The Escapee Domain: A Multi-Agent Planning Domain

Gregory Gelfond
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Research Fellow
Department of Computer Science
University of Nebraska Omaha
Outline

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This talk covers a multi-agent planning domain, called the “Escapee Domain”, illustrating some of the interesting issues that arise with multi-agent planning, together with its axiomatization in the language \( mA^+ \).
The Escapee Domain
Let us consider the following domain:

- Agent A has been bound and captured by a hostile agent B.
- To escape, A must be freed from his bonds.
- Fortunately, agent C is a double agent in B’s organization and may release A.
- C must maintain his cover however, and will only release A if he can remain undetected.
- Once A has been released, he must work together with C to subdue B before making his escape.
- A will only work with C if he believes C is an ally.

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This domain presents a number of interesting challenges:

• Agent C must preserve his cover. This means that he has to be able to release A while keeping B oblivious of his actions.

• In other words, not only must he reason about the physical effects of his actions, but also about whether or not other agents will perceive them.

• Furthermore, to effect his escape, A must act in concert with C, and this collaborative action is predicated on A's beliefs about C.
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These challenges have been met by the action languages $mA+$ and $mAL$ through:

- The recognition that both the direct and indirect effects of actions may alter the physical and epistemic properties of a domain, and the addition of linguistic constructs to represent them.
- The discovery of a certain class of fluent (called perspective fluents), which govern how the agents perceive the action occurrences in a given state, and the incorporation of this discovery into the semantics of the language.

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The Action Language $mA+$
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As is the case with its single-agent counterparts, we begin by establishing the domain’s signature. For a multi-agent domain, the signature is defined as a triple of finite, disjoint sets:

- \( \mathcal{A} \) — is a set of agent names;
- \( \mathcal{F} \) — is a set of fluents;
- \( \mathcal{A} \) — is a set of elementary actions
In the case of the Escapee Domain, a partial domain signature could be:

\[ \mathcal{AG} = \{ A, B, C \} \]
\[ \mathcal{F} = \{ \text{bound}(\alpha), \text{attentive}(\alpha), \text{free}(\alpha), \text{allies}(\alpha_1, \alpha_2), \text{united}(\alpha_1, \alpha_2) \} \]
\[ \mathcal{A} = \{ \text{release}(\alpha_1, \alpha_2), \text{unite}(\alpha_1, \alpha_2), \text{distract}(\alpha_1, \alpha_2) \} \]

where \( \alpha, \alpha_1, \) and \( \alpha_2 \) are variables over \( \mathcal{AG} \).
With the signature in place, the initial state is defined by a collection of *initial state axioms*:
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- \( \text{initially } C_{\{A,B,C\}}(\text{attentive}(A) \land \text{bound}(A)) \)
- \( \text{initially } C_{\{A,B,C\}}(\mathcal{B}_B \neg \text{allies}(A, C)) \)
- \( \text{initially } (\mathcal{B}_C \text{allies}(A, C) \land \mathcal{B}_A \text{allies}(A, C)) \)
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- \( \text{initially } \mathcal{C}_{\{A,B,C\}}(\text{attentive}(\alpha) \land \text{bound}(A)) \)
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- \( \text{initially } (\mathcal{B}_{\text{allies}}(A, C) \land \mathcal{B}_{A\text{allies}}(A, C)) \)

Generally speaking, such axioms are statements of the form:

\[
\text{initially } \varphi
\]

where \( \varphi \) is a restricted kind of *modal formula*, and have the informal reading of: “\( \varphi \) is initially true.”
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- **Ontic**
- **Epistemic**
  - Sensing
  - Communication
In a multi-agent context, actions fall into three distinct categories:

In $mA+$, each of these distinct classes of actions is paired with a construct of the language.
The causal relationships between an *ontic action* and its *direct effects* are represented by *dynamic causal laws* which are statements of the form:

\[ a \text{ causes } f \text{ if } \phi \]

where \(a\) is an action, \(f\) is a fluent literal, and \(\phi\) is a modal formula\(^1\).

\(^1\)As with initial state axioms, these are from a syntactically restricted class.
For instance: A single agent may release another agent causing him to no longer be bound. This may be readily represented by the following dynamic causal law:
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What's new is that in this particular domain, such an action may have additional epistemic effects. For example:

• If C releases A but B is mindful of his surroundings, B will become aware of this.
• If C releases A while B is distracted, B will not be aware of what has transpired.

Perspective axioms allow us to represent the dependance of such indirect effects on the values of perspective fluents.
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where \(X\) is a set of agents, \(a\) is an action, and \(\phi\) is a modal formula.
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Note that the second axiom encodes the idea that attentive agents are aware of occurrences of the action *release* (and hence its consequences).
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Note that this second point requires us to be able to *constrain the executability* of this action to agents who *believe themselves to be allied*. 
This kind of constraint may be readily expressed by an *executability condition*, which is a statement of the form:

\[ \text{executable } a \text{ if } \phi \]

where \( a \) is an action, \( \phi \) is a modal formula.
This leads us to the following axiomatization of the action \textit{unite}: 

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This leads us to the following axiomatization of the action $\text{unite}$:

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This leads us to the following axiomatization of the action \textit{unite}: 

\[\text{unite}(\alpha_1, \alpha_2) \text{ \texttt{causes} \ united}(\alpha_1, \alpha_2)\]

\[\text{executable \ unite}(\alpha_1, \alpha_2) \text{ \texttt{if} } \mathcal{B}_{\alpha_1} \text{ allies}(\alpha_1, \alpha_2)\]

along with the requisite perspective axioms\(^2\).

\(^2\)Omitted for the sake of brevity.
With all of these elements in place, a *collaborative action* such as *subdue* may be expressed in a straightforward manner³:

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With all of these elements in place, a collaborative action such as *subdue* may be expressed in a straightforward manner\(^3\):

\[ \text{subdue}(α_1, α_2, α_3) \text{ causes } \text{bound}(α_3) \]

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\(^3\)As before, the relevant perspective axioms have been omitted.
Concluding Thoughts
Once the domain has been axiomatized, the semantics of the language enables us to answer questions involving both temporal projection and planning in such a setting. For example:

- If $C$ immediately releases $A$ while $B$ is attentive, he will be discovered.
- If $C$ however chooses to distract agent $B$ prior to releasing $A$, his cover will be intact.
- In order for $A$ to escape, $B$ must first be distracted, then $A$ must be released. Once this is done, $A$ and $C$ unite to subdue $B$, after which $A$ makes his way to freedom.
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It should be noted that the semantics of $mA+$ has a natural translation into a logic program under the answer-set semantics. This allows us to reduce *temporal projection* and *planning* to finding the answer sets of programs based on this translation.
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Lastly, the successor to $mA+$, called $mAL$ further extends the language by the inclusion of *state constraints* in the manner of $AL$. 
Thank You