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### Multiagent Planning as an Emerging Behavior in Agent Societies

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| Availability:  |                            |  |
| This version is available http://hdl.handle.net/2318/151901  | since 2016-06-28T08:39:33Z |  |
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## Multiagent Planning as an Emerging Behavior in Agent Societies

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NorMAS 2014

Micalizio, Baroglio & Baldoni

**Multiagent Planning in Agent Societies** 

NorMAS 2014 1 / 29

### Outline

- Motivations and Idea
  - Multiagent planning as Social Computing
- BACKGROUND
  - Classical Planning
  - Social Commitments & Goals
- $\bullet\ {\rm Social}\ {\rm Continual}\ {\rm Planning}$  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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These assumptions are unpractical when agents constitute a *society* rather than a team

### **IDEA**:

#### • Enrich the (classical) BDI planning agent with *social capabilities*

- 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
- commitments are tightly related to goals [Telang et al. 2011]
- commitments enable *practical reasoning*, that can be seen as a form of planning

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#### Why?

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  - $\Rightarrow\,$  an agent can create expectations on the behaviors of others just relying on the active commitments
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  - $\Rightarrow\,$  a planning agent can be driven by the commitments it is responsible for
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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 a 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*<sub>1</sub> is applicable to the initial state *I*
  - *a<sub>i</sub>* is applicable to the state resulting after the application of *a<sub>i</sub>*-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

Image: A = A

### 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

 $\frac{guard}{S_1 \rightarrow S_2}$ 

- *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

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- *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 goals to commitments

$$\frac{\langle G^A, C^N \rangle}{create(C)}$$
 ENTICE

• rules from commitments to goals

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

- 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

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Pragmatical Rules to Define Agent's Strategy

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e.g.

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

"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?)

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$$\stackrel{\leq G^{A}, C^{N} >}{\stackrel{\text{create}(C)}{\xrightarrow{}} \text{ ENTICE}} \implies \stackrel{\text{ENTICE }(G, C)}{\Rightarrow} : precondition \langle G^{A}, C^{N} \rangle : effect \ create(C)$$

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

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- 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:

- American Trucks: 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

```
\begin{array}{l} \textbf{load}(?t - truck ?p - parcel ?l - location) \\ :precondition at(?t, ?l) \land at(?p, ?l) \\ :effect \neg at(?p, ?l) \land loaded(?p, ?t) \end{array}
```

```
drive(?t - truck ?l1, ?l2 - location)
:precondition at(?t, ?l1)
:effect ¬at(?t, ?l1) ∧ at(?t, ?l2)
```

```
\begin{array}{l} \textbf{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) \end{array}
```

### Blackboard of Services

| agent          | service                                 | price |
|----------------|---|-------|
| AmericanTrucks | at(?p, Oklahoma) ∧ delivered(?p)        | \$?x  |
|                | at(?p, New York) $\land$ delivered(?p)  | \$?x  |
|                | at(?p, San Francisco) ∧ delivered(?p)   | \$?x  |
|                |   |       |
| EuropeanTrucks | at(?p, Rome) ∧ delivered(?p)            | \$?x  |
|                | at(?p, Paris) $\land$ delivered(?p)     | \$?x  |
|                | at(?p, Bertinoro) $\land$ delivered(?p) | \$?x  |
|                |   |       |
| BlueVector     | at(?p, Rome)                            | \$?x  |
|                | at(?p, Paris)                           | \$?x  |
|                | at(?p, New York)                        | \$?x  |
|                |   |       |
| RedVector      | at(?p, Rome)                            | \$?x  |
|                | at(?p, San Fransisco)                   | \$?x  |
|                |   |       |

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### **Pragmatical Actions**

From the point of view of AmericanTrucks (AmT):

```
entice_delivery(?a - agent ?p - parcel ?l - location)

:precondition

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

:effect create(C)
```

```
entice_at(?a - agent ?p - parcel ?l - location)
:precondition G<sup>A</sup>(at(?p,?l), C<sup>N</sup>(AmT,?a,at(?p,?l),$?x)
:effect create(C)
```

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

 AmericanTrucks has to deliver parcel p1, initially located in Oklahoma City, to Bertinoro

entice\_delivery(AmT, EuT, {at(p1, Bertinoro), delivery(p1)}, \$?x)

- The planner finds a trivial plan: "ask EuropeanTrucks to deliver p1"
- The execution of such a pragmatic action triggers a negotiation phase between AmericanTrucks and EuropeanTrucks

As an effect of the negotiation...

Social State

CC(AmT, EuT, {at(p1, Bertinoro), delivery(p1)}, \$100)

CONDITIONAL

CC(EuT, AmT, at(p1, Rome),{at(p1, Bertinoro), delivery(p1)})

- AmericanTrucks has now a new goal: *at*(*p*1, *Rome*)
- A new planning phase is activated

A new trivial plan is found:

entice\_at(AmT, BlueV, at(p1, Rome), \$?x)

which triggers a new negotiation phase:

Social State

CC(AmT, EuT, {at(p1, Bertinoro), delivery(p1)}, \$100) CONDITIONAL

CC(EuT, AmT, at(p1, Rome),{at(p1, Bertinoro), delivery(p1)})

CONDITIONAL

CC( AmT, BlueV, at(p1, Rome), \$500)

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

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#### AmericanTrucks

load(AmTruck27, p1, OC)

drive(AmTruck27, OC, NY)

unload(AmTruck27, p1, OC)

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

CONDITIONAL

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#### AmericanTrucks

load(AmTruck27, p1, OC)

drive(AmTruck27, OC, NY)

unload(AmTruck27, p1, OC)

CC(BlueV, AmT, T, at(p1, Rome))

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### BACKUP

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