# 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)

  $\Rightarrow$ *agents are not really autonomous*

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# 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

  $\Rightarrow$ 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]

  $\Rightarrow$ 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:
  - $a_1$ is applicable to the initial state $I$
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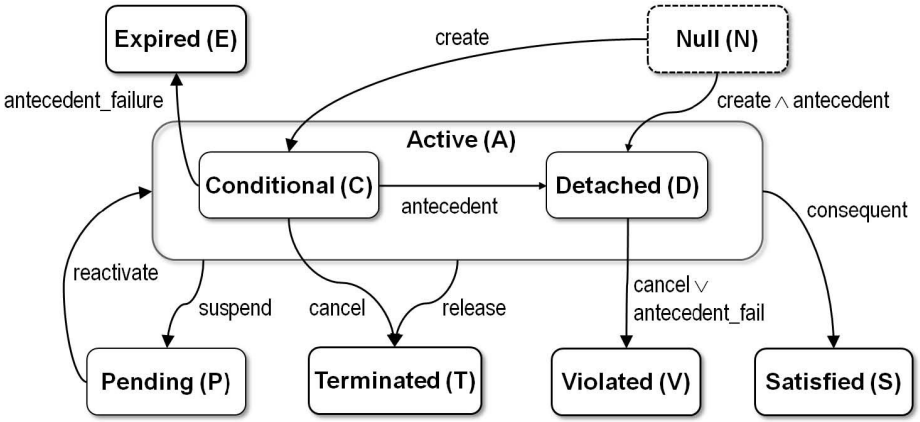
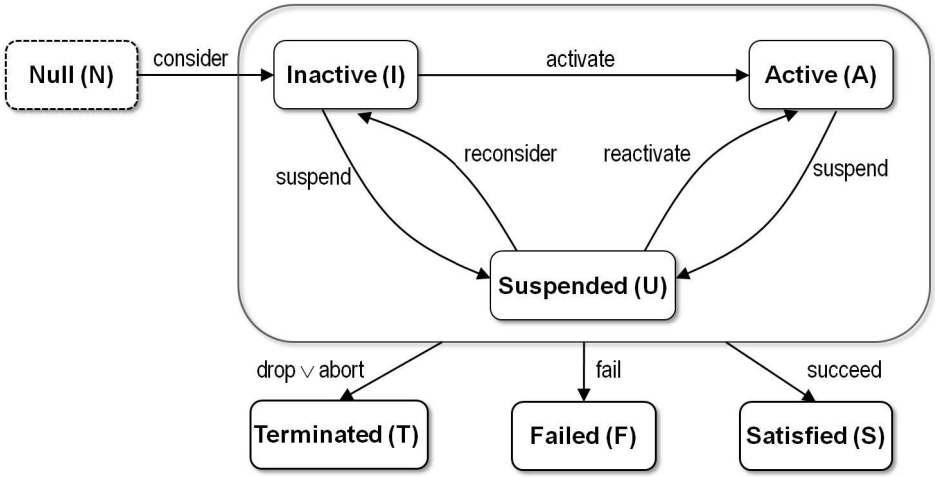



Life cycle of a commitment




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

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

- *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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- Pragmatical Rules are divided into:
  - rules from goals to commitments

$$\frac{<G^A, C^N>}{create(C)} \text{ ENTICE}$$

  - rules from commitments to goals

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

# 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
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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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ENTICE $(G, C)$

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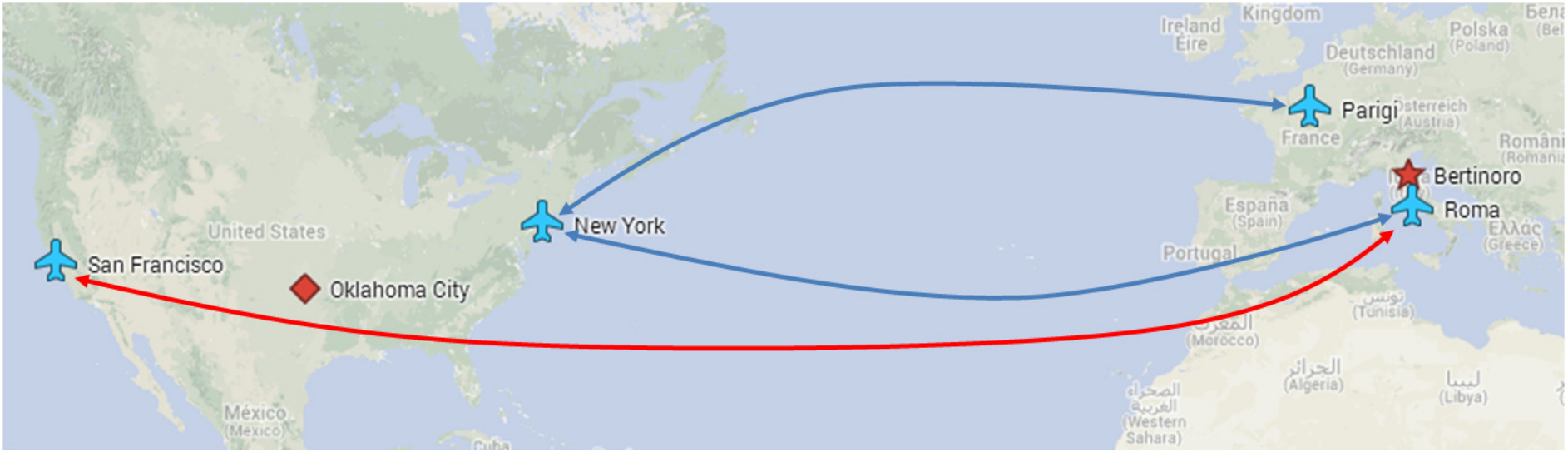
- SOLUTION
  - **blackboard of services**

# 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!*

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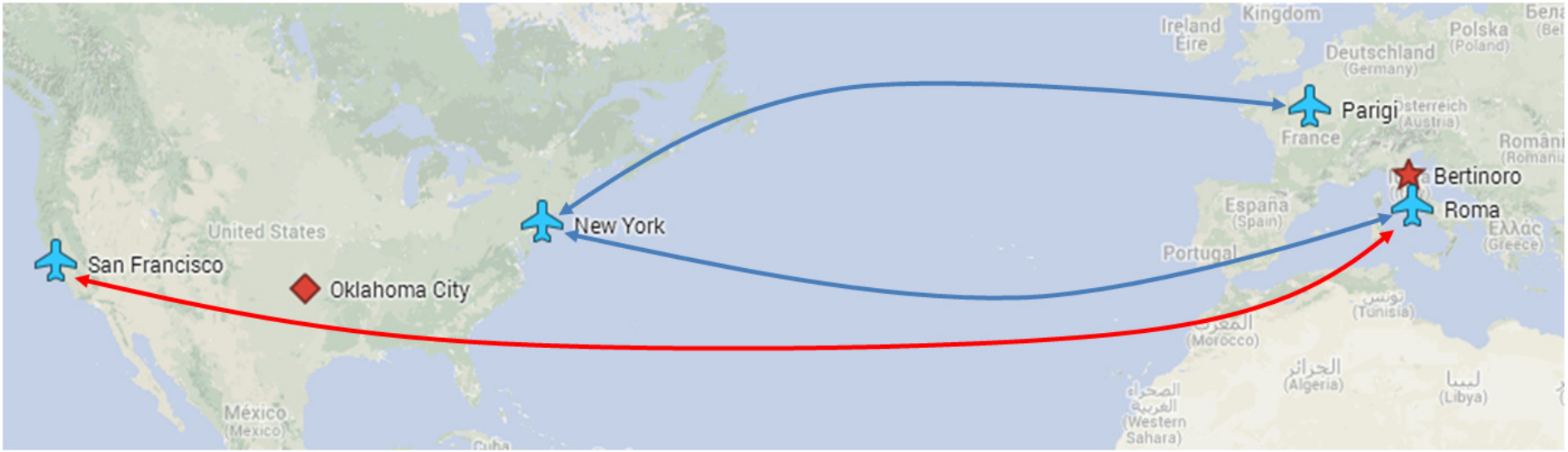


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# Physical Actions

A subset of physical actions for the truck agencies

**load**(?t - truck ?p - parcel ?l - location)
*:precondition* at(?t, ?l) $\wedge$ at(?p, ?l)
*:effect* $\neg$at(?p, ?l) $\wedge$ loaded(?p, ?t)

**drive**(?t - truck ?l1, ?l2 - location)
*:precondition* at(?t, ?l1)
*:effect* $\neg$at(?t, ?l1) $\wedge$ at(?t, ?l2)

**deliver**(?t - truck ?p - parcel ?l - location)
*:precondition* at(?t, ?l) $\wedge$ loaded(?p, ?t) $\wedge$ dest(?p, ?l)
*:effect* $\neg$loaded(?p, ?t) $\wedge$ at(?p, ?l) $\wedge$ delivered(?p)

# Blackboard of Services

| agent | service | price |
|---|---|---|
| AmericanTrucks | at(?p, Oklahoma) $\wedge$ delivered(?p) | $?x |
| | at(?p, New York) $\wedge$ delivered(?p) | $?x |
| | at(?p, San Francisco) $\wedge$ delivered(?p) | $?x |
| | ... | ... |
| EuropeanTrucks | at(?p, Rome) $\wedge$ delivered(?p) | $?x |
| | at(?p, Paris) $\wedge$ delivered(?p) | $?x |
| | at(?p, Bertinoro) $\wedge$ 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 |
| | ... | ... |

# Pragmatical Actions

From the point of view of AmericanTrucks (AmT):

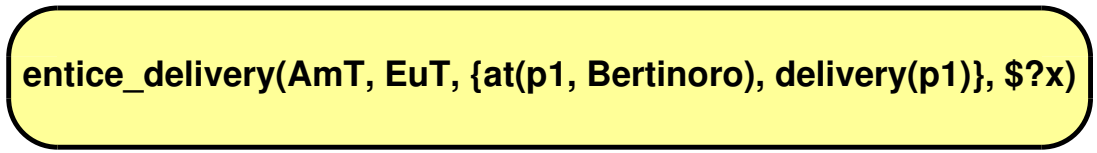
**entice_delivery**(?a - agent ?p - parcel ?l - location)
*:precondition*
$G^A(at(?p, ?l) \wedge delivery(?p)), C^N(AmT, ?a, at(?p, ?l) \wedge delivery(?p), \$?x)$
*:effect* $create(C)$

**entice_at**(?a - agent ?p - parcel ?l - location)
*:precondition* $G^A(at(?p, ?l), C^N(AmT, ?a, at(?p, ?l), \$?x)$
*:effect* $create(C)$

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

# Solving the Problem

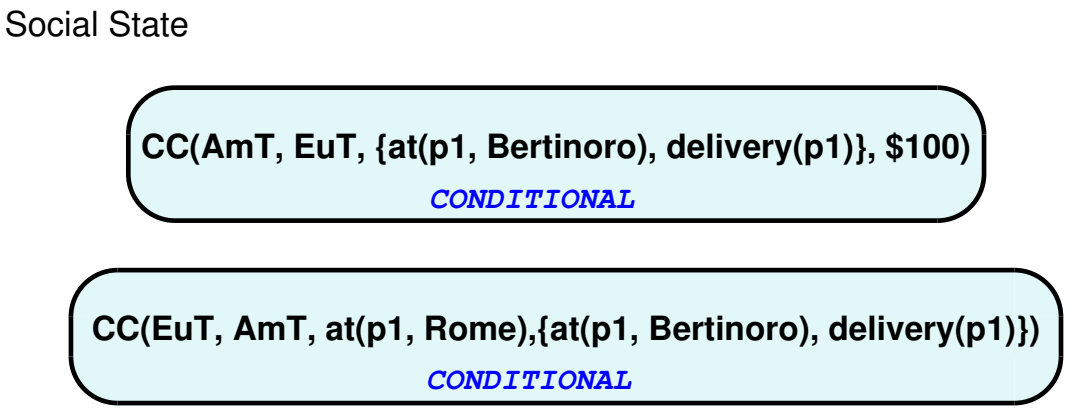
- AmericanTrucks has to deliver parcel $p1$, initially located in Oklahoma City, to Bertinoro




- 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

# Solving the Problem

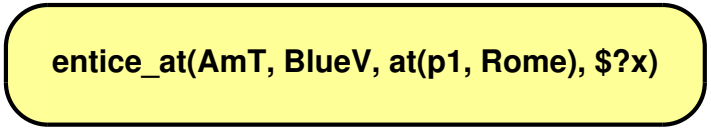
As an effect of the negotiation...



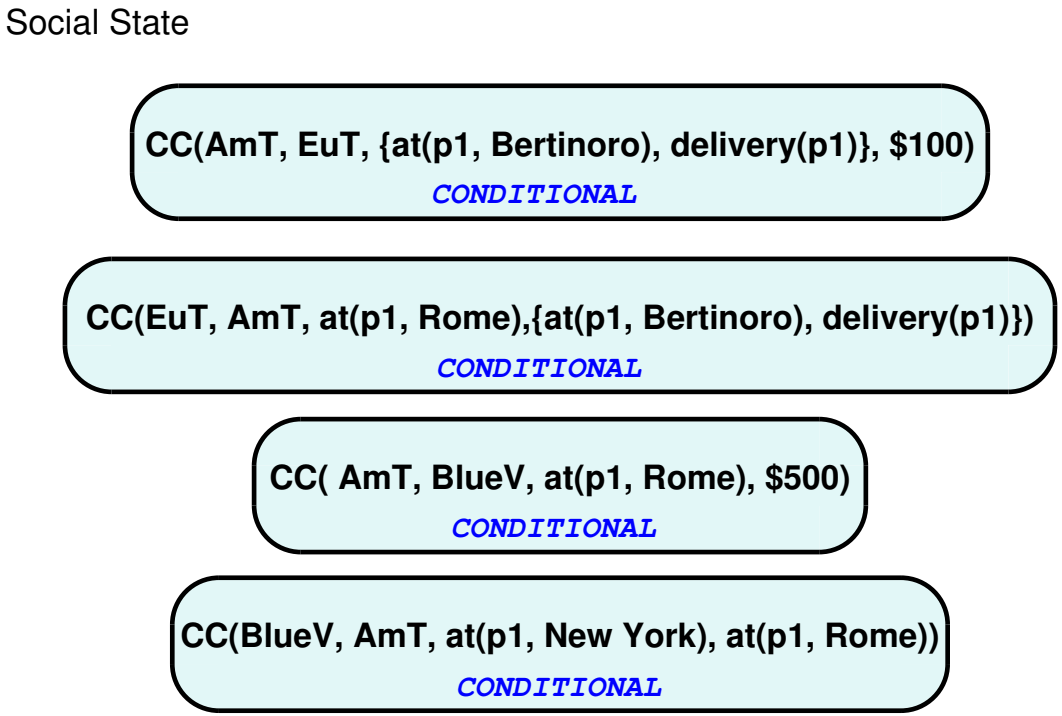

- AmericanTrucks has now a new goal: $at(p1, Rome)$
- A new planning phase is activated

# Solving the Problem

A new trivial plan is found:




which triggers a new negotiation phase:



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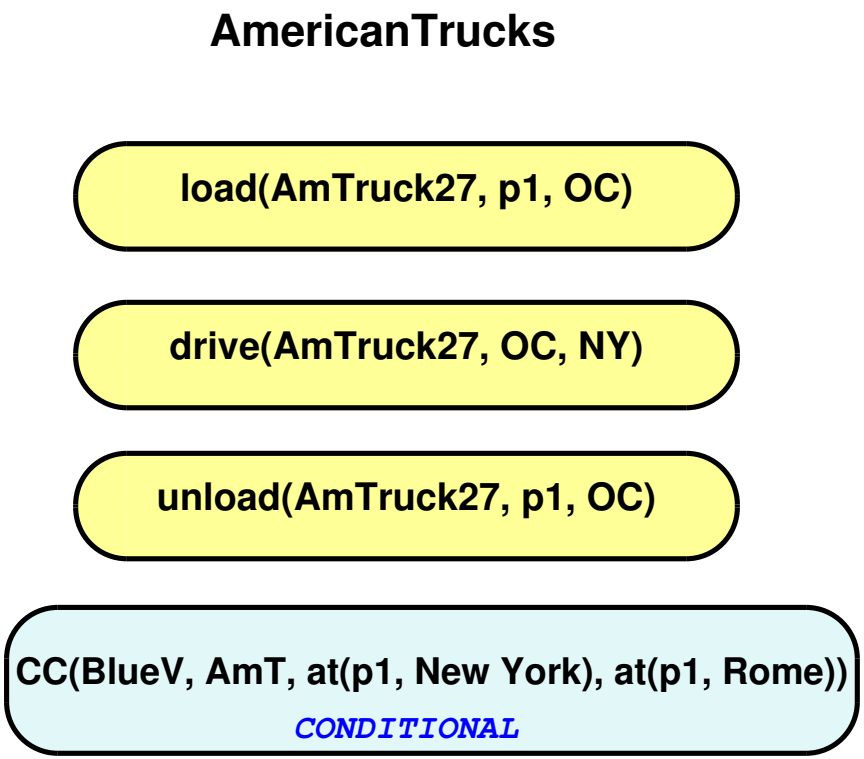

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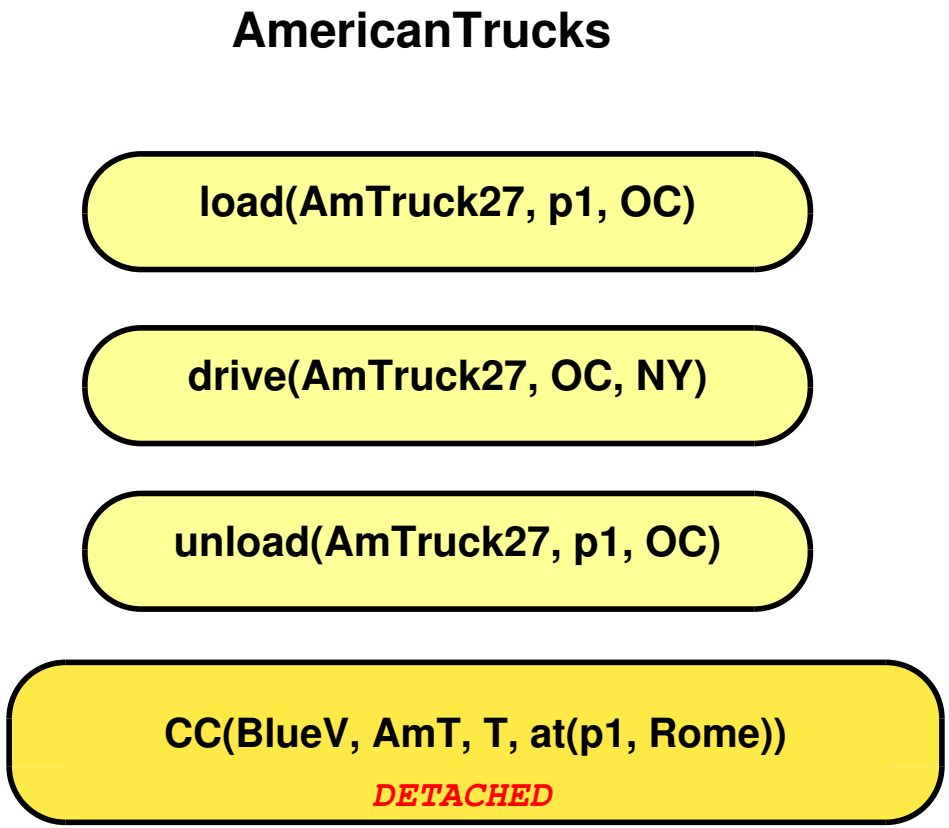

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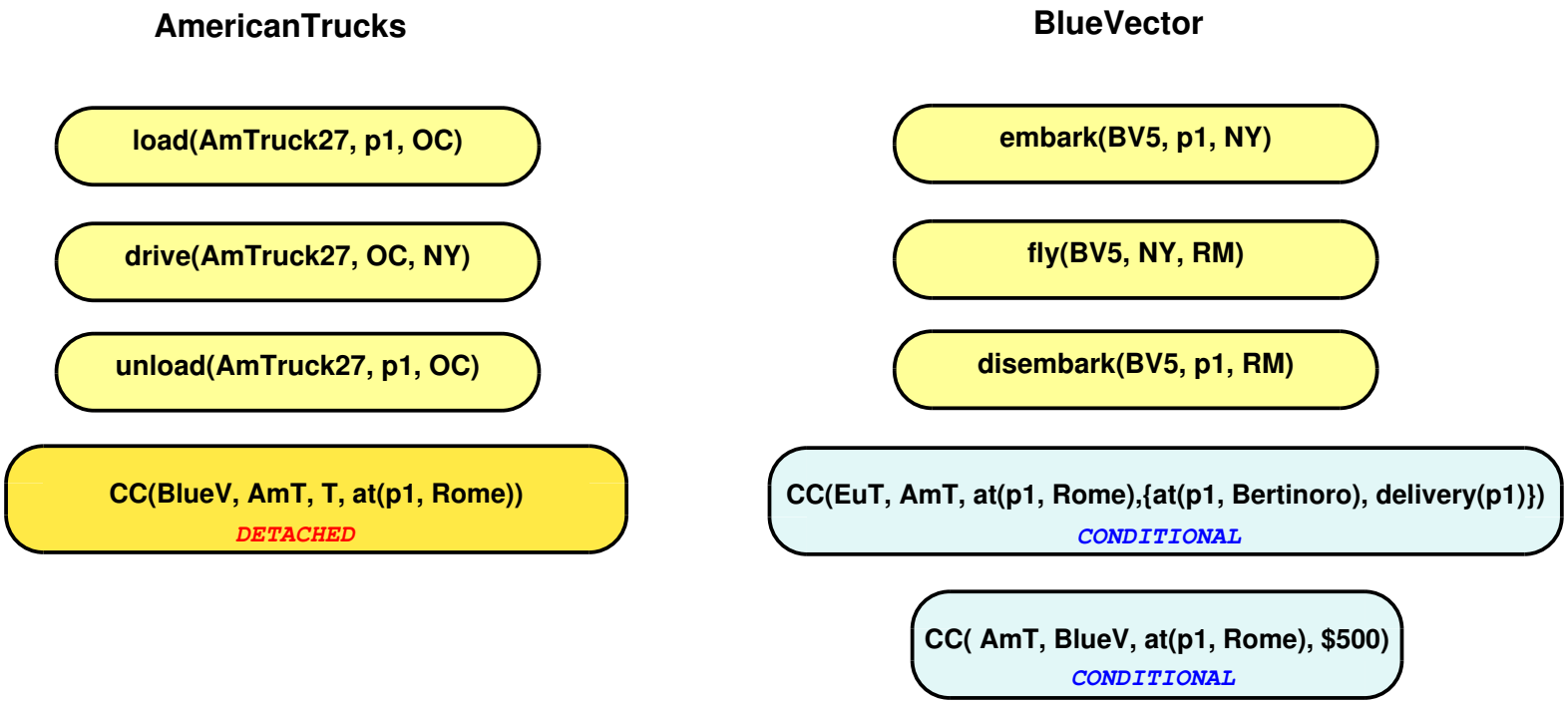

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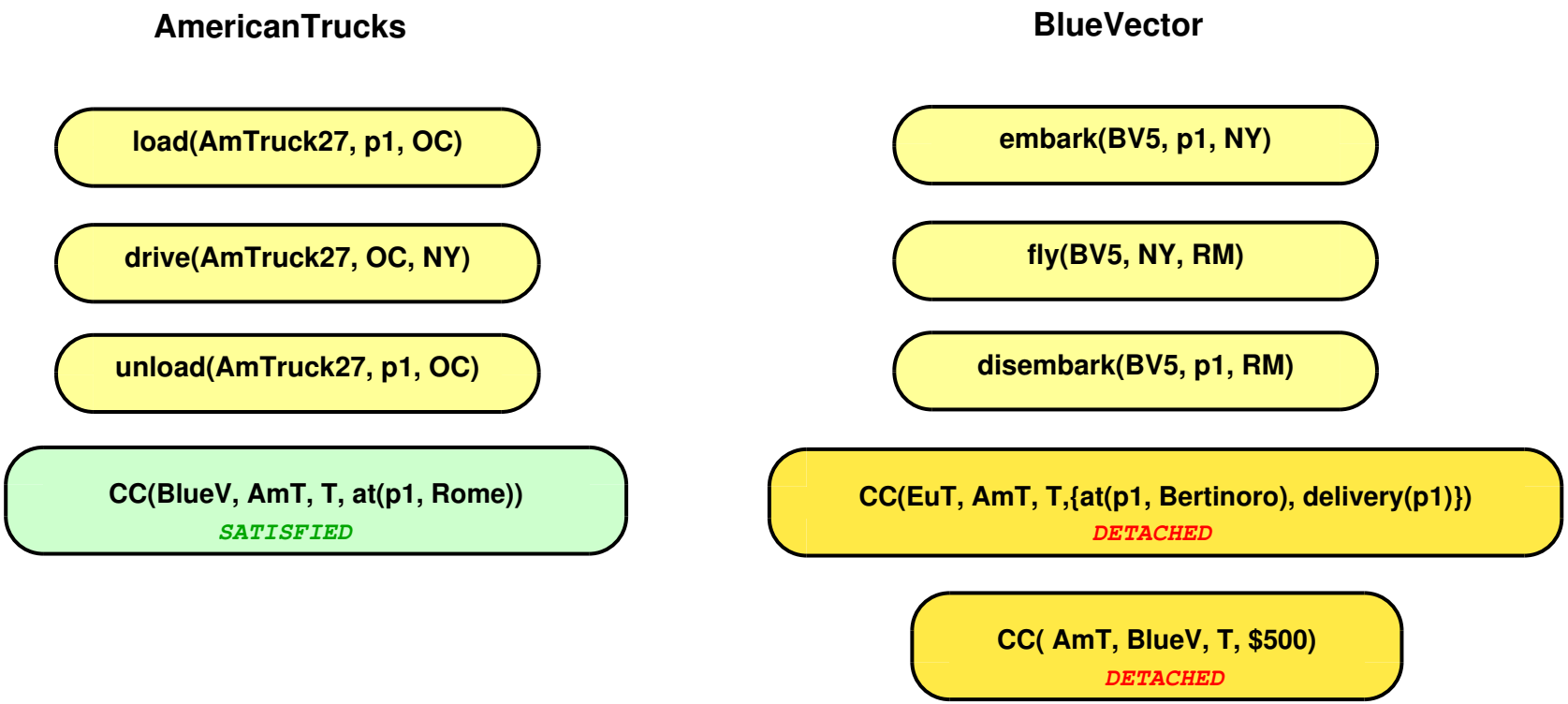

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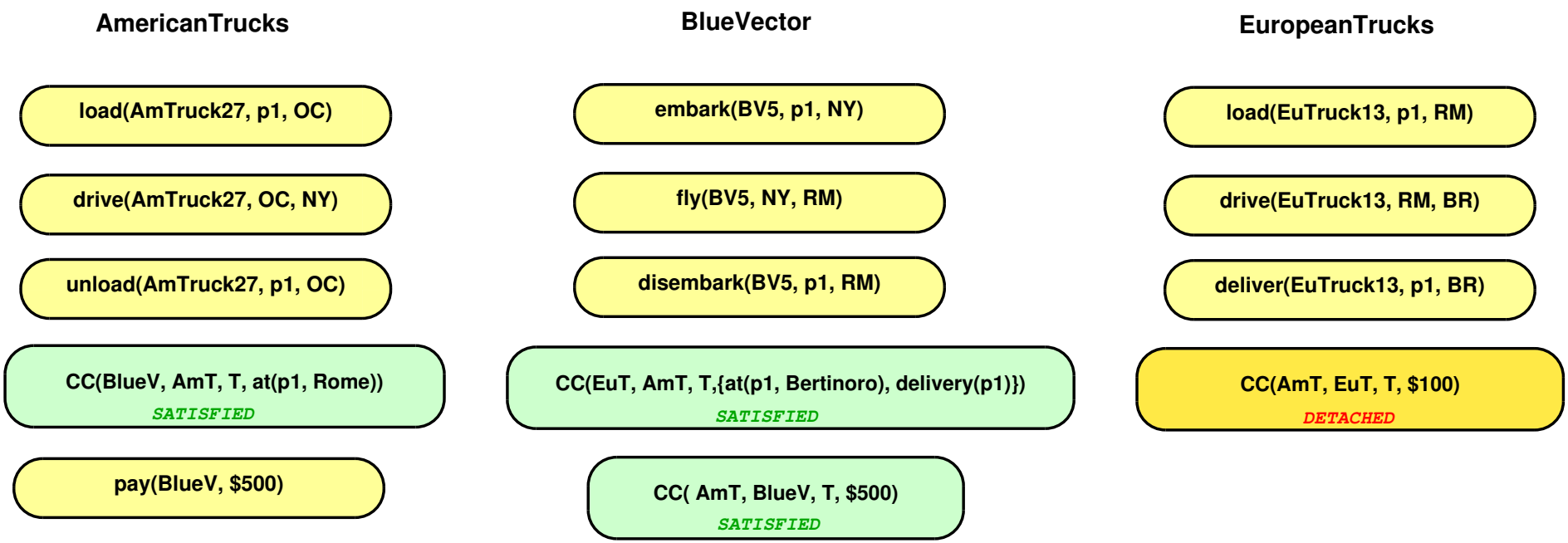

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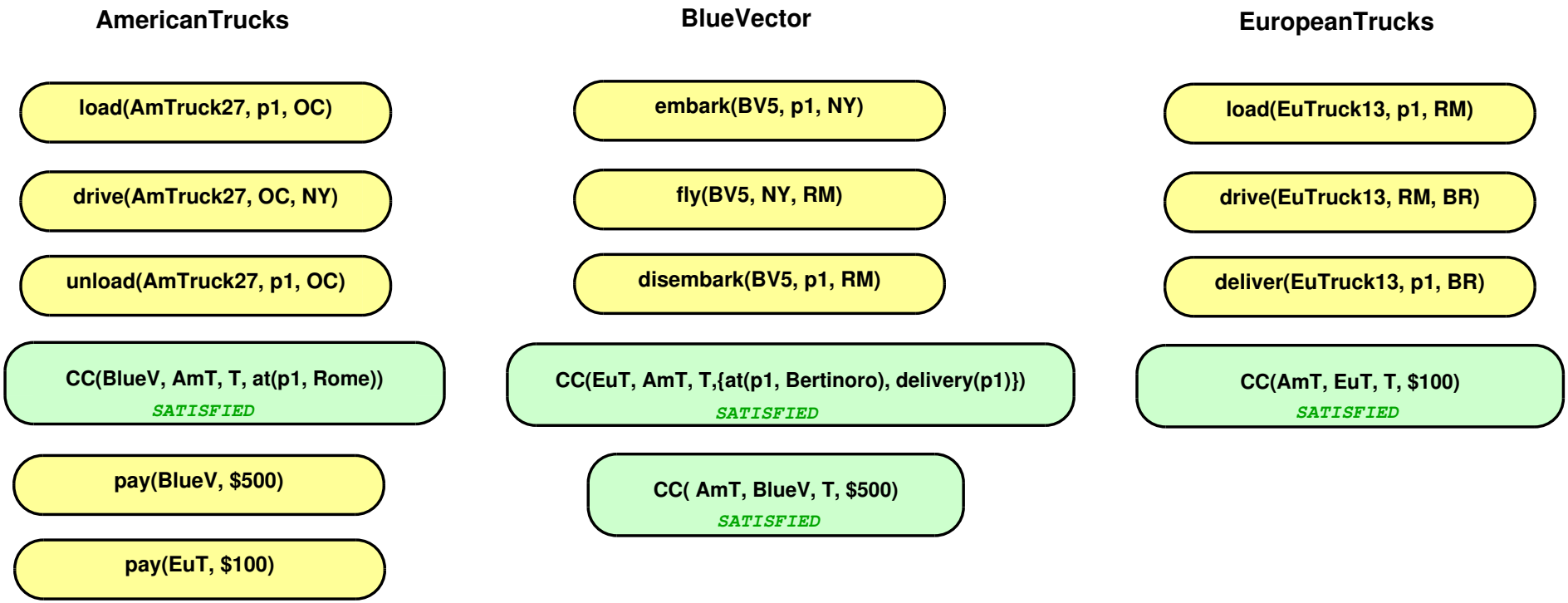

# BACKUP

# 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 $S_x : \langle B, C, G, A_x, A_x^{gc}, R_x^{cg} \rangle$:
  - $A_x$ : 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)