Abstraction for Model Checking Modular Interpreted Systems over ATL

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Outline

Motivation

Model Checking

Advantages:

- Faster than **Theorem Proving**

Disadvantages:

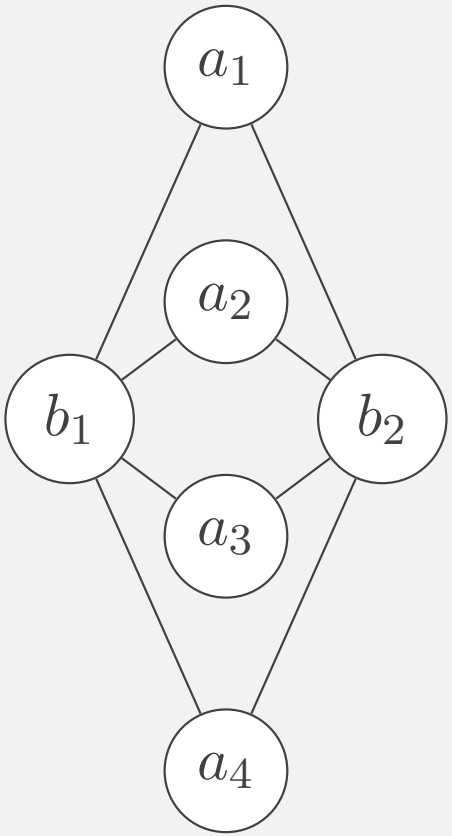
- Explicit representation: a lot of states, in practise not usable
- Compact representation: model checking complexity increases

Idea:

- Reduce the state space before model checking

Communication between Agents

Example 1 (Communicating Agents)



- Agents of team B are not allowed to send a message back.
- If an agent b_j has received a message from a_i then it has to send it to some agent a_k in the following round, $k > i$.

Is it possible for team A to ensure that a_4 will know the message eventually?

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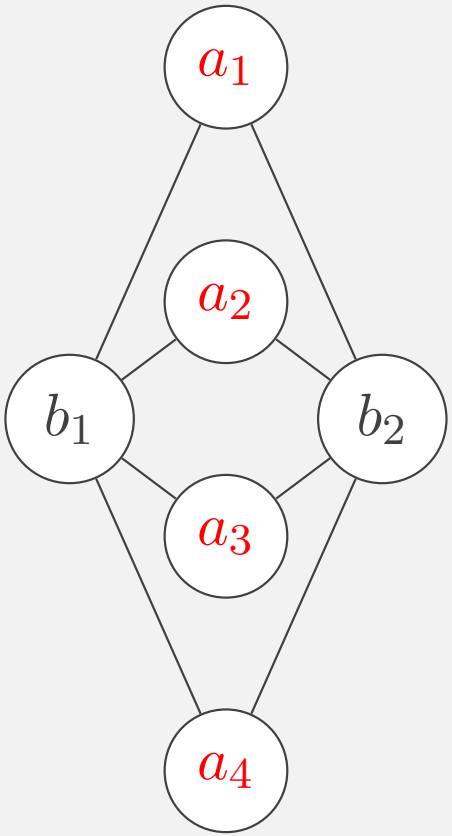

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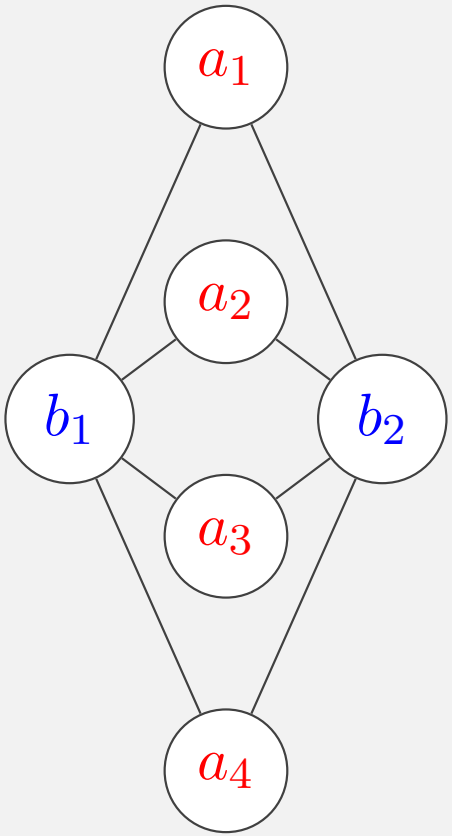

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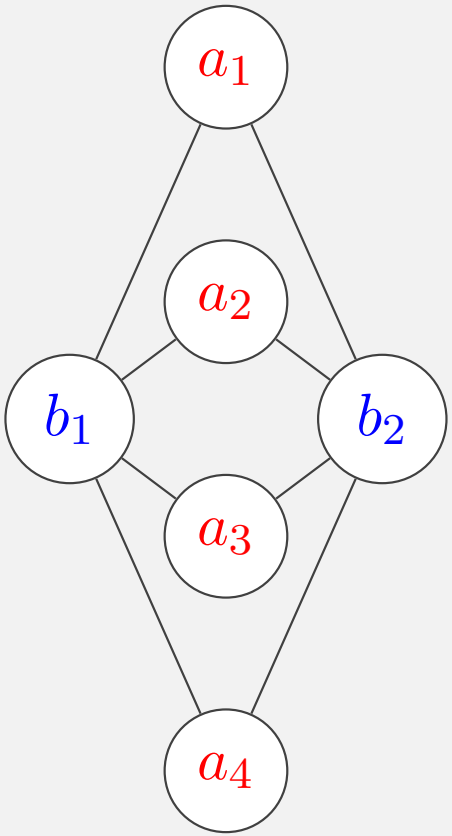

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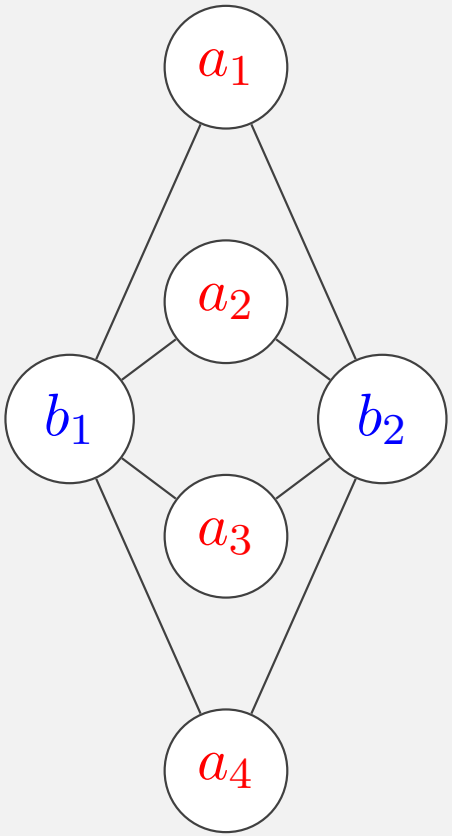

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How can we

- formalize such a system?
- deal with big systems?
- formulate minimal properties (fairness, liveness, safety)?
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- ensure that the minimal properties hold?
  Model Checking

Modular Interpreted System

Modular Interpreted System

Idea:

- Several **loosely** connected components.
- Work is done in the components.
- Little **interaction** between the components.

Modular Interpreted System

Definition 2 (Modular Interpreted System (MIS))

A MIS is a tuple $S = (\mathbb{A}\text{gt}, Act, \mathcal{I}n)$ where:

- $\mathbb{A}\text{gt} = \{a_1, \ldots, a_k\}$ agents,
- Act actions,
- $\mathcal{I}n$ interaction alphabet.

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Example 3

- $\mathbb{A}\mathrm{gt} = \{a_1, a_2, a_3, a_4, b_1, b_2\}$,
- $Act = \{\mathrm{send_x} \mid \mathrm{x} \in \mathbb{A}\mathrm{gt}\} \cup \{\mathrm{noop}\}$
- $\mathcal{I}n = \{\mathbf{nothing}, \mathbf{m_{a_1}}, \mathbf{m_{a_2}}, \mathbf{m_{a_3}}, \mathbf{m_{a_4}}\} \cup \mathrm{P}(\{\mathbf{m_{a_i b_j}} \mid i \in \{1, \ldots, 4\}, j \in \{1, 2\}\}))$

MIS Agent I

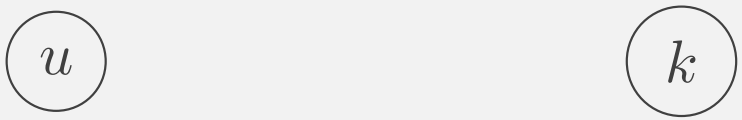
Definition 4 (MIS Agent)

Each agent has the following **internal structure**:

$$a_i = (St_i, \quad , \quad , \quad , \quad , \quad)$$

The global state space is defined as $St := St_1 \times \cdots \times St_k$.

Example 5 (Agent a_1)



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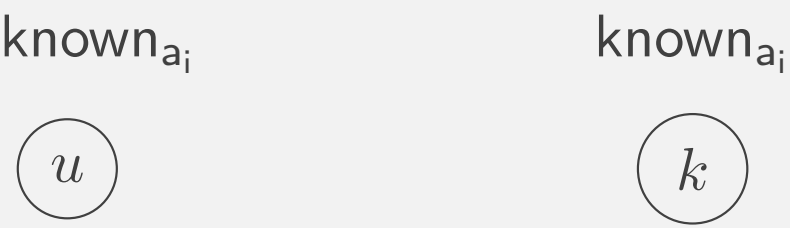

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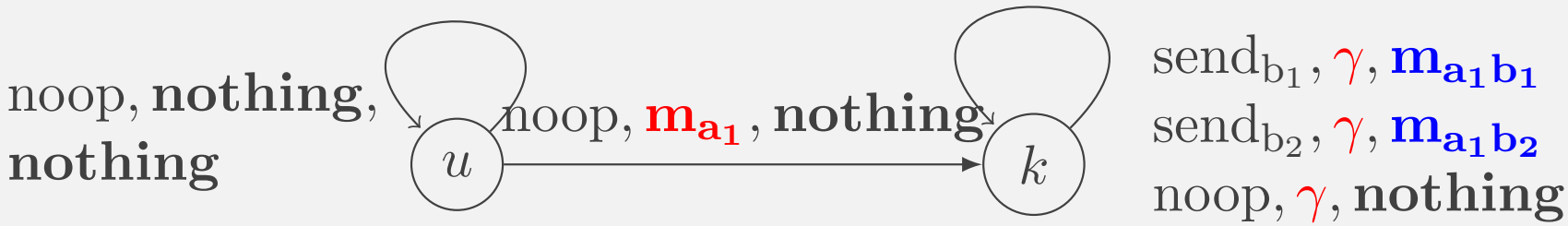

MIS Agent II

Example 6 (Agents b_j)

- 256 states
- Every state is labeled with known_{b_j} if the agent received some time ago the message from a_i.
- Others are labeled with unknown_{b_j}.
- While the agent is waiting for a message it does nothing.
- When it receives a message it has to send the message to one of the opponents with a higher number then i.
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- **Modular** (removing, replacing of agents)
- **Interaction** reduced to an abstract **interaction symbol**
- **Computational ground**

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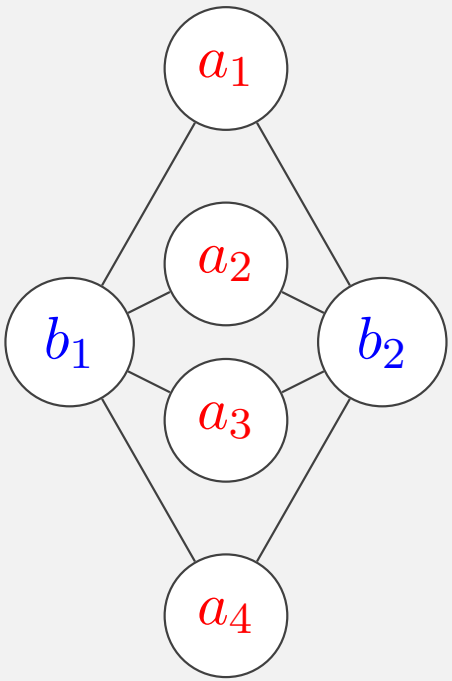

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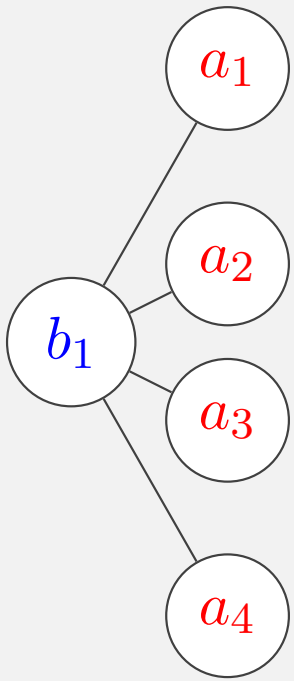

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Advantages of Modular Interpreted Systems II

Example 8 (Communicating Agents)

- Simple example
- $256 + 256 + 2 + 2 + 2 + 2 = 520$ states
- Remove agent b_2: 264 states

Specification Logic: ATL

Alternating-time Temporal Logic

Definition 9 (Alternating-time temporal Logic (ATL))

The language of plain ATL is defined over the non-empty sets:

- Π of **Propositions** $\mathsf{p} \in \Pi$
- $\mathbb{A}\mathrm{gt}$ of **Agents** $A \subseteq \mathbb{A}\mathrm{gt}$

$$\varphi ::= \mathsf{p} \mid \neg\varphi \mid \varphi \vee \varphi \mid \langle\langle A \rangle\rangle \mathbf{X}\varphi \mid \langle\langle A \rangle\rangle \mathbf{G}\varphi \mid \langle\langle A \rangle\rangle \varphi \mathbf{U} \varphi.$$

Main Idea: cooperation modalities

- $\langle\langle A \rangle\rangle \mathbf{X}\varphi$ "coalition A has a collective strategy to enforce that φ holds after the next step"

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Example 10

Is it possible for team A to ensure that a_4 will know the message eventually?

$$S, \mathrm{q} \models \langle\langle A \rangle\rangle (\top \mathbf{U} \mathsf{known}_{\mathsf{a}_4})$$

Abstraction for MIS

Basic Idea I

Partitioning the **local state space** by using **handcrafted equivalence relation**:

- Reducing all equivalent states to just one
- Agents get **fewer choices** and the **opponents more choices**
- **Influence symbols** of the abstract states:
  - all influence symbols that are an outcome of executing a action in each concrete state
- **Local transition function**:
  Input: **abstract state**, **action**, **influence symbol**
  Output: **abstract state**
  - unfold both equivalence classes
  - connection between concrete state of 1st equivalence class to concrete state of 2nd equivalence class?

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Example for Abstraction

Example 11 (Agents b_j)

- 256 states

$$
\begin{aligned}
S_i &:= \{(R,N) \mid \emptyset \neq R \subseteq \{r_1,\ldots,r_i\}, n_i \in N\} \setminus \textstyle\bigcup_{j=1}^{i-1} S_j \\
&\quad \text{for } i = 1,\ldots,3 \\
S_{\text{rest}} &:= \{(R,N) \mid (R,N) \notin S_1 \cup \cdots \cup S_3\}
\end{aligned}
$$

Result: **4 states**

Advantages of Abstraction of Modular Interpreted Systems

Example 12 (Communicating Agents)

- $256 + 256 + 2 + 2 + 2 + 2 = 520$ states
- Remove agent b_2: 264 states
- Abstraction of b_1: 12 states

The Model Checking Algorithm

Idea

- **Input**:
  - MIS S
  - $init$ of global states of S
  - ATL formula φ
  - for each quantifier subformulae an abstraction relation
- **Output**:
  - true : if $S, q \models \varphi$ for all $q \in init$
  - unknown : we do not know whether S satisfies φ or not

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Complexity and Soundness

Theorem 13

Algorithm modelcheck$(S, init, \varphi, (\equiv_\psi)_{\psi \in \mathrm{qsf}(\varphi)})$ *runs in time*

$$O\left(|init| + |S| \cdot |\varphi|\right) \cdot 2^{O\left(\sum_{\psi \in \mathrm{qsf}(\varphi)} \left| S^{[\![\psi]\!]}_{\equiv_\psi} \right|\right)}$$

where $|S|$ *denotes the size of the* MIS S *in a compact representation. The cardinality of the global state space of* S *may then be upto* $2^{\Theta(|S|)}$.

Theorem 14

Algorithm modelcheck is sound, i.e. if modelcheck$(S, init, \varphi, (\equiv_\psi)_{\psi \in \mathrm{qsf}(\varphi)})$ *outputs* true *then* $S, q \models \varphi$ *for all* $q \in init$.

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- **ATL** allows to talk about strategic properties
- The **abstraction for MIS** :
  - is sound
  - allows to deal with bigger Systems
    (depending on the equivalent relations)

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References


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