# Improving Efficiency of Model Checking for Variants of Alternating-time Temporal Logic (Extended Abstract)

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## 1 Multi-agent Systems and ATL$^\star$

Multi-agent systems describe interactions of multiple entities called *agents*, often assumed to be intelligent and autonomous [1, 14]. *Alternating-time temporal logic* (ATL$^\star$) and its fragment ATL [2] are logics which allow for reasoning about strategic interactions in such systems, by extending the framework of temporal logic with the game-theoretic notion of *strategic ability*. Hence, ATL$^\star$ enables to express statements about what agents or their groups can achieve. Such properties can be useful for specification, verification, and reasoning about interaction in agent systems [12, 13], as well as about security and usability in e-voting protocols [4, 9]. They have become especially relevant due to active development of algorithms and tools for verification [16], where the "correctness" property is given in terms of strategic ability. While model checking of ATL under perfect information seems to be feasible in practice [5], model checking of ATL under imperfect information [17] is still applicable only to small and medium size systems [10]. This lecture is about selected approaches which can make model checking ATL$^\star$, ATL and its time extension TATL more efficient.

## 2 Model Reduction Methods for Variants of ATL$^\star$

Abstraction is a method which typically transforms large (or infinite) models into smaller (or finite) ones, but frequently defined over lattices of more that two *truth* values. We present *multi-valued* ATL$^\star$ (mv-ATL$^\star_{\preccurlyeq}$), an expressive logic to specify strategic abilities in multi-agent systems [7]. We show how to identify constraints on mv-ATL$^\star_{\preccurlyeq}$ formulas for which the general method for model-independent translation from multi-valued to two-valued model, can be suitably adapted to mv-ATL$^\star_{\preccurlyeq}$, Moreover, we present a model-dependent reduction that can be applied to all formulas of mv-ATL$^\star_{\preccurlyeq}$. In all cases, the complexity of verification increases only polynomially when new truth values are added to the evaluation domain.

*Partial order reduction (POR)* is another method used to alleviate the state space explosion in model checking [15]. We define a general semantics for strategic abilities of agents in asynchronous systems, with and without perfect information, and present some general complexity results for verification of strategic abilities in asynchronous

systems [11]. A methodology for *POR* in verification of agents with imperfect information is discussed, based on the notion of *traces* introduced by Mazurkiewicz. We define the logic *simple* ATL$^\star$, which is the restriction of ATL$^\star$ such that the strategic modalities cannot be nested and the next step modality is not allowed. Two semantics of *simple* ATL$^\star$ are considered and it is shown that for memoryless imperfect information contrary to memoryless perfect information, one can apply the partial order reduction techniques known for Linear-time Temporal Logic without the next step operator.

## 3 Timed ATL

Finally, we discuss Timed Alternating-time Temporal Logic (TATL), a discrete-time extension of ATL. A new semantics, based on counting the number of visits in locations of the history, is introduced in addition to timed memoryful and memoryless ones [3]. We show that all the defined semantics are equivalent for TATL$_{\leq,\geq}$, i.e., when $=$ is not allowed in the formulas. We provide a strategy analysis revealing that it suffices to consider only two actions per location to verify any TATL$_{\leq,\geq}$ formula. This does not extend to TATL. The above results allow for building a hierarchy of strategies comparing the expressive power of the logics against ATL. We discuss a possible impact of this hierarchy on improving efficiency of model checking for TATL$_{\leq,\geq}$.

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