = {a1i, a2i, . . . , ami}. An agent’s repertoire of choices Ri : Li → 2Etvi \ {∅} selects the events available at each local state.

Figure 1: The AMAS from Ex. 2.4 and its model Mconf. In bold: strategy of coalition {gc, oc} and the transitions it enables.

T1 : L1 × Etv1 → L1 is a local transition function such that T1(l1, a) is defined iff a ∈ R1(l1). Etv = \{i ∈ Agt | a ∈ Etvi\} is the set of all events, and Agent(a) = \{i ∈ Agt | a ∈ Etvi\} is the set of agents whose repertoires include event a. Each agent i is endowed with a disjoint set of its local propositions PVi, and their valuation Vi : L1 → 2PVi. PVi = \{i ∈ Agt | PVi\} is the set of all local propositions.

We use the standard execution semantics from concurrency models, i.e., interleaving with synchronization on shared events.

Definition 2.2 (Model). Let S be an AMAS with n agents. Its model JIS(S) extends S with: (i) the set of global states ST ⊆ L1 × L2 × Ln, including an initial state (l1, . . . , ln); (ii) the global transition function T : ST × Etv \→ ST, defined by T(γ, α) = γ 2 for all i ∈ Agent(α) and γi1 = γi2 for all i ∈ Agt \ Agent(α); (iii) the global valuation of propositions V : ST → 2PV, defined as V(l1, . . . , ln) = \bigcup\∈Agt Vi(l1).

Definition 2.3 (Enabled events). α ∈ Etv is enabled at g ∈ St if g α → γ for some γ ∈ ST; enabled(g) is the set of such events.

Moreover, let A = (1, . . . , m) and FA = (a1, . . . , am). β ∈ Etv is enabled by FA at g ∈ St iff for every i ∈ Agent(β) ∩ A, we have β = ai, and for every i ∈ Agent(β) \ A, it holds that β ∈ R1(gi). We denote the set of such events by enabled(g, FA). Clearly, enabled(g, FA) ⊆ enabled(g).
An automata network is typically required to produce no deadlock states. In case of AMAS, the situation is more delicate. Even if the AMAS as a whole produces no deadlocks, some strategies might, which makes the interpretation of strategic modalities cumbersome. We illustrate this on the following example.

Example 4.1. Consider the 3-agent AMAS and its model $M_{\text{conf}}$, which are depicted in Figure 1. Clearly, $M_{\text{conf}}$ has no deadlock states. Let us now look at the collective strategies of coalition $\{gc, oc\}$, with agent $oc$ serving as the opponent. It is easy to see that the coalition has no way to prevent the opening of the conference, i.e., it cannot prevent the system from reaching state 101. However, the strategy depicted in Figure 1 produces only one infinite path, namely $\langle 000 \text{ giveup} \rangle$, since the semantics in Section 3 disregards finite paths. We get $M_{\text{conf}}, 000 \models \langle \phi \rangle$ and $M_{\text{conf}}, 000 \not\models \langle \phi \rangle$, which is counterintuitive.

Things can get even trickier. For the ir-semantics, it may happen that the outcomes of some (or even all) strategies of a coalition are empty, which leads to situations where the intuitive meaning of a strategic formula differs significantly from its formal interpretation.

Example 4.2. Let us add the transition $0 \xrightarrow{\text{proceed}} 0$ in agent $oc$, and remove the transitions labeled with $\text{giveup}$ in agent $sc$. The resulting model $M'_{\text{conf}}$ has no deadlock states, yet all the joint strategies of $\{gc, oc\}$ produce only finite runs. Since finite paths are not included in the outcome sets, and the semantics in Section 3 rules out strategies with empty outcomes, we get that $\neg \langle \langle \phi \rangle \rangle \text{F} \top$, which seems definitely wrong.

Notice that removing the non-emptiness requirement from the semantic clause in Section 3 does not help. In that case, any joint strategy of $\{gc, oc\}$ could be used to demonstrate that $\langle \langle \phi \rangle \rangle \text{G} \bot$.

4.2 Strategies in Asymmetric Interaction

In this section, we point out that AMAS is too restricted to model the strategic aspects of asymmetric synchronization (e.g., a sender sending a message to a receiver) in a natural way.

Example 4.3. Consider the global state 101 of the conference model $M_{\text{conf}}$, i.e., the state where it has just been decided to proceed with the conference. In that state, we have $\langle \langle \phi \rangle \rangle \text{G} \neg \text{median}$, meaning that the GC chair can make sure that the epidemic risk is always low. This is achieved by $gc$ selecting online at its local state 1. Then, the next transition can be obtained only if the $oc$ module synchronizes with $gc$ on event online. On the other hand, we also have that $\langle \langle \phi \rangle \rangle \text{F} \text{epid}$ holds at $M_{\text{conf}}, 101$, which is obtained by the OC’s strategy selecting onsite at 0. That is rather odd, in particular it violates the standard postulate of superadditivity [24].

The problem arises because the repertoire functions in AMAS are based on the assumption that the agent can choose any single event in $R(I)$. This does not allow for a natural specification of the situation when the transition is determined by another agent.

5 CONCLUSIONS

In this paper, we reconsider the asynchronous semantics of strategic ability for multi-agent systems, proposed recently in [14]. We show that adding strategic reasoning on top of the modeling machinery, inherited from distributed systems, leads to counterintuitive interpretation of formulas. We identify two main sources of problems. First, the execution semantics does not handle reasoning about deadlock-inducing strategies well. Secondly, the class of representations lacks constructions to resolve the tension between the asymmetry imposed by strategic operators on the one hand, and the asymmetry of interaction, e.g., between communicating parties.

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REFERENCES


