Multiagent Planning as an Emerging Behavior in Agent Societies

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Multiagent Planning as an Emerging Behavior in Agent Societies

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Outline

**Motivations and Idea**
- Multiagent planning as Social Computing

**Background**
- Classical Planning
- Social Commitments & Goals

**Social Continual Planning by examples**
Motivations

- Multiagent planning: synthesis of plans for a number of agents in a given *team*
  - each agent reaches its own goals
  - the agent plans are altogether consistent (i.e., no deadlock, no open preconditions, correct usage of resources)

- Multiagent planning as *distributed problem solving*:
  - agents are homogeneous
  - agents can trust each other
  - agents can inspect each other their beliefs
  - agents do not change over time (the team is fixed at the beginning)

  ➞ agents are not really autonomous

These assumptions are unpractical when agents constitute a *society* rather than a team
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  - agents do not change over time (the team is fixed at the beginning)
  \[\Rightarrow \text{agents are not really autonomous}\]

These assumptions are unpractical when agents constitute a *society* rather than a team
Multiagent Planning as Social Computing

Idea:

- Enrich the (classical) BDI planning agent with *social capabilities*
- The planning system is thought of as a *normative system*:
  - social norms define the constraints within which agents can operate
  - an agent’s plan must be “socially acceptable”

How to get there:

- use of *social commitments* for modeling agent interactions

Why?

- commitments have a normative power
  - an agent can create expectations on the behaviors of others just relying on the active commitments
- commitments are tightly related to goals [Telang et al. 2011]
  - a planning agent can be driven by the commitments it is responsible for
- commitments enable *practical reasoning*, that can be seen as a form of planning
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Background: Classical Planning

- a single-agent planning domain $D : \langle P, S, A, R \rangle$
  - $P$ is the (finite) set of atomic propositions
  - $S \subseteq 2^P$ is the set of possible states
  - $A$ is the (finite) set of actions
  - $R \subseteq S \times A \times S$ is a transition relation

- a single-agent planning problem $Pr : \langle D, I, G \rangle$
  - $D$ is the planning domain
  - $I \subseteq S$ initial state
  - $G \subseteq S$ goal state

- a solution $\pi$ for $Pr$ is a sequence of actions $\langle a_1, \ldots, a_n \rangle$ such that:
  - $a_1$ is applicable to the initial state $I$
  - $a_i$ is applicable to the state resulting after the application of $a_{i-1}$ (for $i : 2..n$)
  - $G$ holds after the application of $a_n$
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Background: Commitments and Goals

Life cycle of a commitment

Life cycle of a goal
Background: Commitments and Goals

- the relation between commitments and goals has been captured by a set of rules [Telang et al. 2011]:
  - **structural rules**: complete and deterministic, describe how commitment and goal states evolve
  - **pragmatical rules**: describe patterns of practical reasoning over commitments and goals; these rules are neither complete nor deterministic
Background: Pragmatical Rules

\[
\begin{align*}
\text{guard} \\
\frac{}{S_1 \rightarrow S_2}
\end{align*}
\]

- \textit{guard} is a condition over an agent beliefs and over the active commitments
- \(S_1 \rightarrow S_2\) is a state transition defining how goals and commitments change
Background: Pragmatical Rules

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\frac{\text{guard}}{S_1 \rightarrow S_2}
\]

- \textit{guard} is a condition over an agent beliefs and over the active commitments
- \(S_1 \rightarrow S_2\) is a state transition defining how goals and commitments change

- Pragmatical Rules are divided into:
  - rules from \textit{goals to commitments}
    \[
    \langle G^A, C^N \rangle \xrightarrow{\text{create}(C)} \text{ENTICE}
    \]
  - rules from \textit{commitments to goals}
    \[
    \langle G^N, C^D \rangle \xrightarrow{\text{consider}(G), \text{activate}(G)} \text{DELIVERY}
    \]
Reasoning about Goal and Commitments via Social Continual Planning

Main idea:

- Interleave planning phases with execution and negotiation phases.

- The planning phase involves both:
  - "Physical" actions: directly change the world.
  - Pragmatical actions: (indirectly) change the social state.

- During the execution phase:
  - A physical action is directly performed by an agent.
  - A pragmatical action triggers a negotiation with others.

- Negotiation involves operations on commitments and it is driven by pragmatical rules.
Reasoning about Goal and Commitments via Social Continual Planning

**Main idea:**

- interleave *planning* phases with *execution* and *negotiation* phases
- the *planning phase* involves both:
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- during the *execution phase*:
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Main idea:

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pragmatical rules **from commitments to goals** define the *strategy* of an agent (i.e., *when to trigger a planning phase*)
Pragmatical Rules to Define Agent’s Strategy

- Pragmatical rules **from commitments to goals** define the *strategy* of an agent (i.e., *when to trigger a planning phase*)
- e.g.

\[
\langle G^N, C^D \rangle \\
\frac{\text{consider}(G), activate(G)}{\text{DELIVERY}}
\]

“an honest agent activates a goal $G$ when $G$ appears as a consequent of a detached commitments it responsible for”

(but are all agents honest?)
Pragmatical Rules as Pragmatical Actions

- pragmatical rules **from goals to commitments** are thought of as pragmatical actions
Pragmatical Rules as Pragmatical Actions

- pragmatical rules **from goals to commitments** are thought of as pragmatical actions

$$\langle G^A, C^N \rangle \xrightarrow{\text{create}(C)} \text{ENTICE} \quad \Rightarrow \quad \text{ENTICE} (G, C)$$

- **precondition** $$\langle G^A, C^N \rangle$$
- **effect** $$\text{create}(C)$$
Pragmatical Rules as Pragmatical Actions

- pragmatical rules **from goals to commitments** are thought of as pragmatical actions

\[
\begin{align*}
&<G^A, C^N> \\
&\text{create}(C) \\
\Rightarrow \\
&\text{ENTICE} (G, C) \\
&:\text{precondition} \langle G^A, C^N \rangle \\
&:\text{effect} \text{create}(C)
\end{align*}
\]

**ISSUE**

- how to determine over which goals and commitments these actions are defined?
Pragmatical Rules as Pragmatical Actions

- Pragmatical rules **from goals to commitments** are thought of as pragmatical actions.

\[
\frac{\langle G^A, C^N \rangle}{\text{create}(C)} \quad \text{ENTICE} \quad \Rightarrow \\
\text{ENTICE} \ (G, C) \\
: \text{precondition} \ \langle G^A, C^N \rangle \\
: \text{effect} \ \text{create}(C)
\]

**ISSUE**
- how to determine over which goals and commitments these actions are defined?

**SOLUTION**
- **blackboard of services**
Example: World-Wide Delivery Service

Problem: sending a parcel from Oklahoma City (Oklahoma) to Bertinoro (Italy)

four shipping agencies:

- **AmericanTrucks**: operates only in north America
- **EuropeanTrucks**: operates only in Europe
- **BlueVector** (flight company): blue connections
- **RedVector** (flight company): red connection
Conclusions

**Social Continual Planning:**
- practical reasoning as a form of planning
- agent’s autonomy is preserved
  - an agent can adopt local optimization strategies
  - each agent can use the planner that suits it most
- commitments support flexible planning solutions
  - help agents take advantage of the opportunities available in a given time
  - help agents find alternative solutions when something wrong happens
multiagent planning = local agents’ planning + social state

Thank you!
Example: World-Wide Delivery Service

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Physical Actions

A subset of physical actions for the truck agencies

**load**(\(t\) - truck ?p - parcel ?l - location)

*precondition* \(at(t, l) \land at(p, l)\)

*effect* \(\neg at(p, l) \land loaded(p, t)\)

**drive**(\(t\) - truck ?l1, ?l2 - location)

*precondition* \(at(t, l1)\)

*effect* \(\neg at(t, l1) \land at(t, l2)\)

**deliver**(\(t\) - truck ?p - parcel ?l - location)

*precondition* \(at(t, l) \land loaded(p, t) \land dest(p, l)\)

*effect* \(\neg loaded(p, t) \land at(p, l) \land delivered(p)\)
## Blackboard of Services

<table>
<thead>
<tr>
<th>agent</th>
<th>service</th>
<th>price</th>
</tr>
</thead>
<tbody>
<tr>
<td>AmericanTrucks</td>
<td>at(?p, Oklahoma) ∧ delivered(?p)</td>
<td>$?x</td>
</tr>
<tr>
<td></td>
<td>at(?p, New York) ∧ delivered(?p)</td>
<td>$?x</td>
</tr>
<tr>
<td></td>
<td>at(?p, San Francisco) ∧ delivered(?p)</td>
<td>$?x</td>
</tr>
<tr>
<td></td>
<td>. . .</td>
<td>. . .</td>
</tr>
<tr>
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<td>at(?p, Rome) ∧ delivered(?p)</td>
<td>$?x</td>
</tr>
<tr>
<td></td>
<td>at(?p, Paris) ∧ delivered(?p)</td>
<td>$?x</td>
</tr>
<tr>
<td></td>
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<td>$?x</td>
</tr>
<tr>
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<td>. . .</td>
</tr>
<tr>
<td>BlueVector</td>
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<td>$?x</td>
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<td>$?x</td>
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</tr>
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<tr>
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<td>. . .</td>
<td>. . .</td>
</tr>
</tbody>
</table>
Pragmatical Actions

From the point of view of AmericanTrucks (AmT):

\[\text{entice\_delivery}(?a - \text{agent} \ ?p - \text{parcel} \ ?l - \text{location})\]

\[\text{:precondition}\]
\[G^A(at(?p, ?l) \land \text{delivery}(?p)), C^N(AmT, ?a, at(?p, ?l) \land \text{delivery}(?p), $?x)\]

\[\text{:effect create}(C)\]

\[\text{entice\_at}(?a - \text{agent} \ ?p - \text{parcel} \ ?l - \text{location})\]

\[\text{:precondition}\]

\[\text{:effect create}(C)\]

These new actions are made available to an off-the-shelf planner
Solving the Problem

- AmericanTrucks has to deliver parcel $p_1$, initially located in Oklahoma City, to Bertinoro

```prolog
entice_delivery(AmT, EuT, \{at(p1, Bertinoro), delivery(p1)\}, $?x)
```

- The planner finds a trivial plan: “ask EuropeanTrucks to deliver $p_1$”
- The execution of such a pragmatic action triggers a negotiation phase between AmericanTrucks and EuropeanTrucks
Solving the Problem

As an effect of the negotiation...

Social State

- \( CC(AmT, EuT, \{at(p_1, Bertinoro), delivery(p_1)\}, \$100) \)
- \( CC(EuT, AmT, at(p_1, Rome),\{at(p_1, Bertinoro), delivery(p_1)\}) \)

- AmericanTrucks has now a new goal: \( at(p_1, Rome) \)
- A new planning phase is activated
Solving the Problem

A new trivial plan is found:

\[
\text{entice}_\text{at}(\text{AmT}, \text{BlueV}, \text{at}(p1, \text{Rome}), $?x)
\]

which triggers a new negotiation phase:

Social State

\[
\begin{align*}
\text{CC}(\text{AmT}, \text{EuT}, \{\text{at}(p1, \text{Bertinoro}), \text{delivery}(p1)\}, $100) \\
\text{CONDITIONAL} \\
\text{CC}(\text{EuT}, \text{AmT}, \text{at}(p1, \text{Rome}), \{\text{at}(p1, \text{Bertinoro}), \text{delivery}(p1)\}) \\
\text{CONDITIONAL} \\
\text{CC}(\text{AmT}, \text{BlueV}, \text{at}(p1, \text{Rome}), $500) \\
\text{CONDITIONAL} \\
\text{CC}(\text{BlueV}, \text{AmT}, \text{at}(p1, \text{New York}), \text{at}(p1, \text{Rome})) \\
\text{CONDITIONAL}
\end{align*}
\]
Solving the Problem

AmericanTrucks

- load(AmTruck27, p1, OC)
- drive(AmTruck27, OC, NY)
- unload(AmTruck27, p1, OC)

CC(BlueV, AmT, at(p1, New York), at(p1, Rome))

CONDITIONAL
Solving the Problem

AmericanTrucks

- load(AmTruck27, p1, OC)
- drive(AmTruck27, OC, NY)
- unload(AmTruck27, p1, OC)
- CC(BlueV, AmT, T, at(p1, Rome))

DETACHED
Solving the Problem

**AmericanTrucks**
- `load(AmTruck27, p1, OC)`
- `drive(AmTruck27, OC, NY)`
- `unload(AmTruck27, p1, OC)`
- `CC(BlueV, AmT, T, at(p1, Rome))`

**BlueVector**
- `embark(BV5, p1, NY)`
- `fly(BV5, NY, RM)`
- `disembark(BV5, p1, RM)`
- `CC(EuT, AmT, at(p1, Rome), {at(p1, Bertinoro), delivery(p1)})`
- `CC(AmT, BlueV, at(p1, Rome), $500)`
Solving the Problem

**AmericanTrucks**
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BlueVector

- embark(BV5, p1, NY)
- fly(BV5, NY, RM)
- disembark(BV5, p1, RM)
- CC(EuT, AmT, T, {at(p1, Bertinoro), delivery(p1)})
- CC( AmT, BlueV, T, $500)
- SATISFIED

EuropeanTrucks

- load(EuTruck13, p1, RM)
- drive(EuTruck13, RM, BR)
- deliver(EuTruck13, p1, BR)
- CC(AmT, EuT, T, $100)
- DETACHED
Solving the Problem

**AmericanTrucks**
- load(AmTruck27, p1, OC)
- drive(AmTruck27, OC, NY)
- unload(AmTruck27, p1, OC)
- CC(BlueV, AmT, T, at(p1, Rome))
- pay(BlueV, $500)
- pay(EuT, $100)

**BlueVector**
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- CC(BlueV, AmT, T, at(p1, Rome))
- pay(BlueV, $500)

**EuropeanTrucks**
- load(EuTruck13, p1, RM)
- drive(EuTruck13, RM, BR)
- deliver(EuTruck13, p1, BR)
- CC(AmT, EuT, T, $100)
- CC(BlueV, AmT, T, $500)

SATISFIED
Reasoning about Goal and Commitments via Continual Planning

- Given an agent $x$, its configuration is $S_x : \langle B, C, G \rangle$ [Telang]:
  - $B$ : set of beliefs about the world state (including beliefs about itself and others)
  - $C$ : set of commitments of the form $C(x, y, s, u)$ (public)
  - $G$ : set of goals of the form $G(x, p, r, q, s, f)$ (private)

- Extended agent configuration $S_x : \langle B, C, G, A_x, A^{gc}_x, R^{cg}_x \rangle$:
  - $A_x$ : set of primitive actions for agent $x$ (change a portion of the world)
  - $A^{gc}_x$ : set of actions corresponding to pragmatical rules from goals to commitments (change the social state)
  - $R^{cg}_x$ : set of reactive rules corresponding to pragmatical rules from commitments to goals (trigger planning phases)