Coordination (III)

7. Coordination in Distributed Systems

Part II: Cooperation (III) Recap

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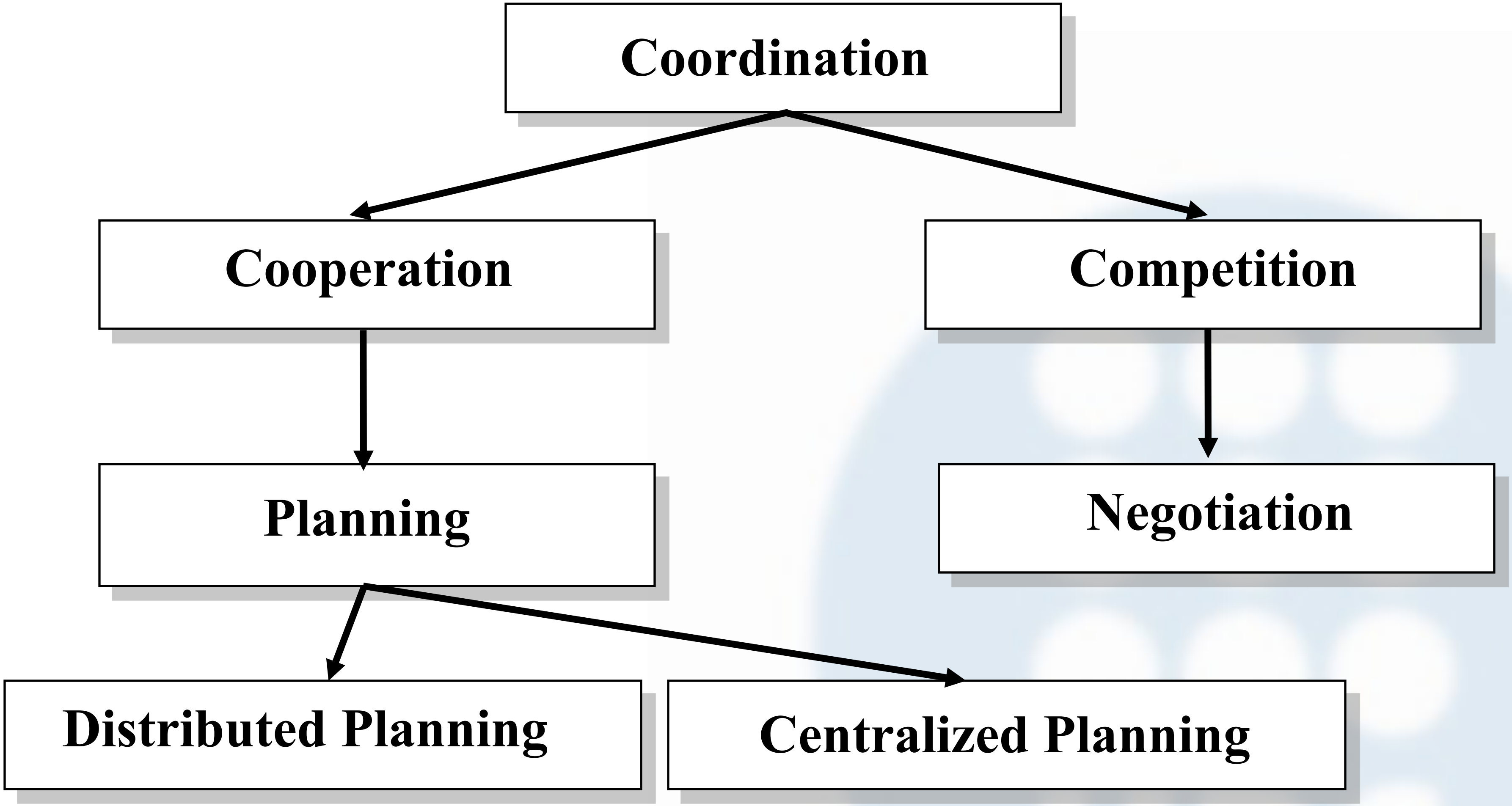
Coordination

Types of coordination



Coordination

Recap

Mechanism	Type of coordination	Examples of implementation
Argumentation	Competition	Fatio
Joint intentions	Cooperation	Commitments
Interaction protocols	Both	Contract-Net, Auctions
Distributed planning	Cooperation	GPGP/TAEMS, MA-STRIPS
Teamwork	Cooperation	TEAMCORE, STEAM
Algorithms	Cooperation	DCOP, Paxos, Raft

More autonomy

Less autonomy

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Example: Commitments

- Example from: *Telang, Pankaj R., and Munindar P. Singh. "Business modeling via commitments." International Workshop on Service-Oriented Computing: Agents, Semantics, and Engineering. Springer, Berlin, Heidelberg, 2009.*
- Commitments are defined as *C(R1, R2, p, q)*, where:
  - *R1* is the *debtor*
  - *R2* is the *creditor*
  - *p* is the *antecedent*
  - *q* is the *consequent*
- If *p* holds, then *R1* is obliged to *R2* to bring about *q*

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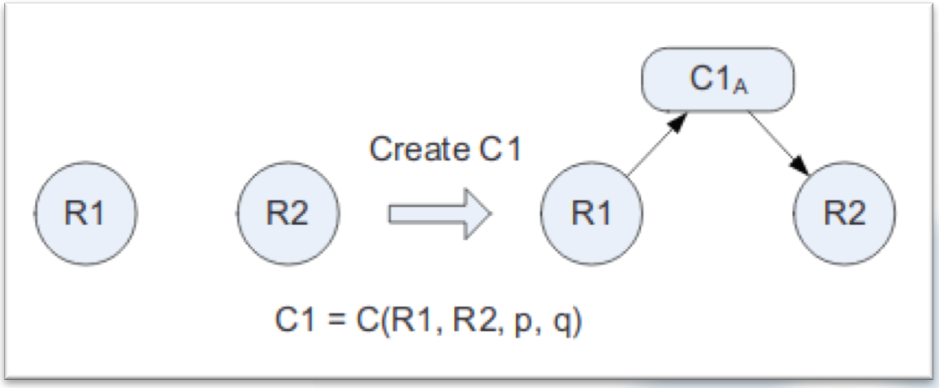
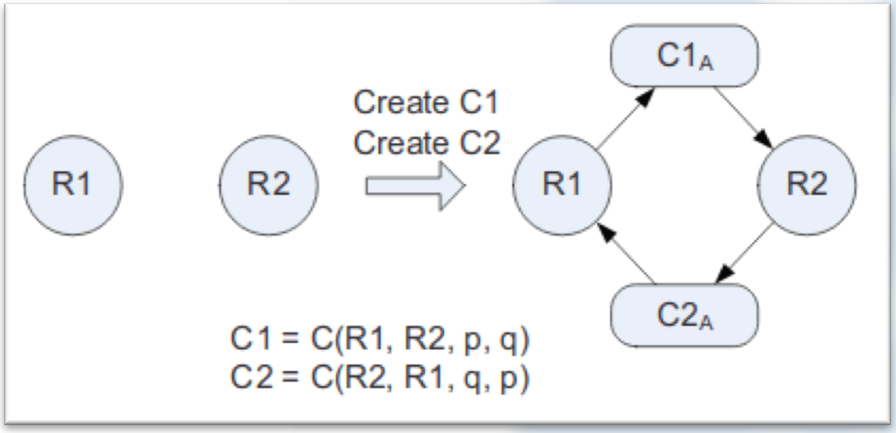
Example: Commitments



Unilateral commitment



Commercial transaction

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Example: Commitments

Algorithm 1: verifyInteractions(m, i): Verify agent interaction model i with respect to business model m

$C = m.C$; // Model Commitments
$CS = ()$; // Satisfied commitments
$CV = ()$; // Violated commitments
$T = i.T$; // Tasks completed in the interaction model
foreach $c \in C$ **do**
    if *(eval(c.consequent, T) = true)* **then**
        $CS.add(c)$;
foreach $((c \in C) \wedge (c \notin CS))$ **do**
    if *(eval(c.antecedent, T) = true)* **then**
        $CV.add(c)$
return CV;

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Example: Commitments

- From individual commitments to group commitments:
  - Castelfranchi, Cristiano. "Commitments: From Individual Intentions to Groups and Organizations." *ICMAS*. Vol. 95. 1995.
  - Brazier, Frances MT, Catholijn M. Jonker, and Jan Treur. "Formalisation of a cooperation model based on joint intentions." *International Workshop on Agent Theories, Architectures, and Languages*. Springer, Berlin, Heidelberg, 1996.
- The formalisation could change depending on the domain or implementation, e.g.,
  - The creditor is a group or organisation
  - Multiple creditors per commitment
  - The creditor is one-self
  - Commitments are assumed to be collective and the creditor is not made explicit

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Example: Argumentation

- Example from: *Sierra, Carles, et al. "A framework for argumentation-based negotiation." International Workshop on Agent Theories, Architectures, and Languages. Springer, Berlin, Heidelberg, 1997.*
- Defines a communication language with illocutions:
  - *request/offer/accept/reject(a, b, d, t)*
  - *withdraw(a, b, t)*
  - *threaten/reward(a, b, statement, condition, t)*
  - *appeal(a, b, d, reason, statement, t)*
  - where *a* and *b* are competing agents, *d* is a deal proposal, *t* is instant of time, and *statement/condition/reason* are recursive formulas of the language

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Example: Argumentation

Type	Id	Parties	Content	Comments
Threaten	1	CSD-VCs	Match the offer I have from another VC, otherwise I'll break off this negotiation.	Threaten to terminate current negotiation thread.
	2	CSD-VCs	Make sure you get back to me in the specified time period or I won't involve you in future rounds of bidding.	Threaten to terminate all future negotiation threads.
	3	DD-SD	If you cannot complete the service sooner, I'll inform your boss that we missed the deadline because of you.	Threaten to inform outside party of (perceived) poor performance.
Reward	4	CSD-DD	If you produce this design by this time we'll be able to get the quote to our major customer ahead of time.	Indicate positive effect of performing action by specified time.
	5	CSD-VCs	If you vet this customer by this time, I'll make sure you're involved in subsequent rounds of bidding.	Promise future involvement for accepting current proposal.
Appeal	6	CSD-VCs	Last time you vetted this customer, it took this length of time and cost this much.	Appeal to precedent.
	7	CSD-DD	You must complete this design within 48 hours because company policy says customers must be responded to within this time frame.	Appeal to (company's) prevailing practice.
	8	VC-CSD	This customer may be in financial trouble, therefore more time is needed to carry out a higher quality vetting.	Appeal to (CSD's) self interest.
	9	DD-CSD	The design will take longer than normal because one of our surveyors is on holiday this week.	Revealing new information.
	10	SD-DD	Customer has many premises and they all need to be surveyed, thus this service will take longer than normal.	Revealing new information.

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Example: Argumentation

Id	Dialogue
1	$\texttt{appeal}(CSD, VC_i, \texttt{offer}(VC_j, CSD, \delta), true)$, $\texttt{threaten}(CSD, VC_i, not\ \texttt{offer}(VC_i, CSD, \delta), \texttt{withdraw}(CSD, VC_i))$
2	$\texttt{threaten}(CSD, VC_i, not\ \texttt{offer}(VC_i, CSD, \ldots \wedge time < limit),$ $not\ \texttt{request}(CSD, VC_i, Future^{a}))$ [a] $Future$ is an universally quantified variable over the future instants in $Time$.
3	$\texttt{threaten}(DD, SD, not\ \texttt{acccept}(SD, DD, \ldots \wedge time < limit),$ $\texttt{appeal}(DD, Boss_{SD}, \psi^{a}, not\ \texttt{acccept}(SD, DD, \ldots \wedge time < limit)))$ [a] ψ expressing the fact that the deadline has been missed.
4	$\texttt{reward}(CSD, DD, \texttt{accept}(DD, CSD, \delta), \texttt{appeal}(CSD, OurBoss, \psi, \texttt{accept}(DD, CSD, \delta)))^{a}$ [a] $\delta = \ldots Vet = Customer_i \wedge time < limit$. The reward consists of passing the information to our boss. ψ represents the satisfaction of $Customer_i$.
5	$\texttt{reward}(CSD, VC_i, \texttt{accept}(VC_i, CSD, \ldots \wedge time = k \wedge \ldots), \texttt{request}(CSD, VC_i, \Delta, Future))^{a}$ [a] Δ stands for a deal, and $Future$ stands for an instant in the future.
6	$\texttt{appeal}(CSD, VC_i, time = t \wedge cost = c, \texttt{accept}(VC_i, CSD, \ldots \wedge time = t \wedge cost = c, Before^{a}))$ [a] *Before* represents a previous instant in $Time$.
7	$\texttt{appeal}(CSD, DD, time = 48h, BT\_policy\_time = 48h)$
8	$\texttt{appeal}(VC_i, CSD, time = high, Financial\_status = trouble \wedge Quality\_vetting = high)$
9	$\texttt{appeal}(DD, CSD, time > t_{normal}, surveyor(Smith) \wedge holiday(Smith))$
10	$\texttt{appeal}(SD, DD, time > t_{normal}, Number\_premises = High)$

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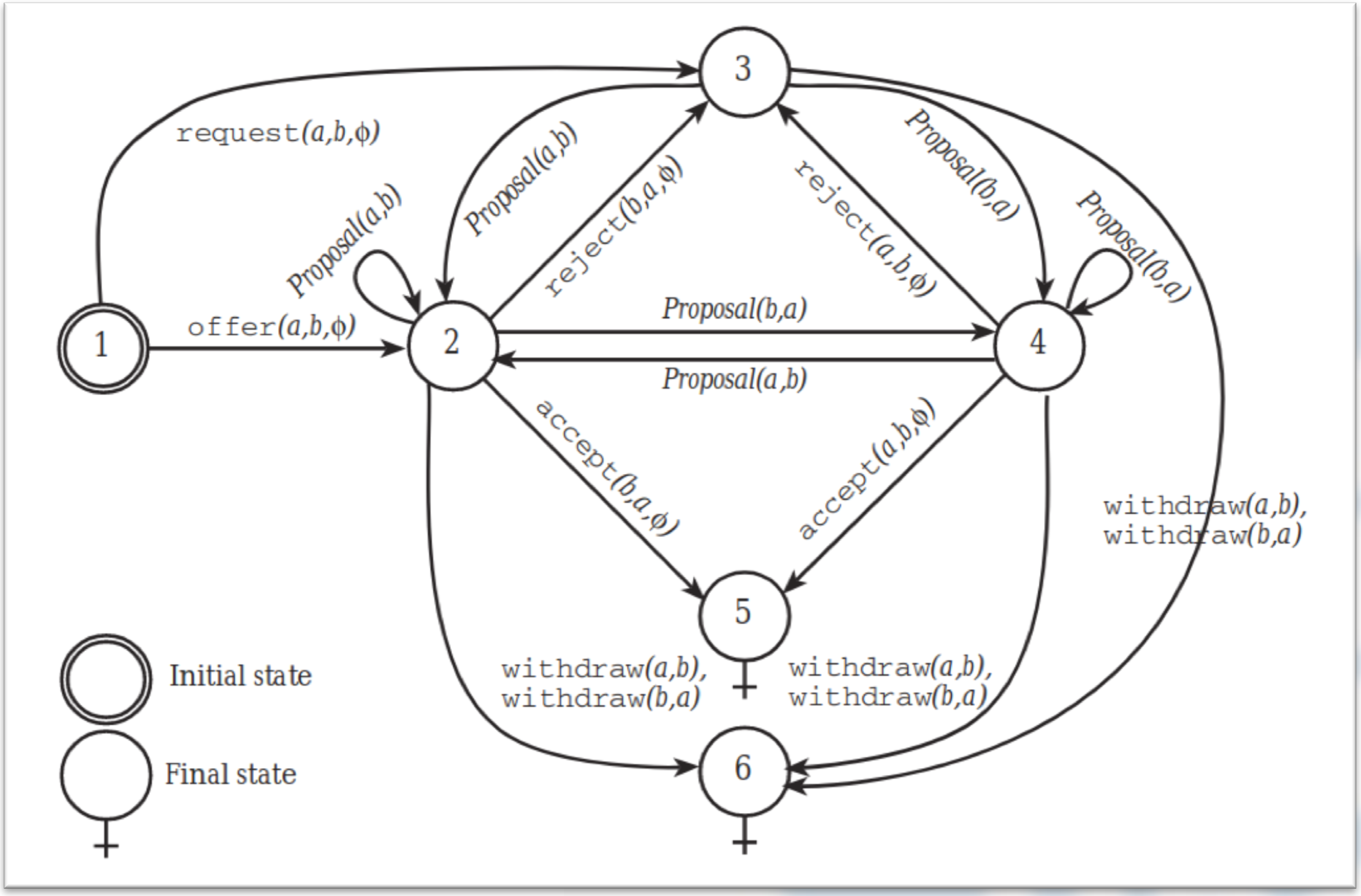
Example: Argumentation



Negotiation protocol for this argumentation framework.
Proposal(x, y) can be: *offer, threaten, reward, appeal*

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Example: Interaction protocols

- Heredia, Guillermo, et al. "Multi-unmanned aerial vehicle (UAV) cooperative fault detection employing differential global positioning (DGPS), inertial and vision sensors." *Sensors* 9.9 (2009): 7566-7579.
- Kiener, Jutta, and Oskar Von Stryk. "Towards cooperation of heterogeneous, autonomous robots: A case study of humanoid and wheeled robots." *Robotics and Autonomous Systems* 58.7 (2010): 921-929.
- Pu-Cheng, Zhou, Han Yu-Sheng, and Xue Mo-Gen. "Extended contract net protocol for multi-robot dynamic task allocation." *Information Technology Journal* 6.5 (2007): 733-738.
- Lee, Jonathan, et al. "Composing web services enacted by autonomous agents through agent-centric contract net protocol." *Information and Software Technology* 54.9 (2012): 951-967.
- Tian, Jiang, et al. "An extended contract net mechanism for dynamic supply chain formation and its application in China petroleum supply chain management." *Multiagent and Grid Systems* 2.2 (2006): 183-207.

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Example: Teamwork

- Example from *Freedy, Amos, et al. "Multiagent adjustable autonomy framework (MAAF) for multi-robot, multi-human teams." 2008 International Symposium on Collaborative Technologies and Systems. IEEE, 2008.*

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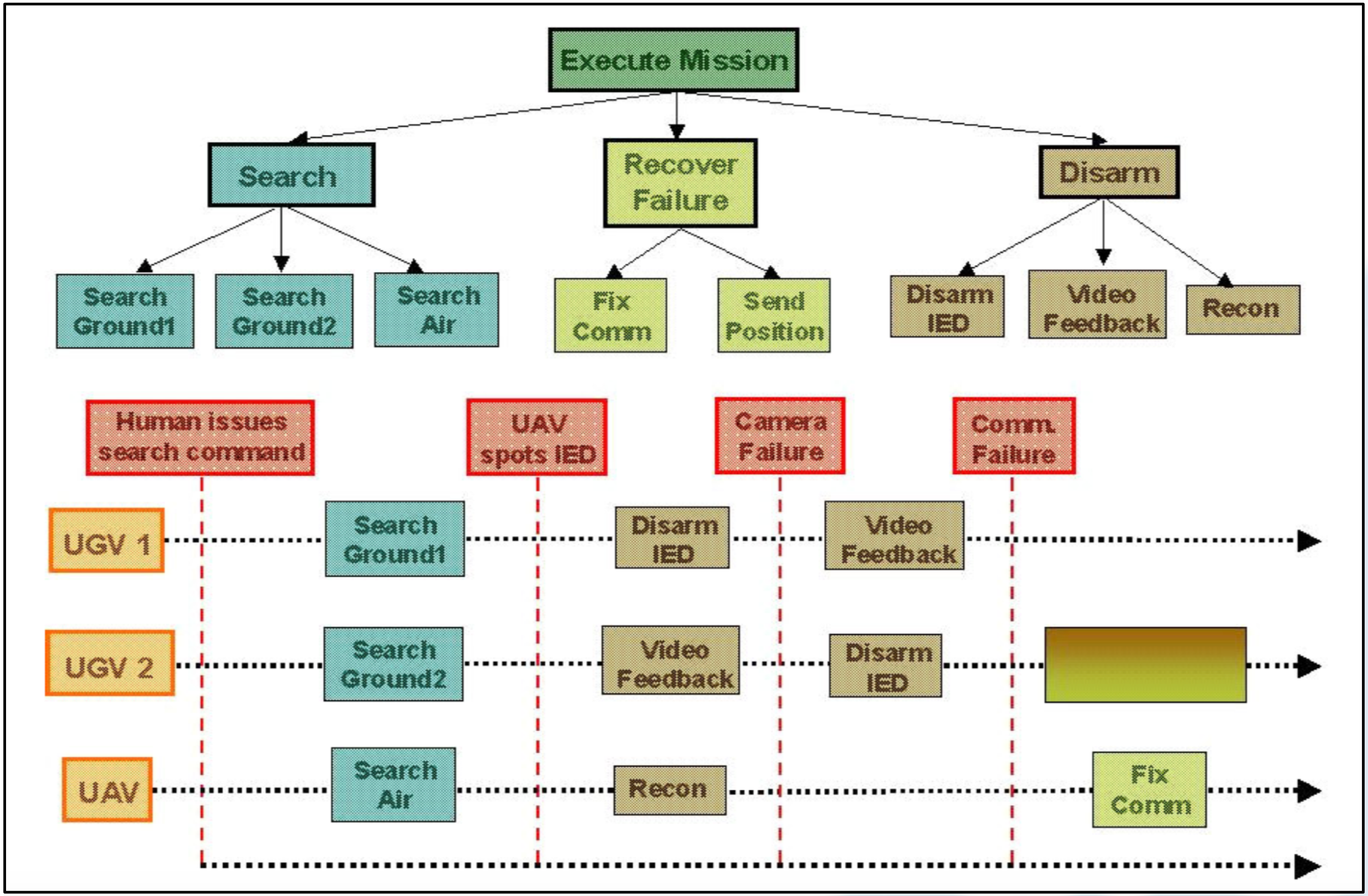
Example: Teamwork



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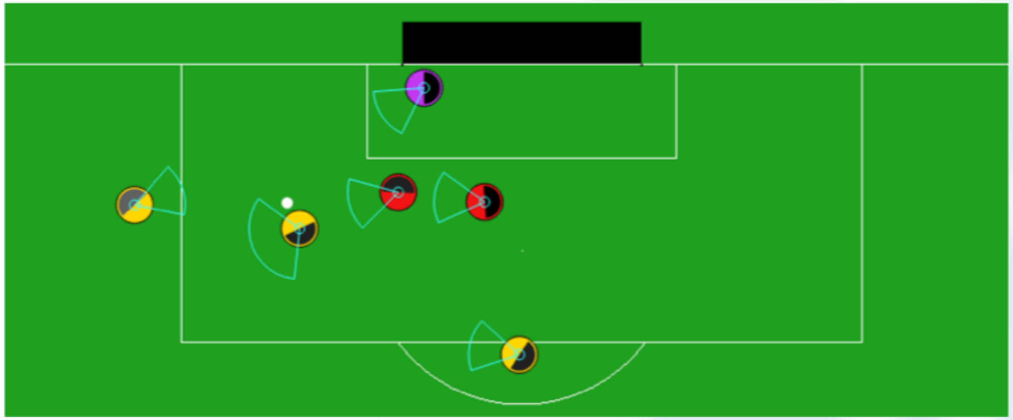
Example: Teamwork

- Example from *Hausknecht, Matthew, et al. "Half field offense: An environment for multiagent learning and ad hoc teamwork." AAMAS Adaptive Learning Agents (ALA) Workshop. 2016.*
- How should the yellow *team* find an opening?
  - Without predefined strategies: *ad hoc teamwork*



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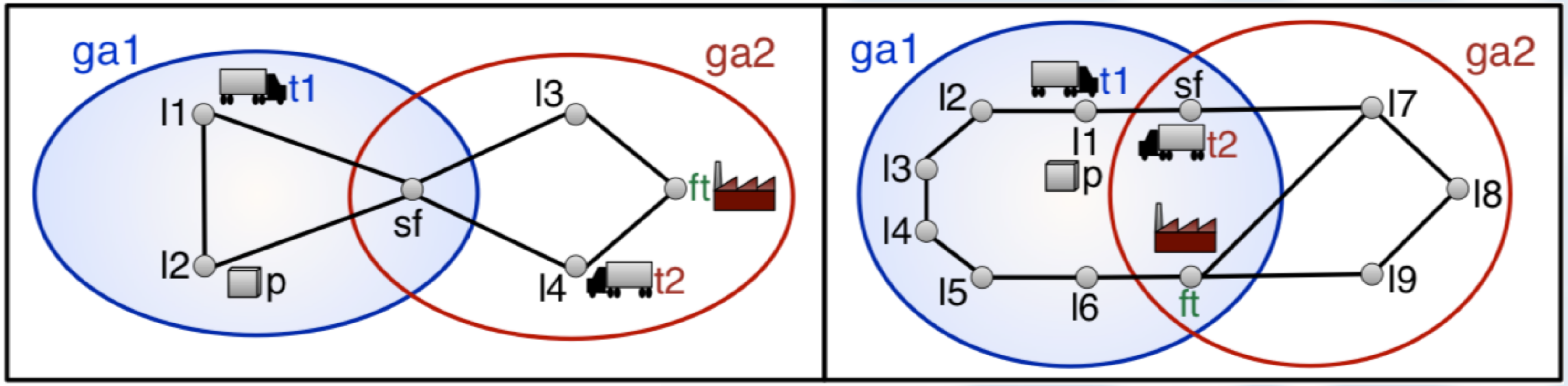
Example: Distributed planning

- Annual competition for this type of problems: http://agents.fel.cvut.cz/codmap/
- Example from *Torreño, Alejandro, et al. "Cooperative multi-agent planning: a survey." ACM Computing Surveys (CSUR) 50.6 (2018): 84.*
- Multiple different partial (*local*) goals, multiple different partial (*local*) knowledge bases



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Example: Distributed planning

Task	$\mathcal{T}_1$			$\mathcal{T}_2$		
$\mathcal{AG}$	$ta1$	$ta2$	ft	$ta1$	$ta2$	ft
$\mathcal{P}^i$	$(pos\ t1\ *)$	$(pos\ t2\ *)$	$(pending\ fp)$	$(pos\ t1\ *)$	$(pos\ t2\ *)$	$(pending\ fp)$
	$(at\ p\ *)$		$(at\ p\ ft)$	$(at\ p\ *)$		$(at\ p\ ft)$
	$(manufactured\ fp)$			$(manufactured\ fp)$		
$\mathcal{A}^i$	drive, load, unload		manufacture	drive, load, unload		manufacture
$\mathcal{I}^i$	$(pos\ t1\ l1)$ $(at\ p\ l2)$	$(pos\ t2\ l4)$	$(pending\ fp)$	$(pos\ t1\ l1)$ $(at\ p\ l1)$ $(at\ p3\ ft)$	$(pos\ t2\ sf)$	
$\mathcal{G}$	$(manufactured\ fp)$			$(at\ p\ ft)$		

```
(define (problem ta1)
  (:domain transport-agency)
  (:objects
    ta1 - transport-agency
    ga1 - area                        l1 l2 sf - place
    p - package                       fp - product
    (:private t1 - truck)
  )
  (:init
    (area ta1 ga1) (pos t1 l1) (owner t1 ta1) (at p l1)
    (link l1 l2) (link l2 l1) (link l1 sf)
    (link sf l1) (link l2 sf) (link sf l2)
    (in-area l1 ga1) (in-area l2 ga1) (in-area sf ga1)
  )
  (:goal (manufactured fp))
)
```

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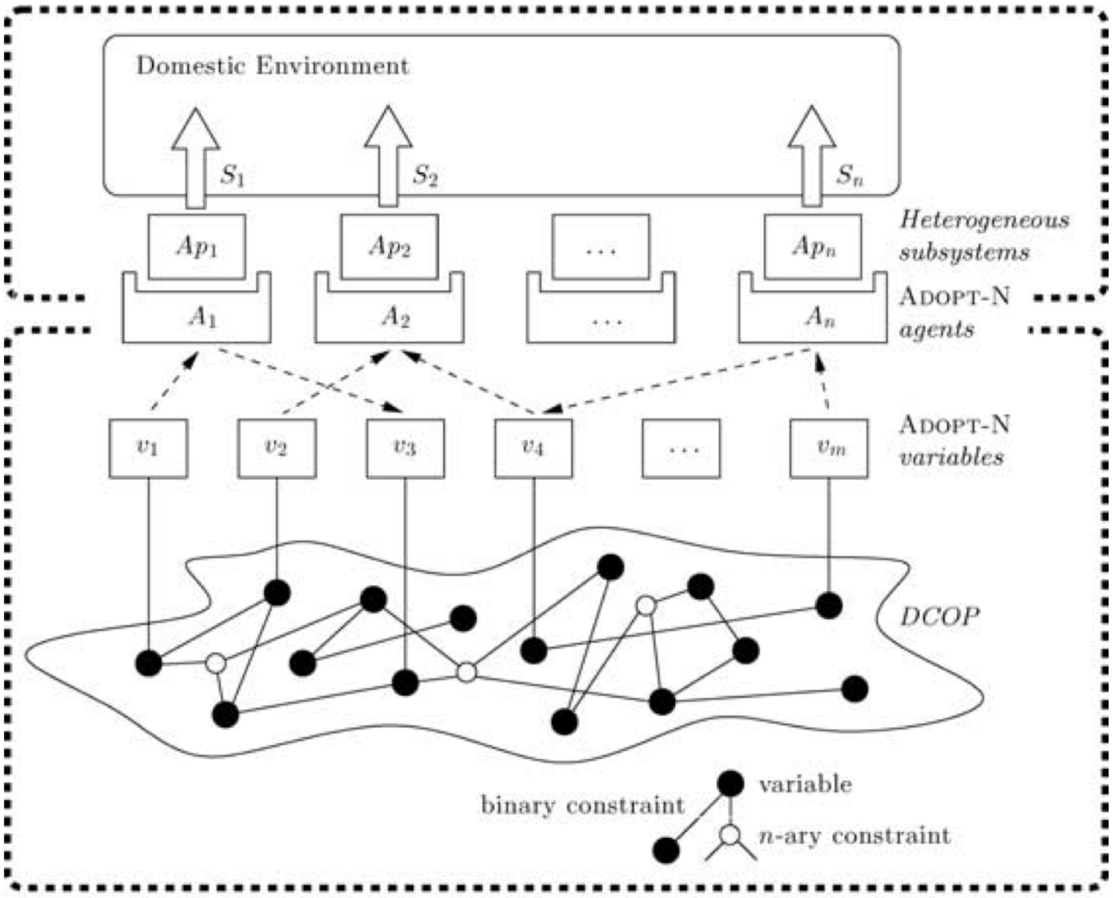
Example: Coordination algorithms (DCOPs)

- Example from *Pecora, Federico, and Amedeo Cesta. "Dcop for smart homes: A case study." Computational Intelligence 23.4 (2007): 395-419.*
- Variables v_i can be inputs or outputs, e.g. person/robot location or service triggers



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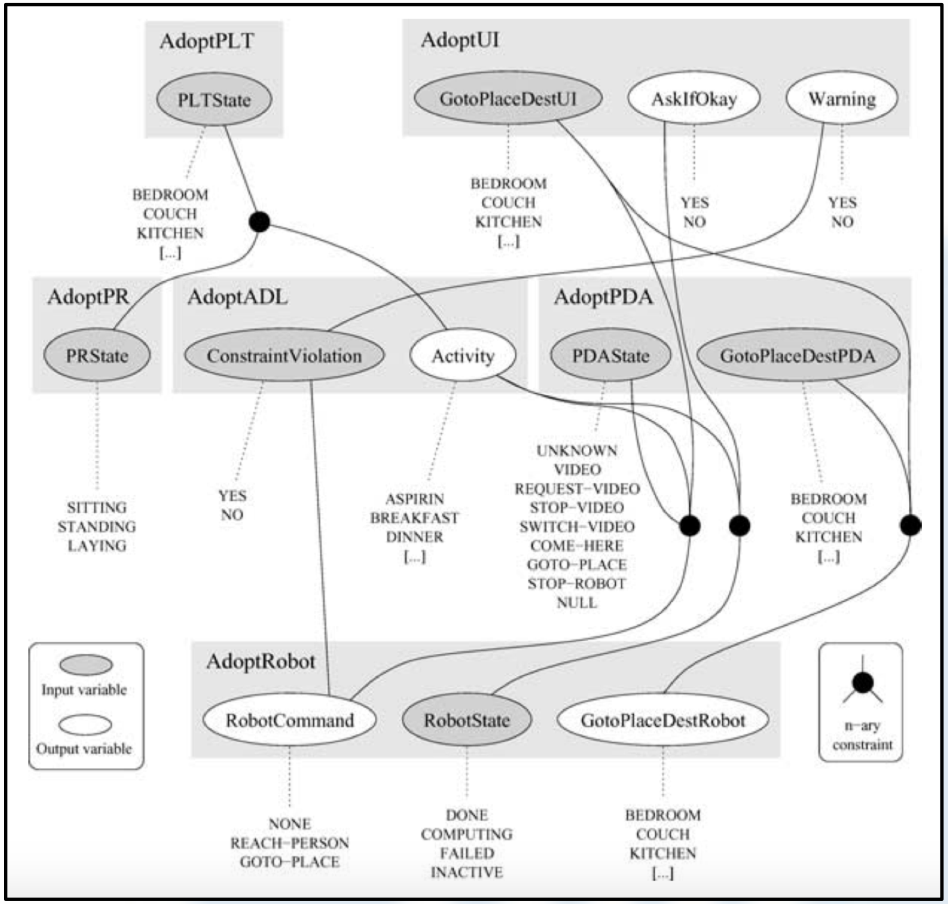
Example: Coordination algorithms (DCOPs)

- The desired behavior of the whole *smart home* is defined as a set of constraints relating variables
- Examples of cost assignments:
  - *f(Activity == EMERGENCY && RobotCommand == REACH-PERSON) = 0*
  - *f(Object == COFFEE && Activity == BREAKFAST) = 10*



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Example: Coordination algorithms (DCOPs)

- ADOPT is the most popular DCOP algorithm
  - Modi, Pragnesh Jay, et al. "ADOPT: Asynchronous distributed constraint optimization with quality guarantees." *Artificial Intelligence* 161.1-2 (2005): 149-180.
- Agents are ordered in a tree
  - Constraints propagated between parents and children
  - No constraints propagated between siblings
- For each node starting from the parent:
  - Choose VALUE with minimum cost
  - Send VALUE to children
  - Send COST to parent
  - When MESSAGE is received from children
    - Update THRESHOLD with minimum values for children
    - Recalculate VALUE, staying within THRESHOLD
      - If not possible to optimize, TERMINATE

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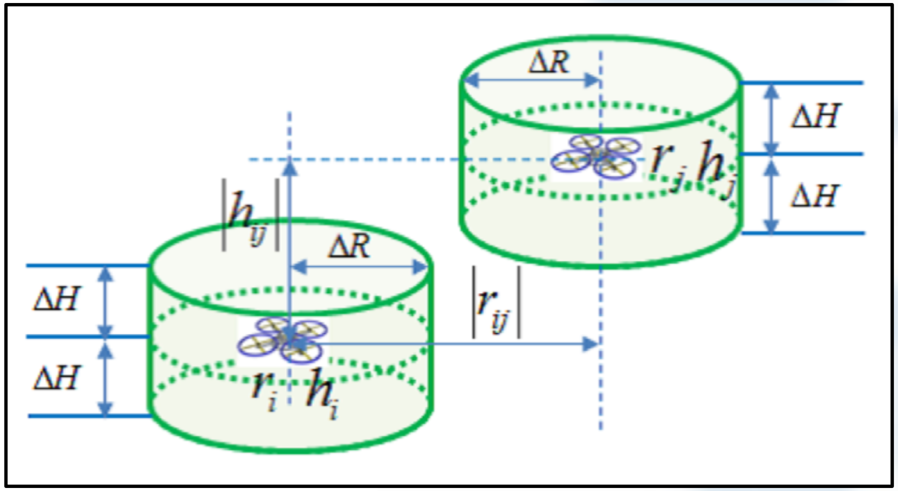
Example: Coordination algorithms (Consensus)

- Example from *Kuriki, Yasuhiro, and Toru Namerikawa. "Consensus-based cooperative formation control with collision avoidance for a multi-UAV system." 2014 American Control Conference. IEEE, 2014.*
- In order to avoid collisions, the leader (which will compute all individual moves) is elected via consensus



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Discussion

- What type of coordination and mechanism(s) would you choose?
  - Autonomous cars in a traffic jam
  - A set of robots dancing a choreography
  - Bots that automatically transact in Wallapop
  - Bots that play a MOBA game
  - Bots that play a MMORPG game
  - The river basin scenario, assuming industries can violate the rules by making illegal discharges