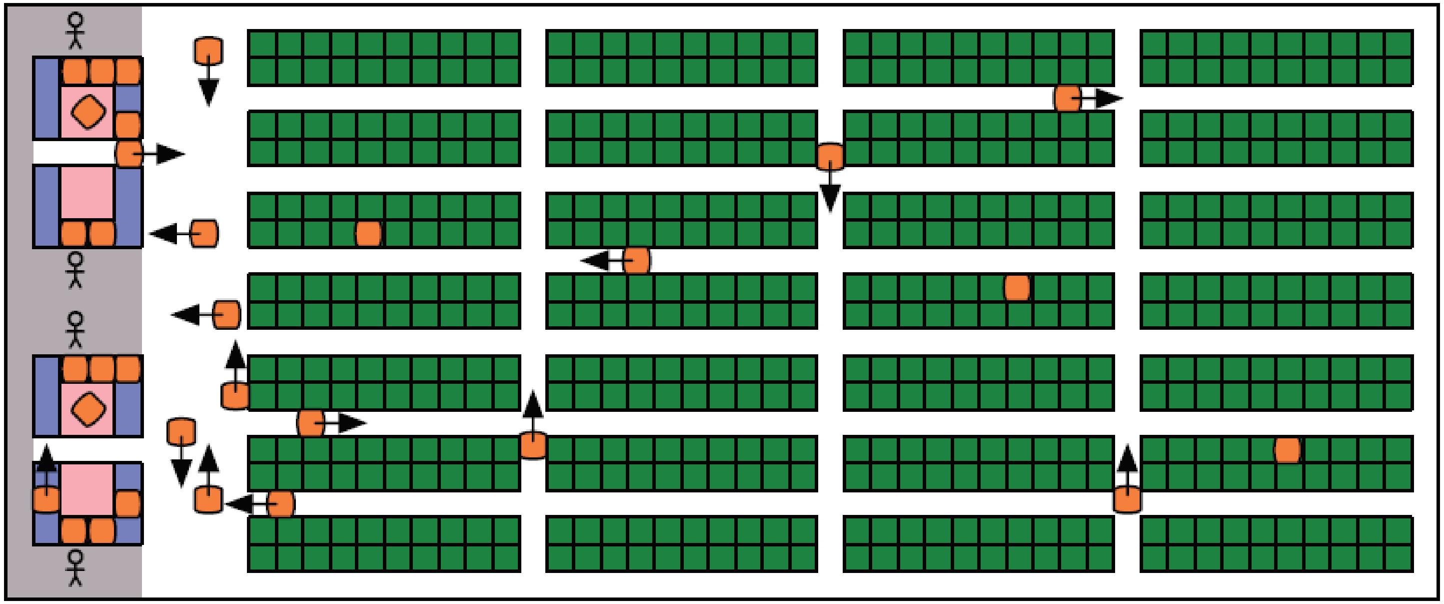
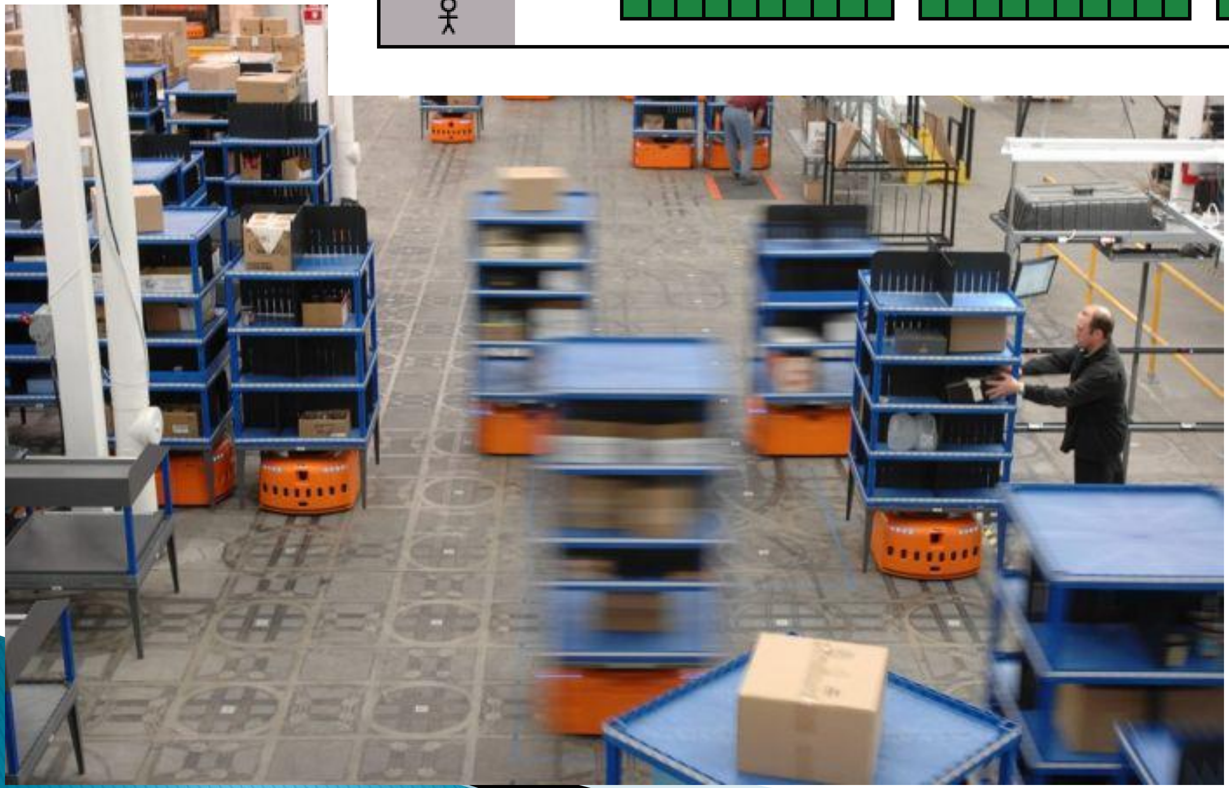
Artificial Intelligence
Cooperative Agent Systems

More about
Jose M Vidal, Fundamentals of Multiagent Systems with NetLogo Examples, March 1, 2010, http://jmvidal.cse.sc.edu/papers/mas.pdf

Outline

- From a Single Agent to Multi Agent Systems
- Organizations
- Cooperation with/via Communication
- Cooperation Protocols
- Cooperation in Competition
- Cooperation in Conflicts

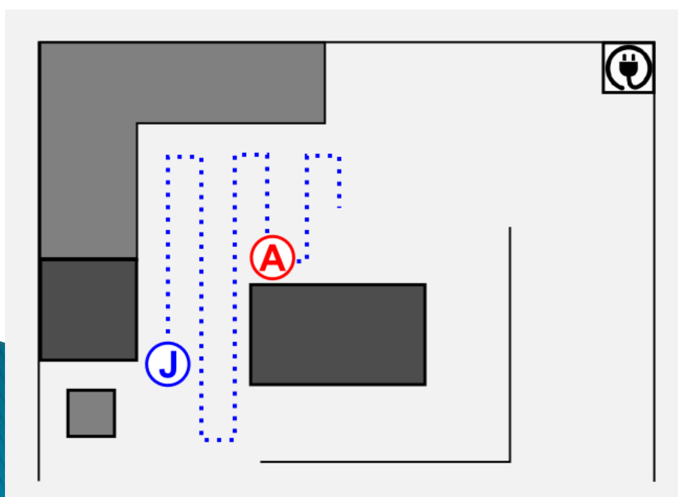


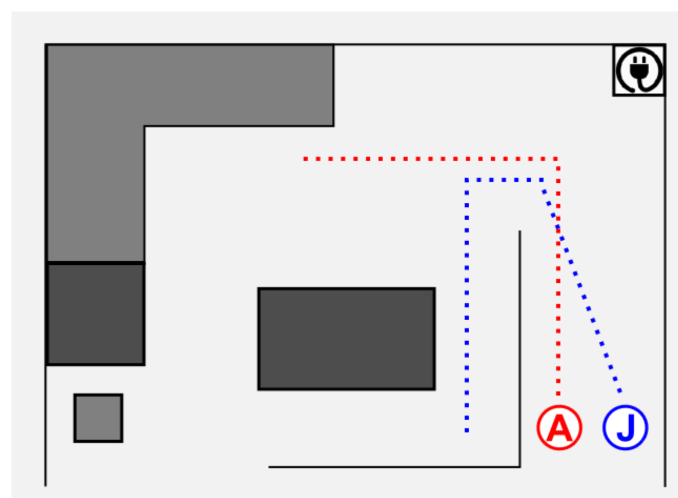


Parallel magazine service with Kiva robots

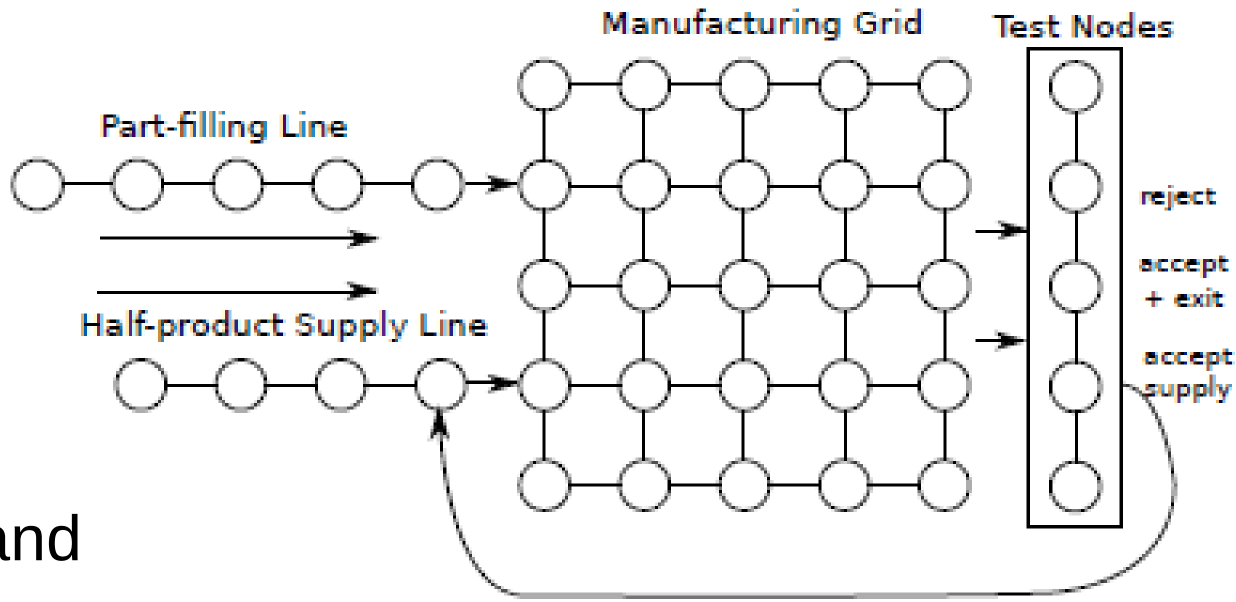
Social and Health Care for Elderly with Fraunhofer Institut Care-O-bot 3

Amigo and Jaguar cleaning – Reconfigurable ROS-based Resilient Reasoning Robotic Cooperating Systems (R5-COP)

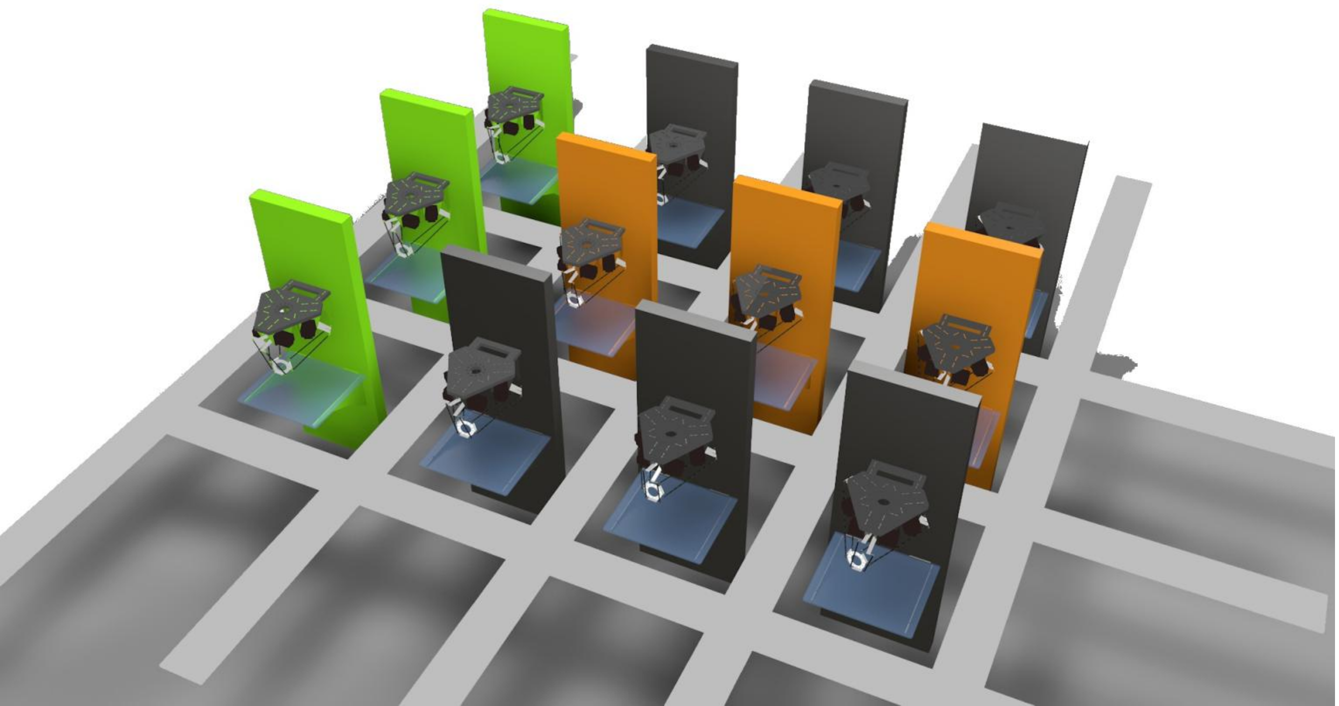




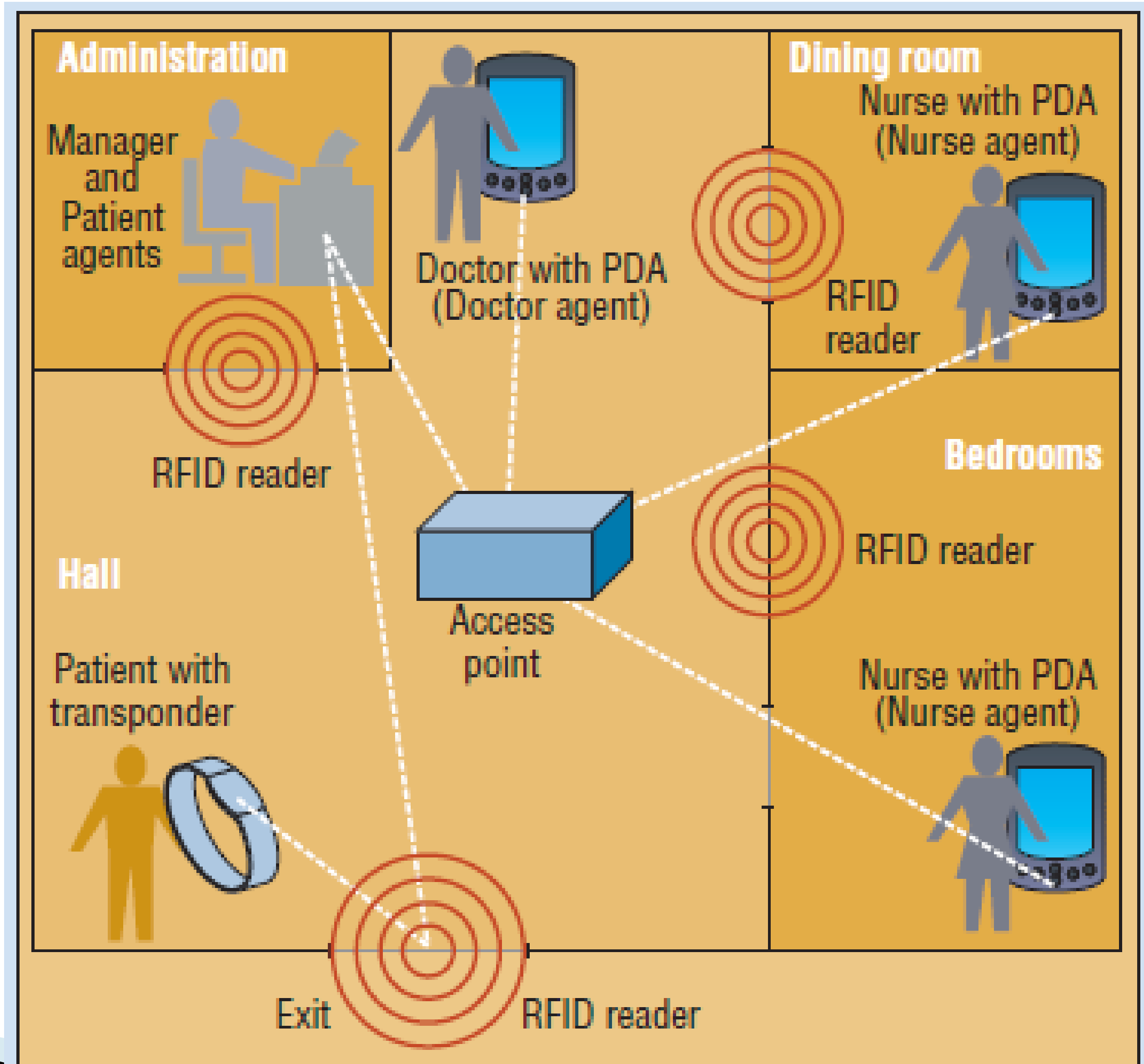
Football as organized activity with Nao robots (Aldebaran Robotics)



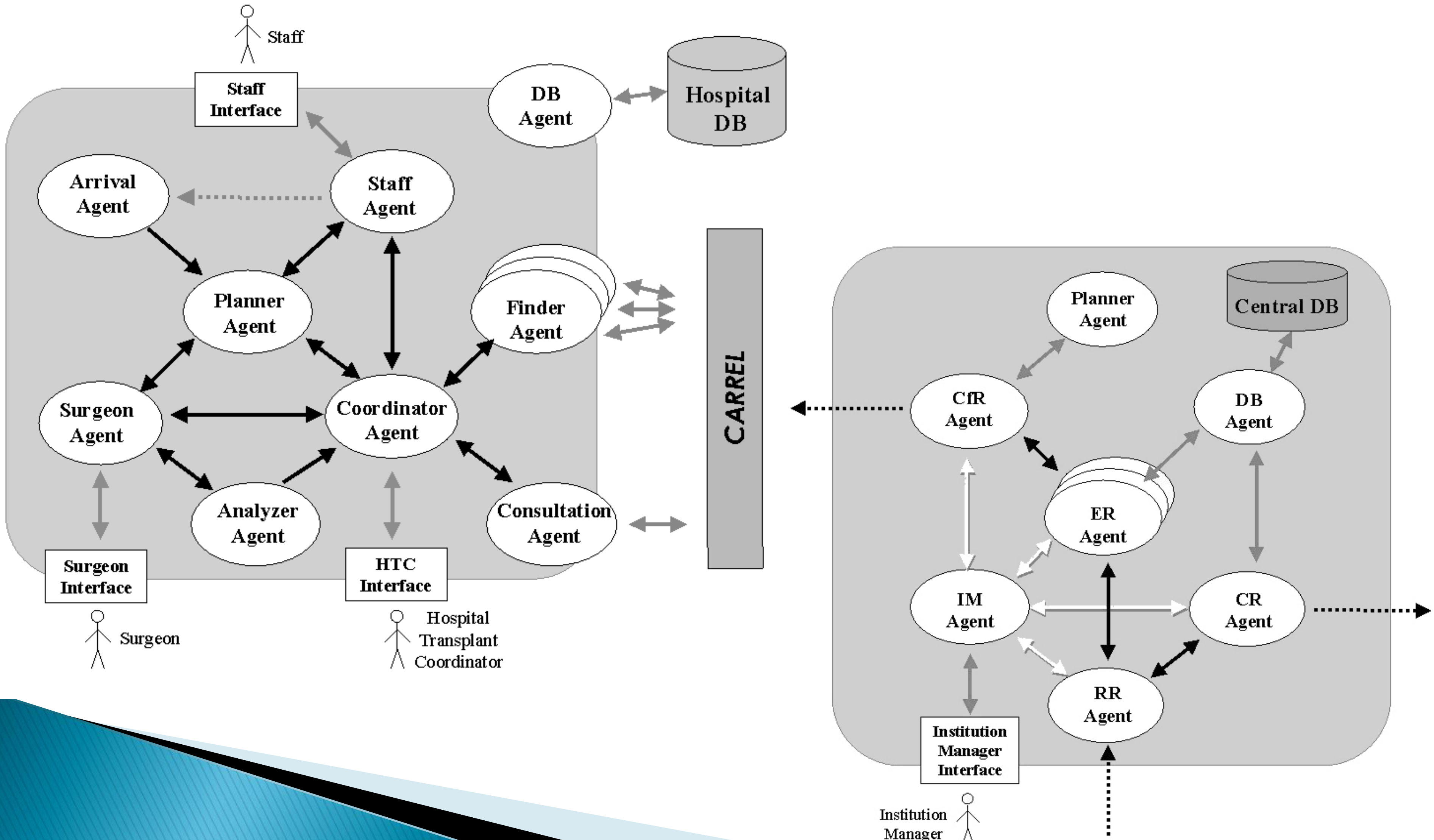
Grid Manufacturing: Society of Equiplet and Product agents



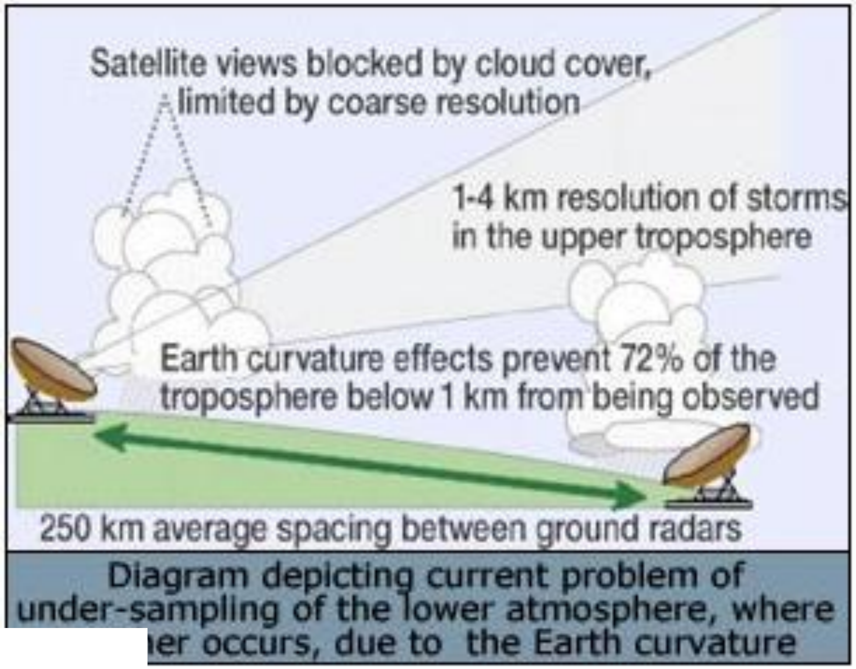
GerAmi – secretary agents in old people's home

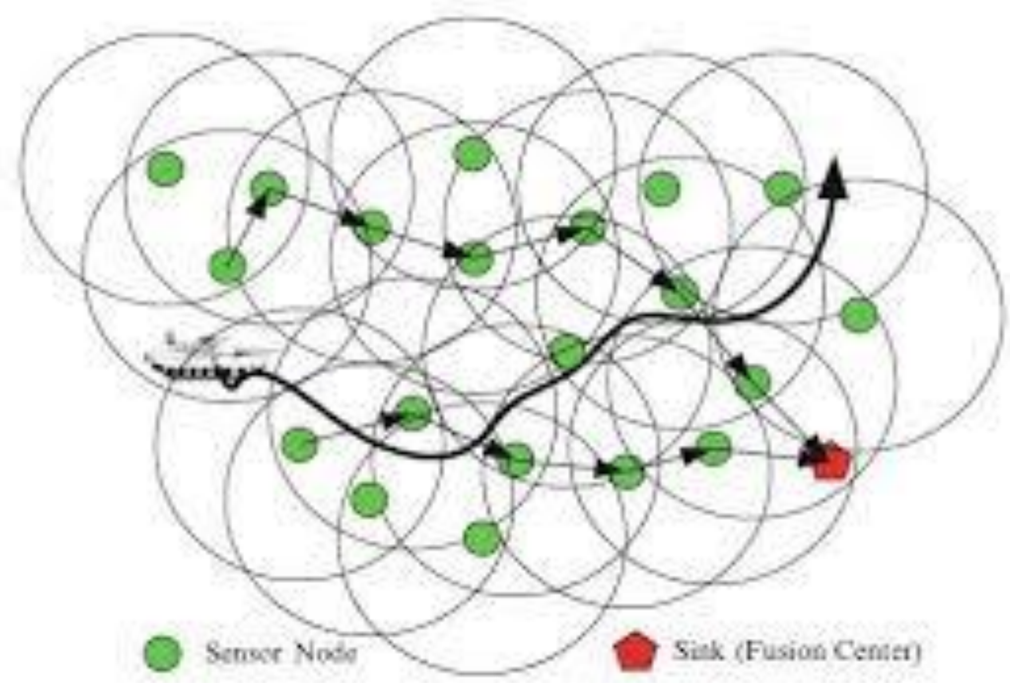


Carrel - e-institution to support organ transplantation

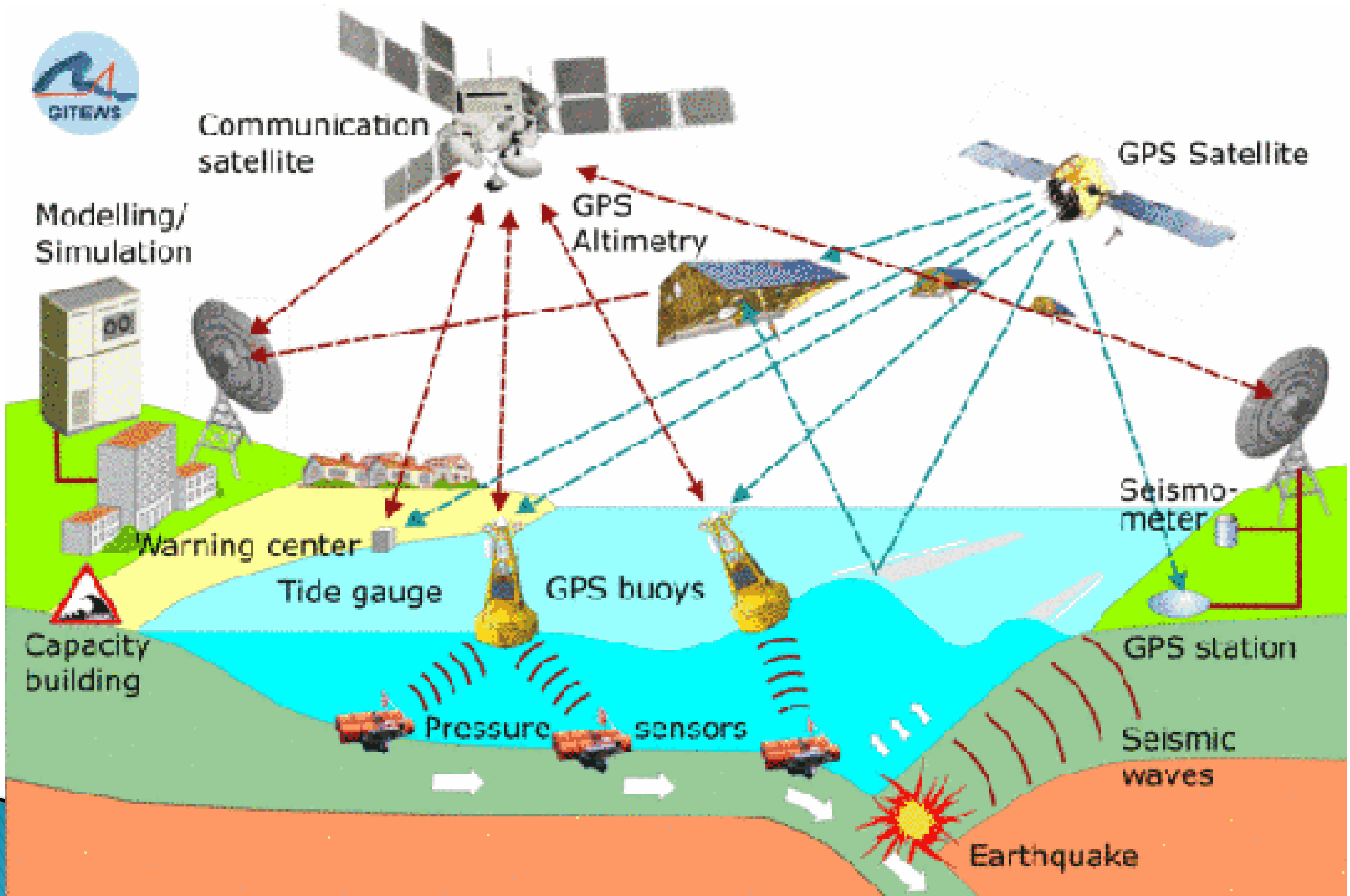


Distributed Sensor Systems Tornado Early Warning with Weather Forecast Radars



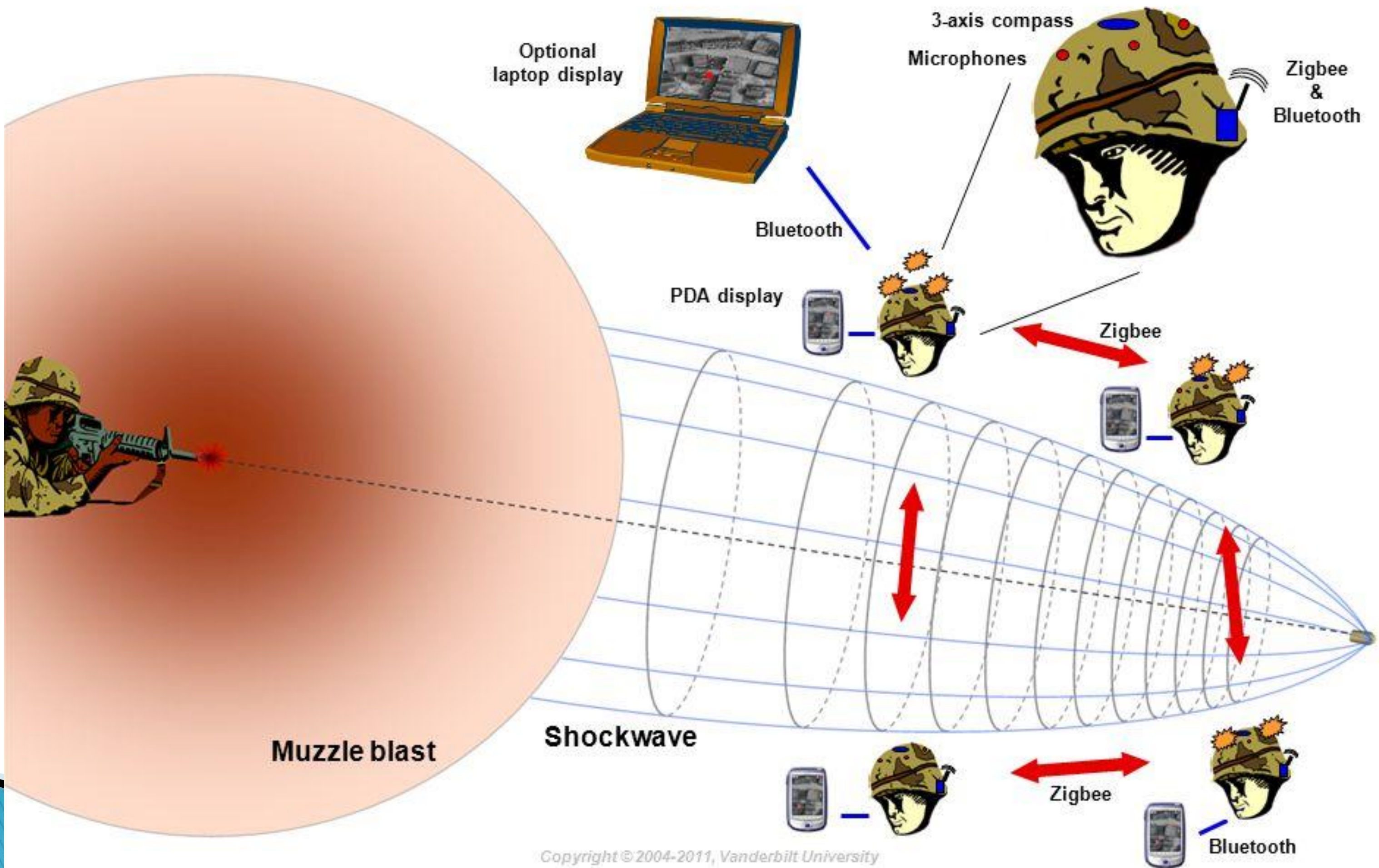


Distributed Sensor Systems
GITEWS: German Indonesian Tsunami Early Warning System

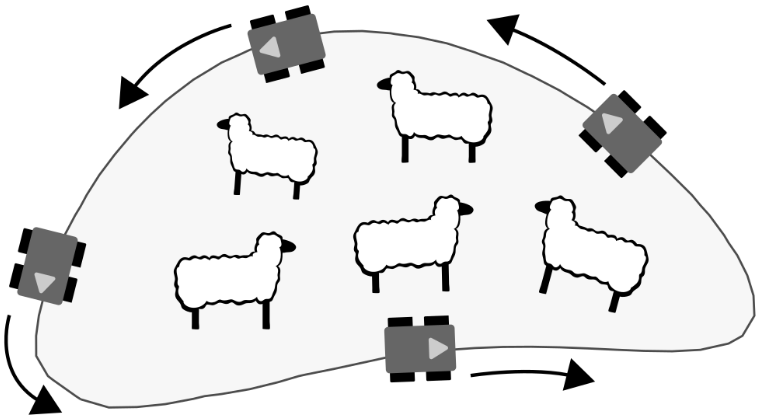


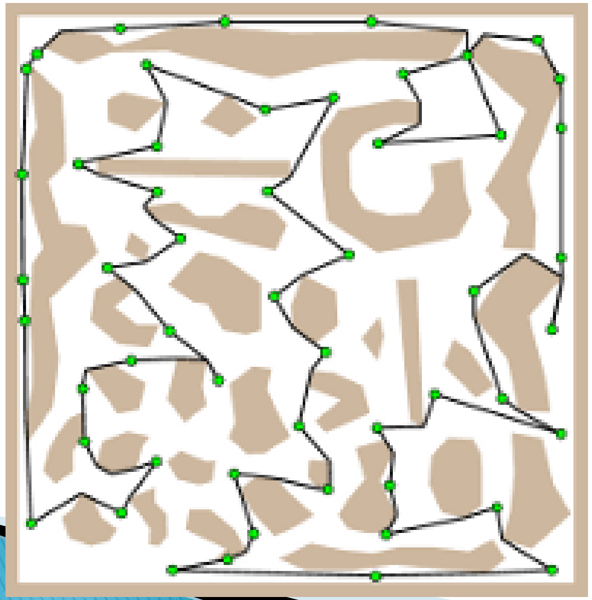
Distributed Sensor Systems
Identifying snipers or poachers

Soldier-Wearable Shooter Localization System
DARPA IPTO ASSIST

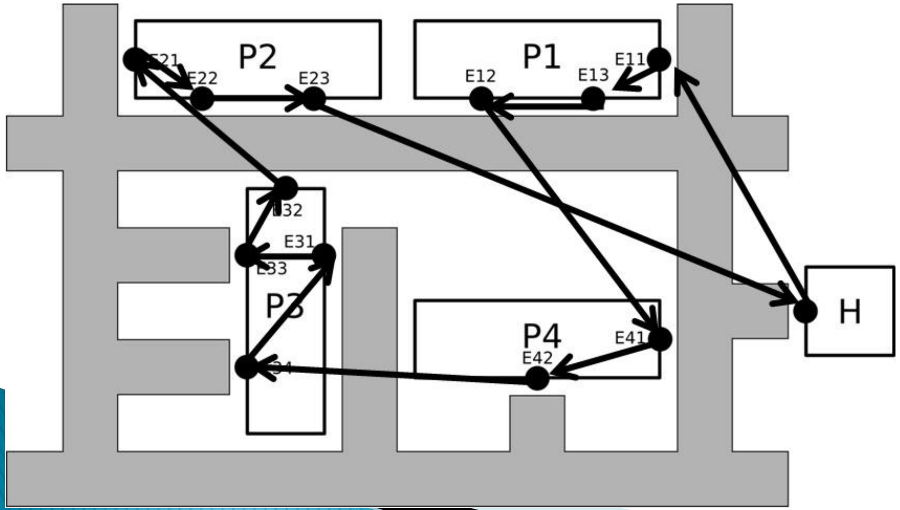


Distributed Sensor Systems
Area Guarding/ Monitoring



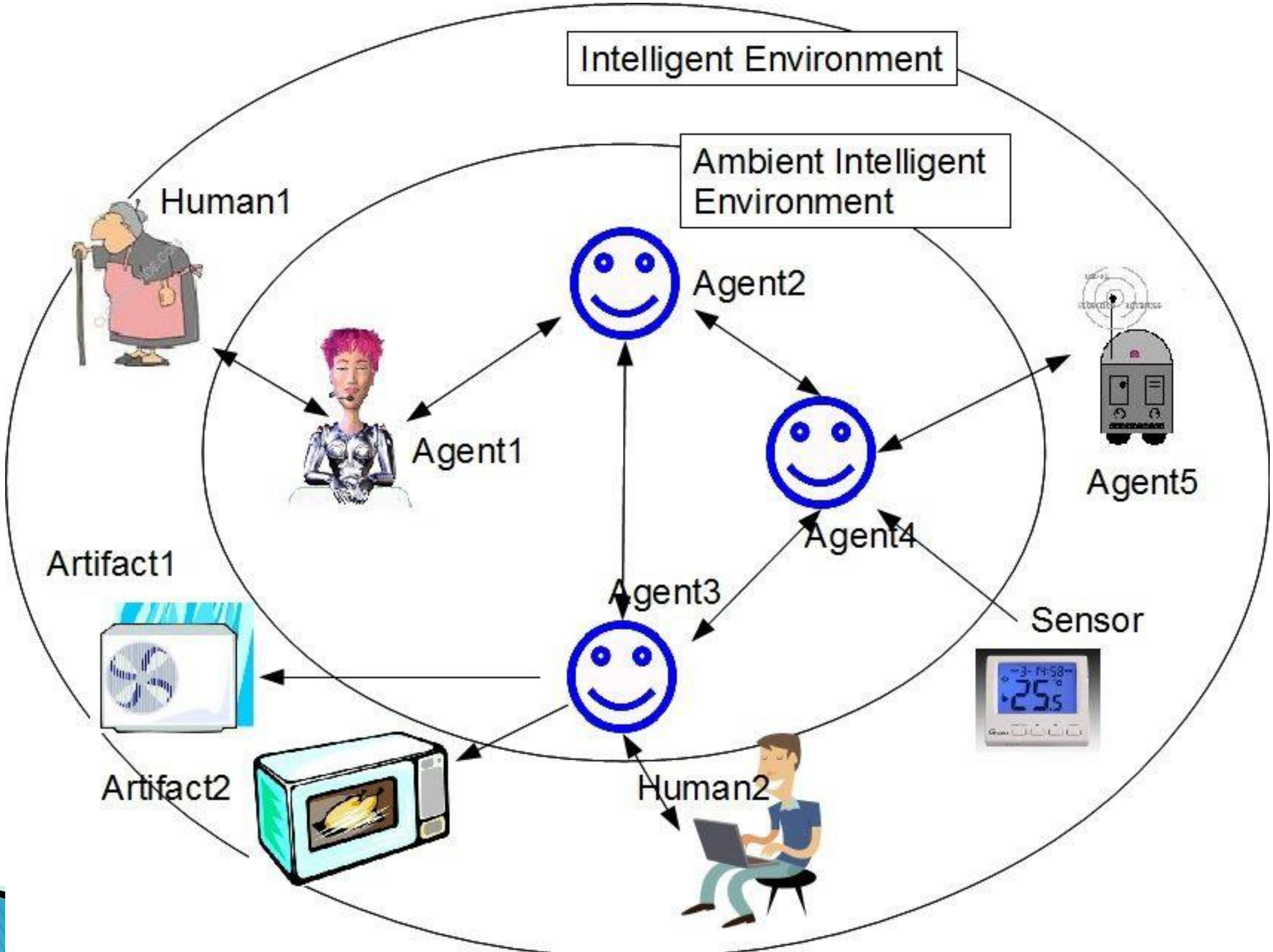


First Responder robots



Intelligent traffic control systems: car drivers, signaling, pedestrians, …

Ambient Intelligence



Smart City: Integrated Ecology

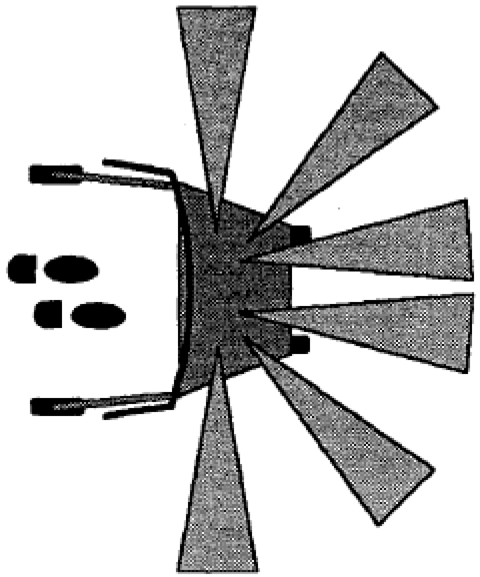
Smart Smart Smart Smart

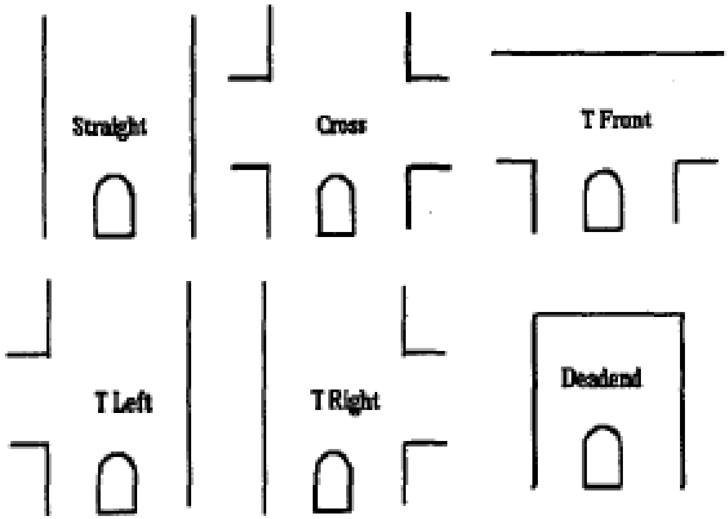
Smart Smart

Mobility Environment Economy Governance Living

People

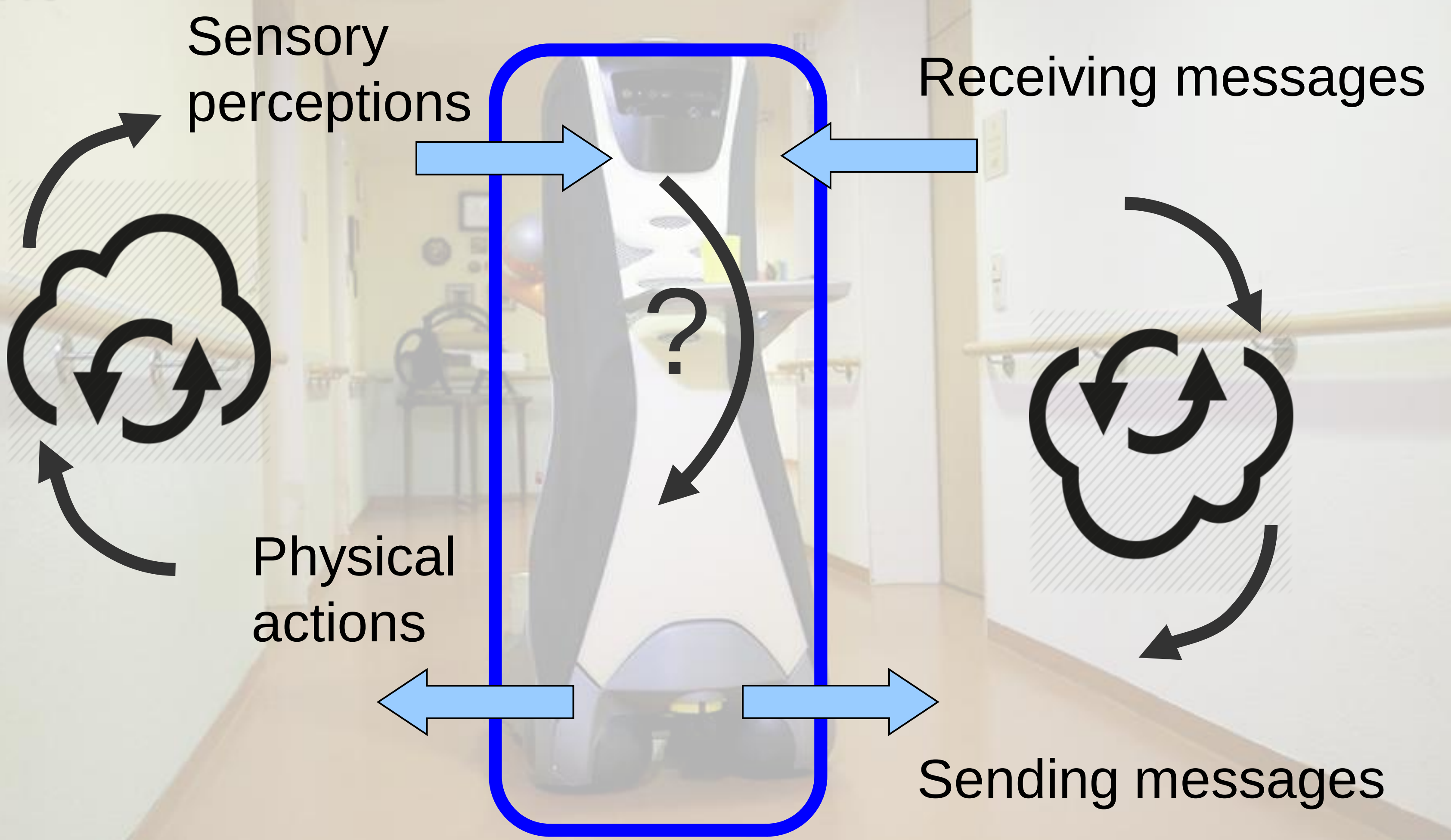
Intelligent walking assistance





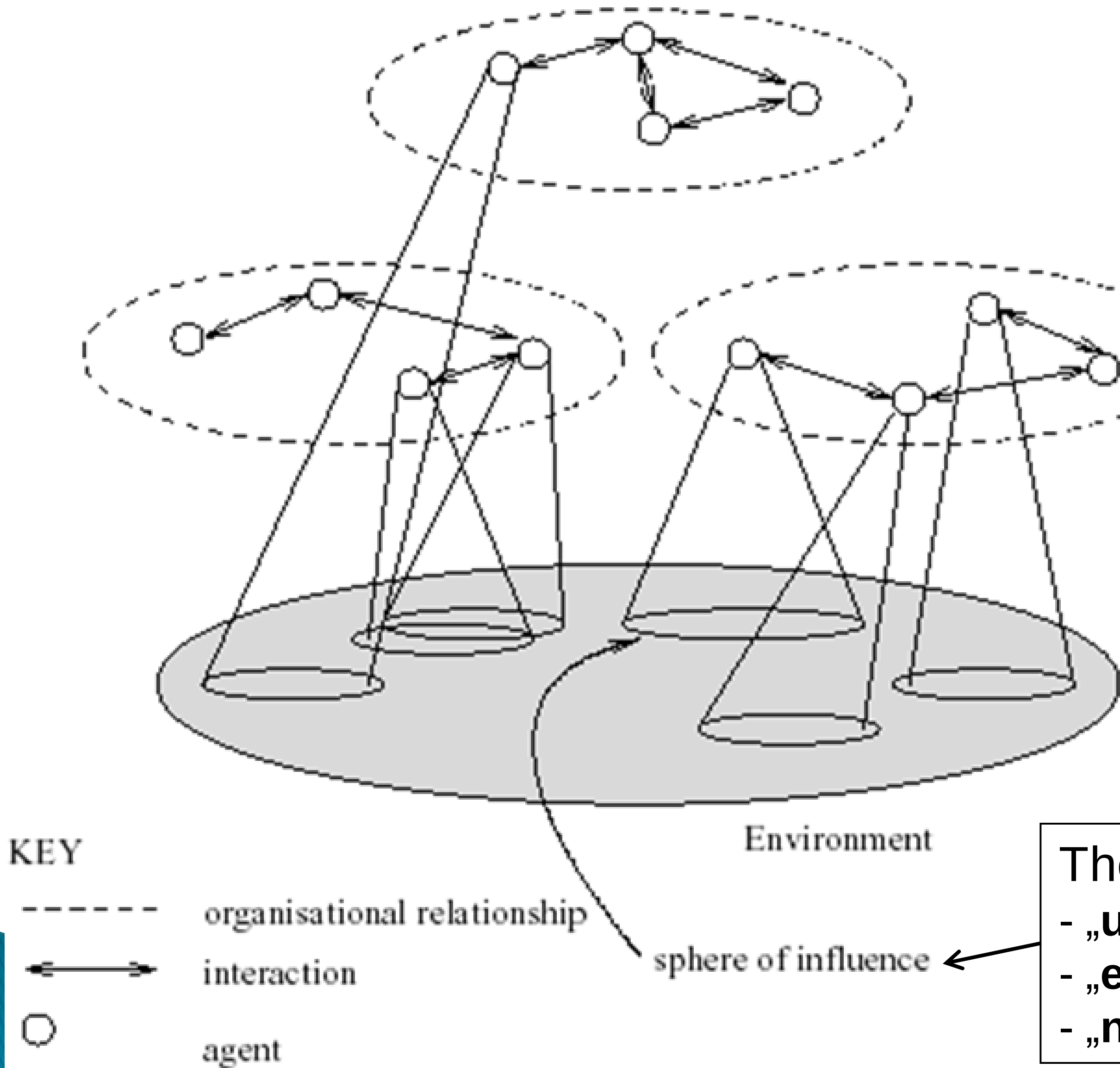
Ambulance drone

Agent



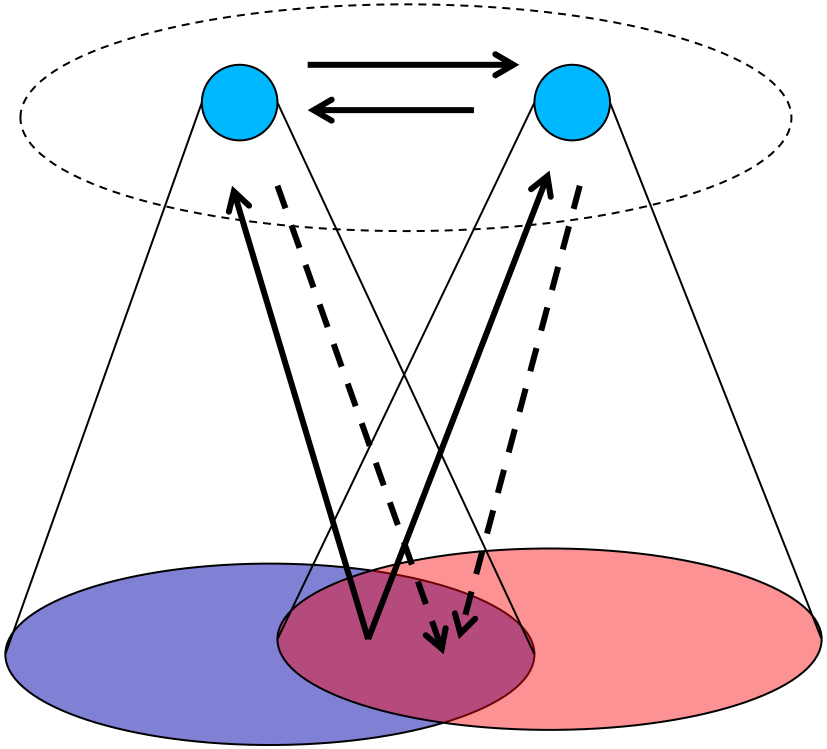
Communication is also an action
Communication has semantic meaning

MAS – Multiagent Systems



Society
Organization
Role
Entity
Task Environment

The other (agent, human)
- „**useful**”, „**friend**”, ...
- „**enemy**”
- „**neutral**”



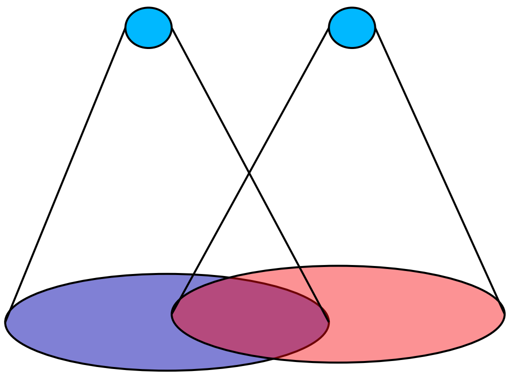
Data/task interaction

- Cooperation
- Competition/Conflict
  - Communication
    - (Mutual) language
      - Protocols
      - Strategies
  - Organization

Agent limited in capacity:

Difficult (in)accessible environment

Finite resources (mainly time)



What an agent knows, he does believe it, but it not need to be true.

Sun-shine $\leftrightarrow$ $\text{Believes}_{\text{Agent}}$(Sun-shine)

Consequences

New agent model: BDI – Belief, Desire, Intention

Communication

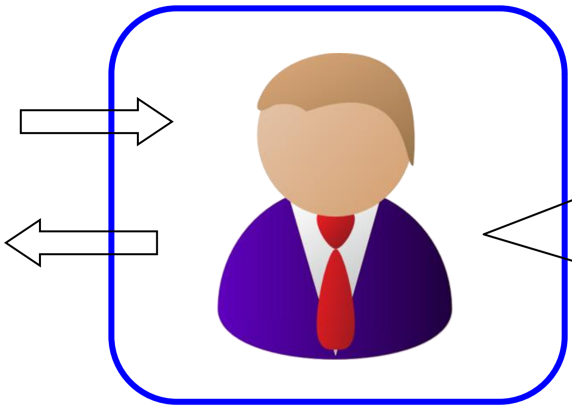
I sent only what I do believe?

Should I receive messages without reservation?

(Bona fide/malice, truthfull, …)

MAS (BDI models in organizations)

BDI model



Belief - information attitude

Desire (Goal) - motivational attitude,
reasons for action

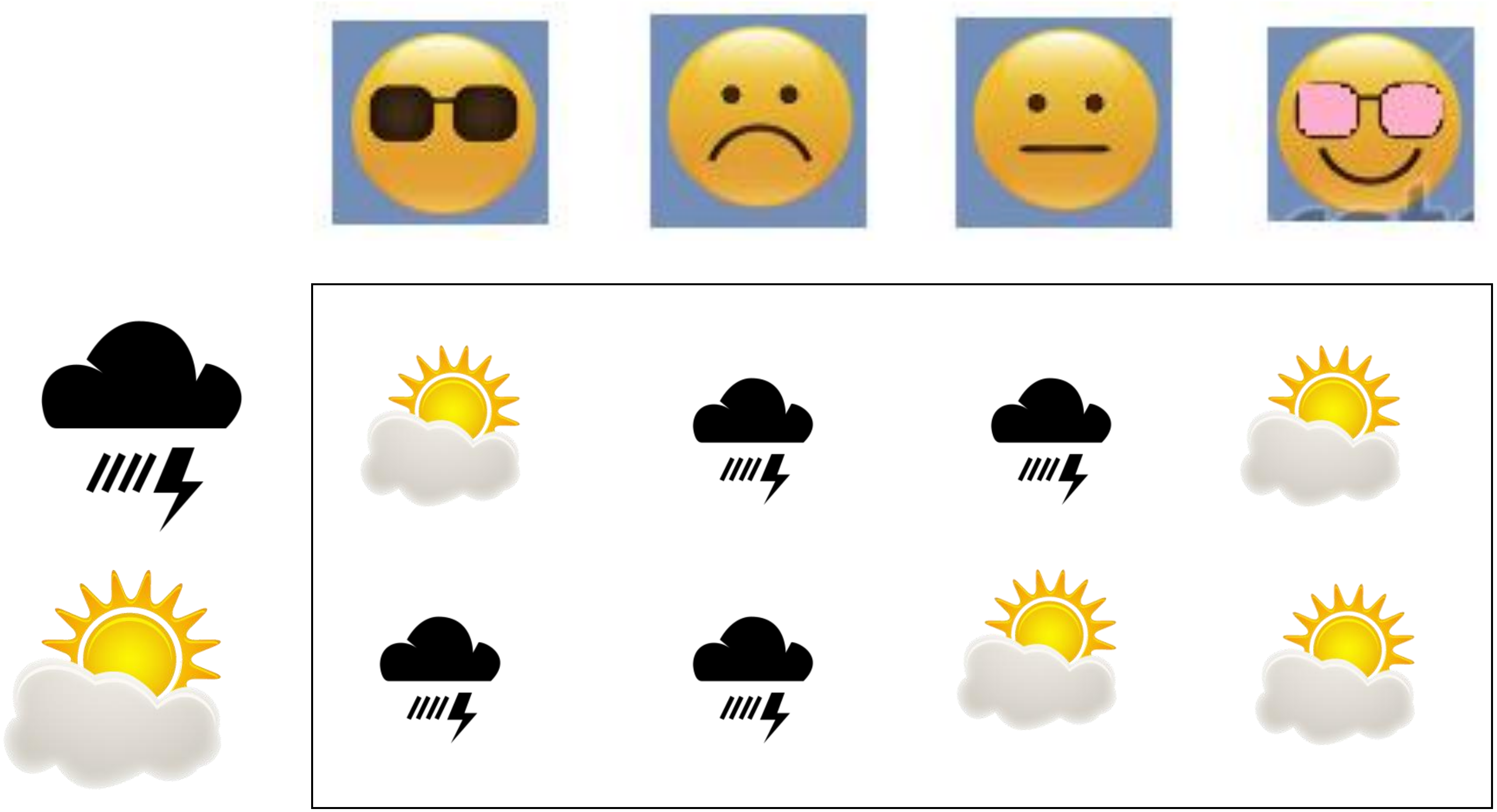
Intention (Plan) - deliberative attitude,
means for achieving goals
→ future actions

Intentional approach

speaking about or predicting complex systems without a real understanding of how do they function (human as a **black box**)

s/he hopes, thinks, fears, likes, believes, knows, …

What is an agent permitted to believe?



Well, we will have problems describing agents with logic

Aims of Communications

Cooperation

Jointly working on mutual goals, …

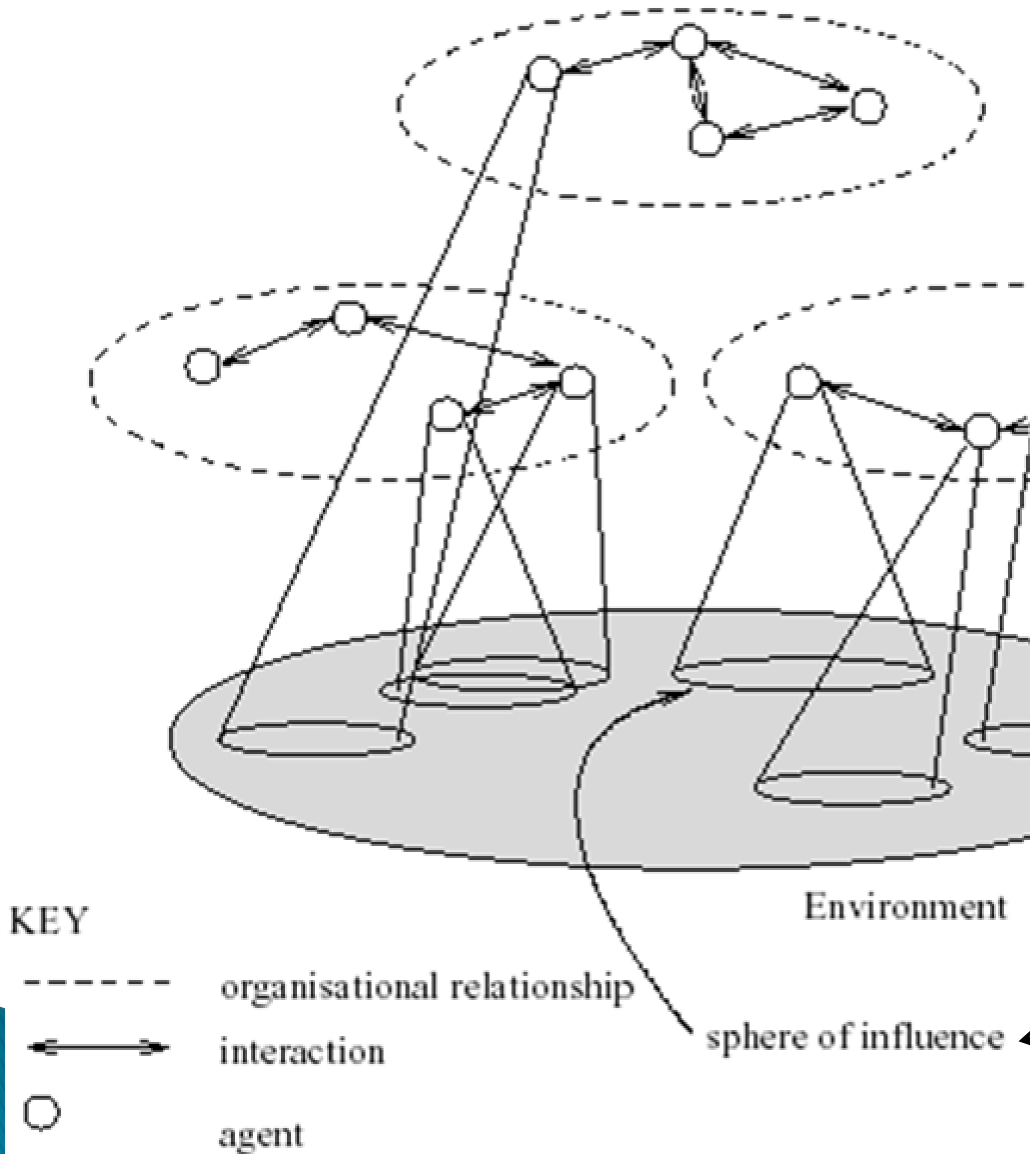
Coordination

Managing interaction between actions, …

Negotiation

Working out agreements on issues falling into a joint spheres of interests, …

MAS – Multiagent Systems



Society
Organization
Role
Entity
Task Environment

The other (agent, human)
- „**useful**”, „**friend**”, ...
- „**enemy**”
- „**neutral**”

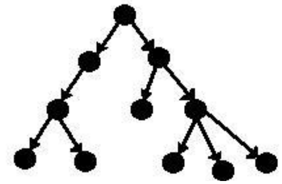
Agent organizations

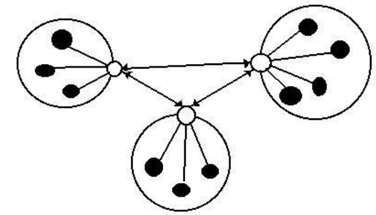
Organization: *roles*, *relations*, *authority structures*

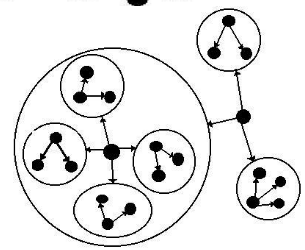
Organization serves aims
Aims: concrete…
abstract: **decreasing** some kind of **complexity**
(work, reasoning, communication, search, …)

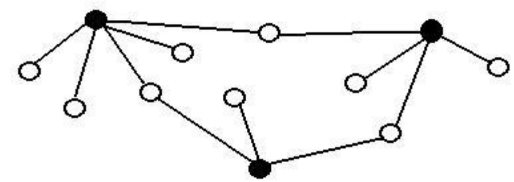
Open
Semi-open (gate-keepers, organizational limitations, …)
Semi-closed
Closed (teams)

Organizations:







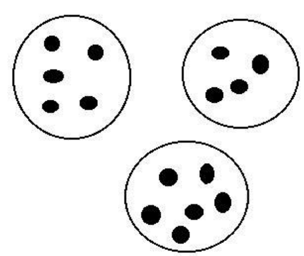


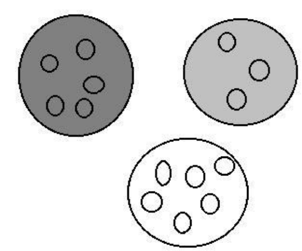
- Hierarchy
- Holarchy
- Coalition
- Team
- Congregation
- Society
- Federation
- Market
- Matrix
- (Compound)

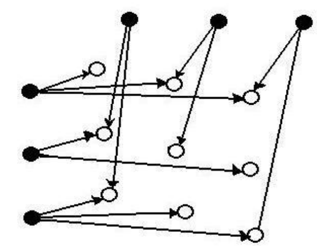
Homogeneous ⇔ heterogeneous agents

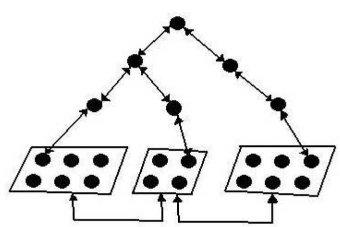
private ⇔ joint goal

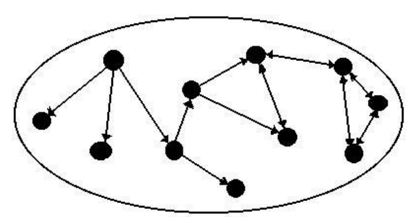
distributed ⇔ centralized decisions

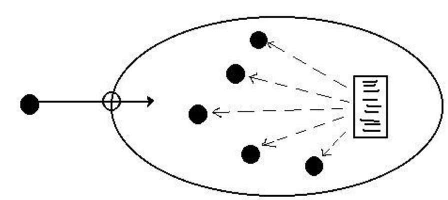












Human Language

A means of **information transfer**

– The weather is sunny today.

A means **of co-ordinating joint actions**

– Would you be free for lunch today?

A means of establishing and **maintaining social relationships**

– Let's do lunch!

A **signalling** system

– Let me pay for lunch!

Linguistic theory distinguishes:

Syntax of a language: words, phrases, sentences and grammar

Semantics of a language: the relationship between well-formed expressions in the syntax and objects or concepts in the world.

Pragmatics of a language: non-semantic aspects of meaning, such as the speaker's intentions in making the utterance.

Human Language

Speaker Intentions

Alice says to Bob: “The meeting is tomorrow at 17:00.”

What can Bob infer?

That the meeting is tomorrow.
That Alice believes that the meeting is tomorrow.
That Alice wants Bob to believe that the meeting is tomorrow.
That Alice wants Bob to believe that the meeting is not tomorrow.
That Alice wants Bob to believe that Alice believes that the meeting is tomorrow.
That Alice wants Bob to believe that Alice does not believe that the meeting is tomorrow.
That Alice wants Bob to believe that Alice wants Bob to believe that the meeting is tomorrow.
That the meeting is not tomorrow.
etc. (ad infinitum).

Human Language – Speech Act theory

Some statements change the world by their very utterance, eg.
– “I name this ship,The Queen Elizabeth.”
– “I declare you man and wife.”

These **statements perform** some **action**, but only under certain preconditions:
– eg, for a marriage declaration to be legally binding, the celebrant must be registered, the location must be a registered location, the individuals must be single, at least two witnesses must be present, etc.

Speech acts can be defined in terms of their felicity conditions and their rational effects.
– Modern theory due to: Austin 1955, Searle 1969.

Speech Act:

locutionary act (speech action)

illocutionary act: projecting intend with a performative verb, e.g. ask, request, state, demand, adhere, agree, warn, order, …

illocutionary force: from whom? (bosss request is an order)

perlocutionary act: the real effect on the hearer.

E.g.

I promise, that tomorrow I help you to paint the fence.

I promise, that tomorrow I help you to paint the fence.

clarifying the illocutionary force, it could be: '*thought*', '*presume*', '*dreamed*', …

Typology of Dialogs

Information-seeking
Inquiry
Persuasion
Negotiation
Deliberation
Eristic (Walton and Krabbe)

Information-giving
Examination
Discovery.
Command
etc.

Two First Responder agents communicate

Ag1 is able to sense with its sensors that there is a gas leakage at an industrial site. Ag2 has no such sensor.

X = „Gas leakage at Valve-1" (a fact for Ag1, a future info for Ag2)

Ag1 transmits X information to Ag2. **When is this act genuine**?

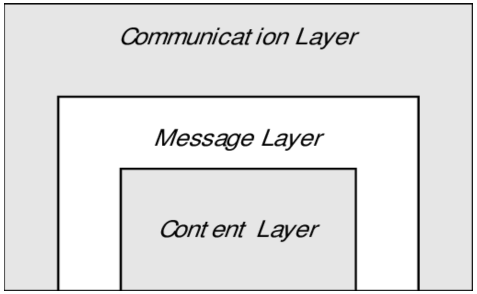
Before Ag1 would send the message confirming the fact, Ag1 should itself believe it, it should believe that without such message Ag2 would be uncertain at least about X. After sending the message, Ag2 already believes the truth of X. In addition Ag1 will believe that Ag2 is believing the world in a consistent way.

Message <Ag1, confirm (Ag2, X)>

Preconditions:	$B_{Ag1}(X) \wedge B_{Ag1}(U_{Ag2}(X))$	B - Belief
Real effects:	$B_{Ag2}(X) \wedge B_{Ag1}(B_{Ag2}(X))$	U - Uncertain

What are Agent Communication Languages (ACLs)?

A means of communication
Programming languages for agents
Software engineering methods
Formal languages



Two major proposals for ACLs:

– USA DARPA's Knowledge Query and Manipulation Language (**KQML**)
– **Foundation for Intelligent Physical Agents ACL** (**FIPA ACL**)

Both ACLs distinguish between two layers in messages:

(1) The topics of conversation (represented in a suitable (logical) language)
(2) The illocutions which refer to these topics

- Eg.:
  – query (It is raining) Is it rainig?
  – inform (It is raining) (Yes) It is raining.

FIPA Agent Communications Language

FIPA ACL: 22 illocutions

– e.g. inform, query-if, request, agree, refuse, …

– Each has a defined syntax:

```
(inform :sender (agent-identifier:name j)
        :receiver (agent-identifier:name i)
        :content "weather (today, raining)"
        :language Prolog)
```

– 11 of the 22 illlocution: requests for or transmissions of information

– 4: negotiation (e.g. cfp, propose, reject-proposal)

– 6: performance of action (e.g. refuse, request)

– 2: error-handling of messages (e.g. failure).

Start – 1995/6, 2002 (semi-)standard

From 2005 IEEE Computer Society,

IEEE FIPA Standard Committee www.fipa.org

Standard topics:

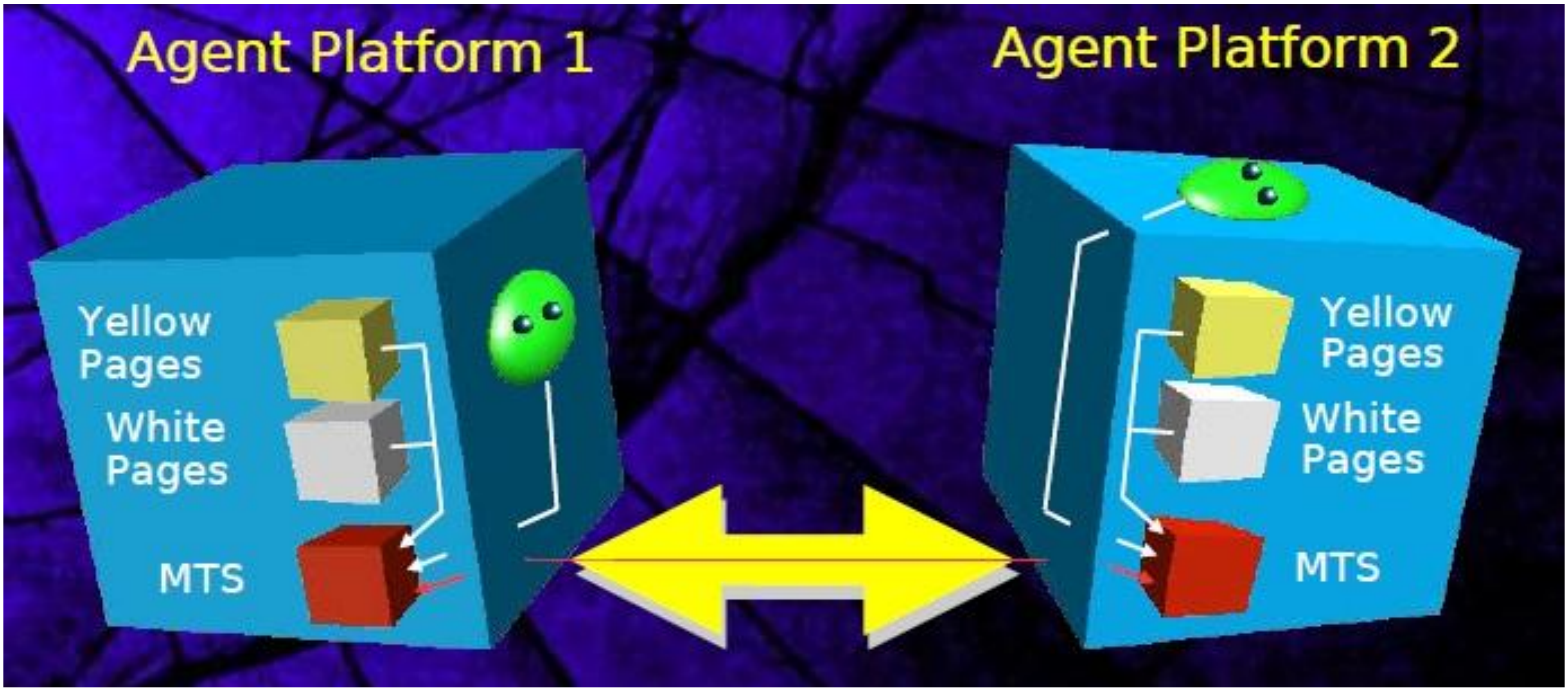
Abstract Architecture

- **Agent Message Transport**
  - Transport Protocols, Envelope Representations
  - ACL Representations - ACL Message Structure
- **Agent Management** (platform, obligatory agents)

Agent Communication Languages

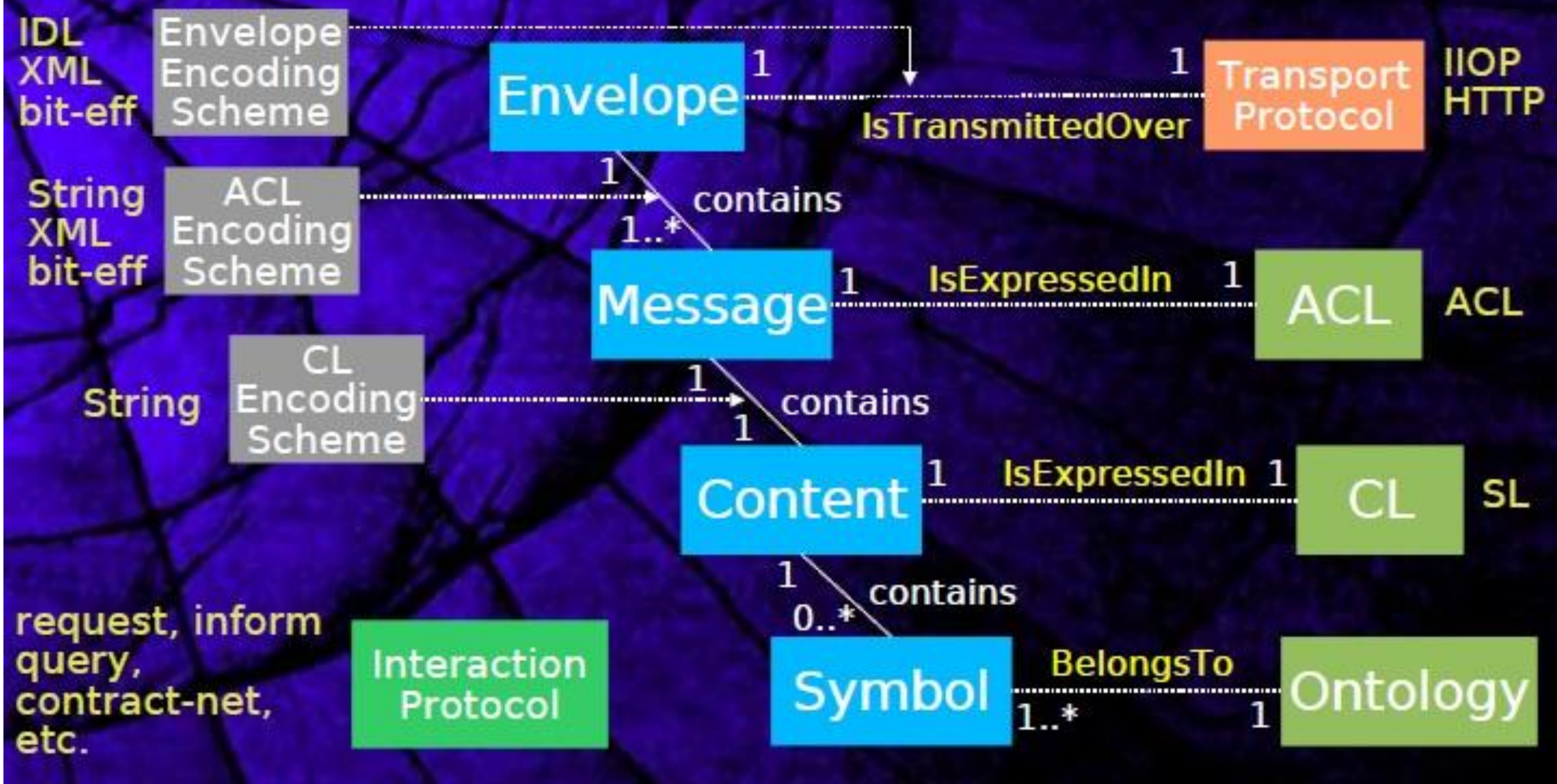
- Interaction Protocols - Interaction Protocol Library Specification (AUML)
- Communicative Acts Library (speech acts)
- Content Languages
  - KIF (Knowledge Interchange Format)
  - CCL (Constraint Choice Language)
  - SL (Semantic Language)
  - RDF (Resource Description Framework)
  - Content Language Library Specification
- Device Ontology Specification
- Message Buffering Service Specification
- Messaging Interoperability Service Specification
- Ontology Service Specification

Reference Applications: Personel Travel Assistance, Nomadic Application Support, ...



Agent Platform 1
Agent Platform 2
Yellow Pages
White Pages
MTS
Yellow Pages
White Pages
MTS

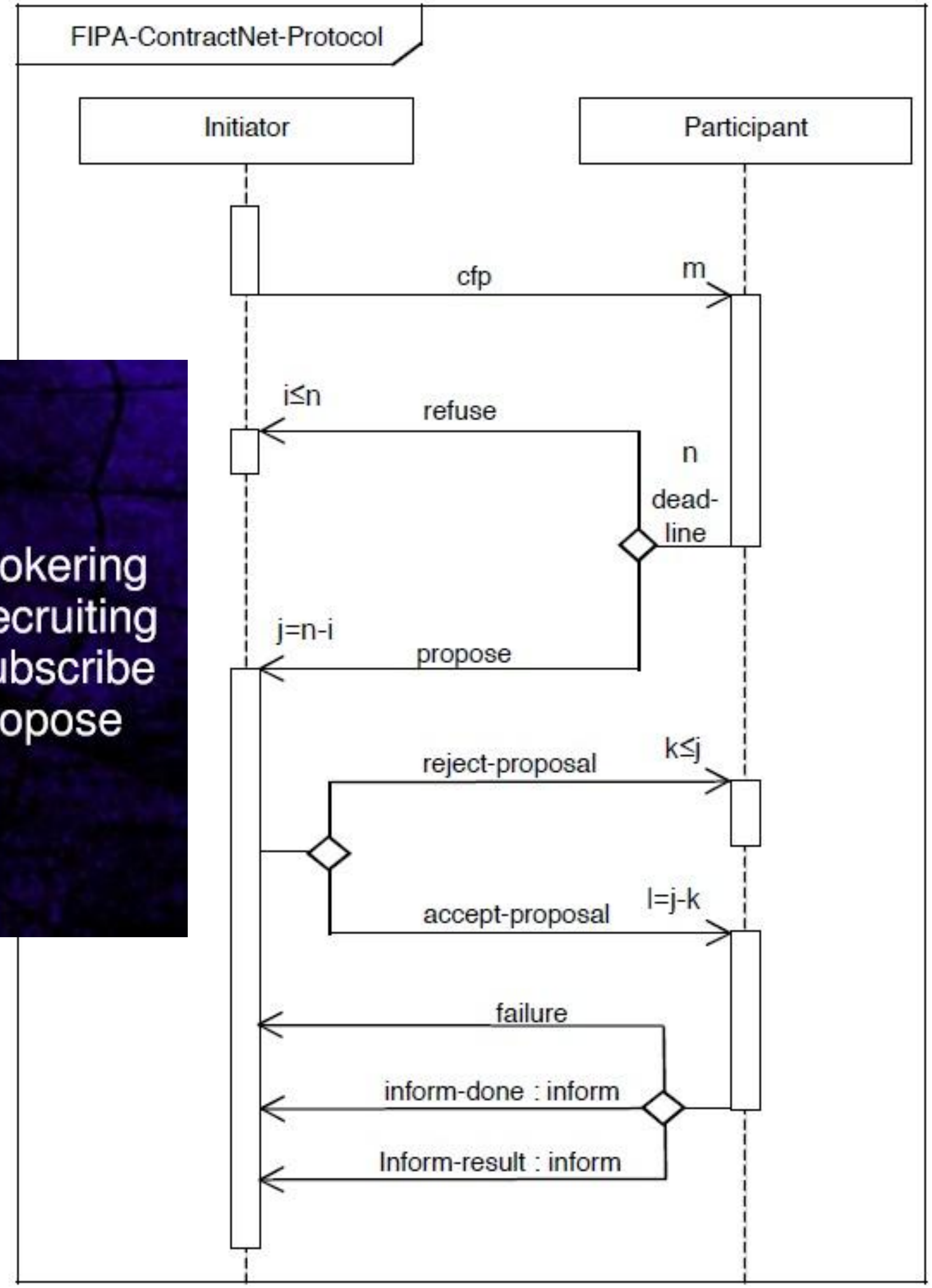
- FIPA Message Structure -



- Interaction Protocols -

FIPA defined IPs are:

- FIPA-Request
- FIPA-Query
- FIPA-Request-When
- FIPA-Contract-Net
- FIPA-Iterated-Contract-Net
- FIPA-Auction-English
- FIPA-Auction-Dutch
- FIPA-Brokering
- FIPA-Recruiting
- FIPA-Subscribe
- FIPA-Propose



Semantic Language SL

(not) (and) (or) (implies) (equiv) (forall) (exists)

B <agent> <expr>
U <agent> <expr>
I <agent> <expr> agent has intention
PG <agent> <expr> agent has persistent goal

(feasible <actexpr> <Wff>) true, that the action can take place, immediately after it Wff will be true
(done <actexpr> <Wff>) true, that the action has just happened, immediately before it Wff was true
(iota x (P x)) an x, for which P(x) is true
(any <term> <formula>) whatever object, fullfilling the formula
(all <term> <formula>) all objects, fullfilling the formula

Bifi ϕ = Bi $\phi \vee$ Bi $\neg\phi$, Abnij ϕ = Bi Bj Bi ..... ϕ

Confirm $<$i, confirm (j, ϕ)$>$
FP: Bi $\phi \wedge$ Bi Uj ϕ
RE: Bj ϕ

FIPA ACL problems

Implicite assumptions
Speech act deficiences
Axiomatix semantics not verifiable

Obligation storage

Dialectical obligation
– eg. to justify a statement
Semantic obligation
– eg. to act

Dialogue Game protocols

- Rules for combining speech acts.
- More information (supporting statements).
- Statements of others can be challenged.
- Statements lead to complex obligatory responsibilities.

Eg. Fatio Protocol, additional speech acts to build up argumentations, extended axiomatic and procedural semantics

assert(A, θ)
question(B, A, θ)
challenge(B, A, θ)
justify(A, Δ |- θ)
retract(A, θ)

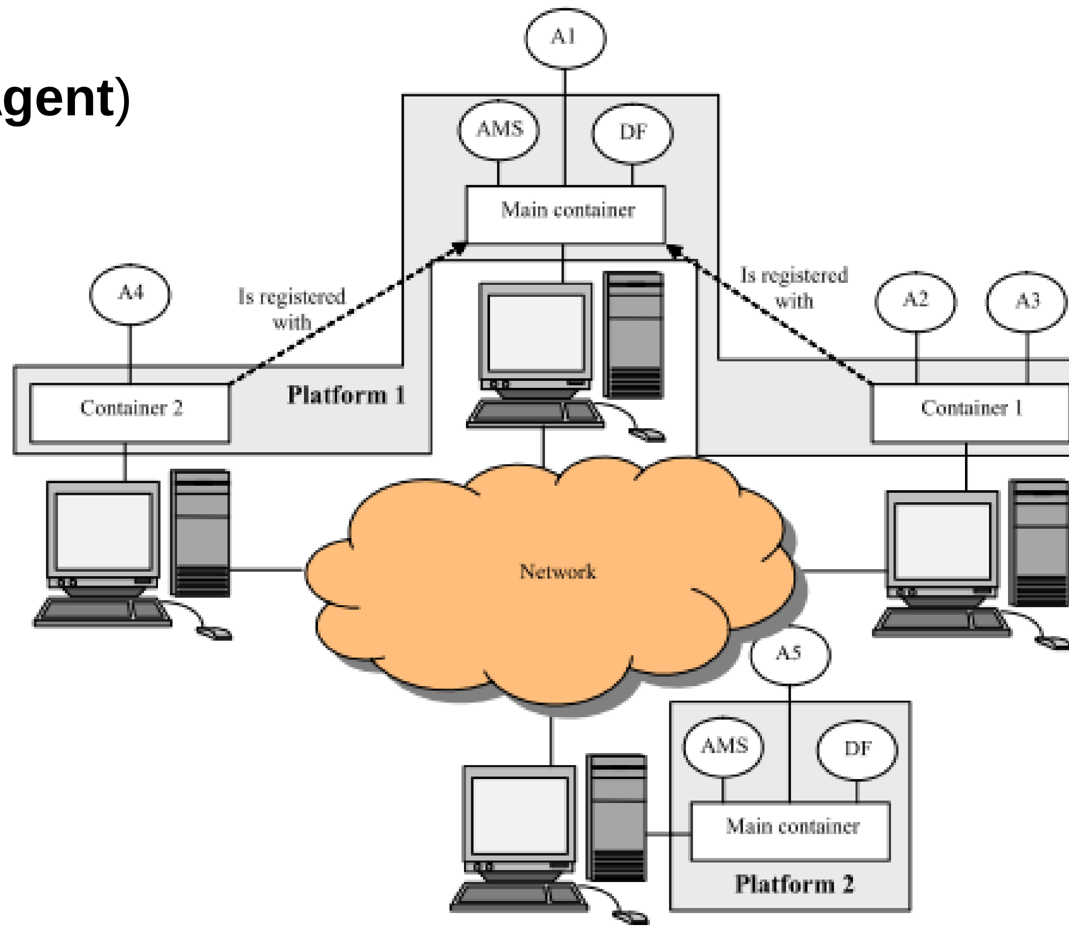
Jade platform – experimental agent society

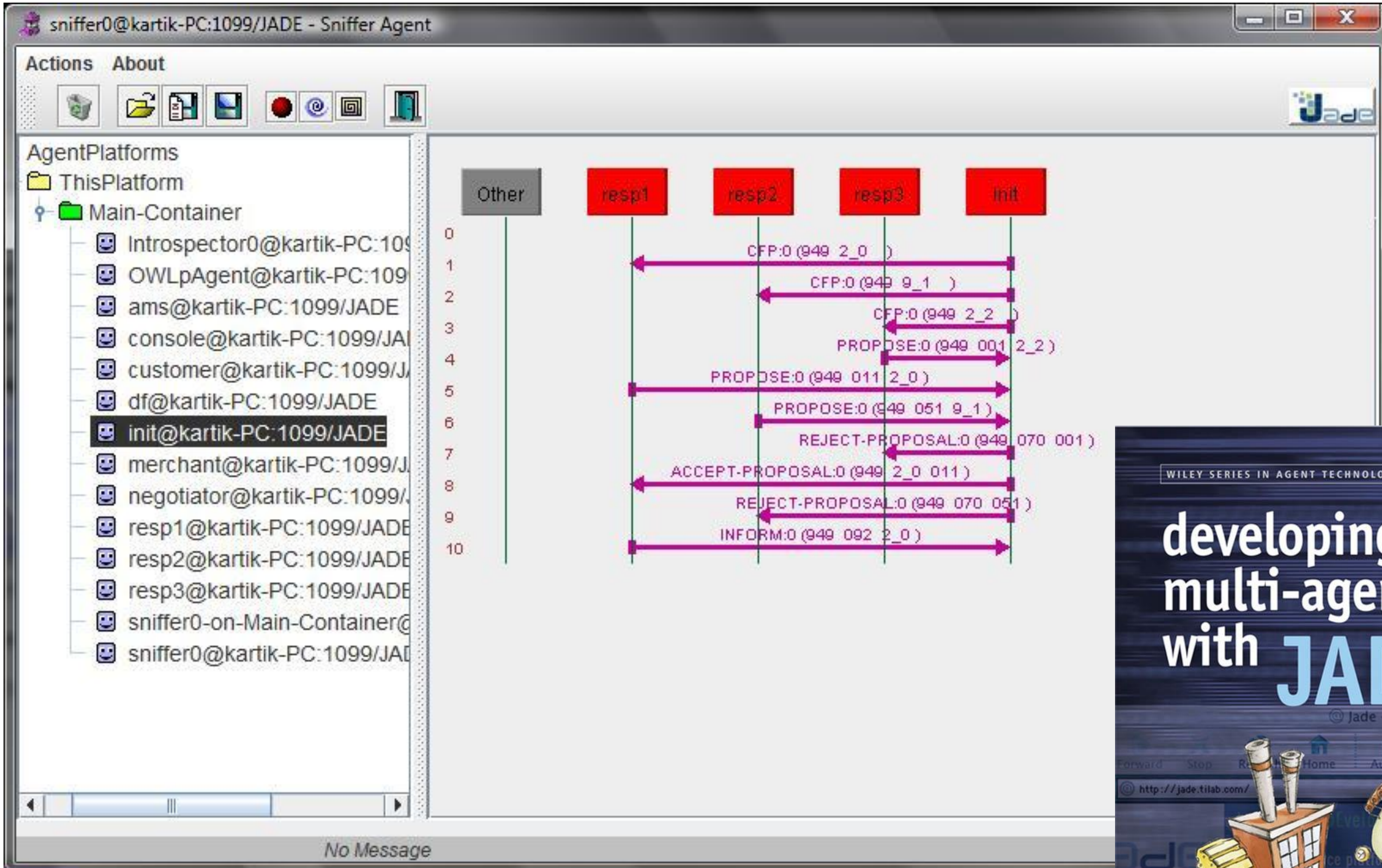
Java implementation of the FIPA standard.

On a platform we have:

- **AMS** (**Agent Management System**)
- **ACC (Agent Communication Channel)**
- **DF** (**Directory Facilitator**)

- **RMA** (**Remote Monitoring Agent**)
- **Sniffer**
- **Introspector**
- **DA** (**Dummy Agent**)




sniffer0@kartik-PC:1099/JADE - Sniffer Agent
Actions
About
AgentPlatforms
ThisPlatform
Main-Container
Introspector0@kartik-PC:10
OWLpAgent@kartik-PC:109
ams@kartik-PC:1099/JADE
console@kartik-PC:1099/JA
customer@kartik-PC:1099/J
df@kartik-PC:1099/JADE
init@kartik-PC:1099/JADE
merchant@kartik-PC:1099/J
negotiator@kartik-PC:1099/
resp1@kartik-PC:1099/JADE
resp2@kartik-PC:1099/JADE
resp3@kartik-PC:1099/JADE
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Other
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resp2
resp3
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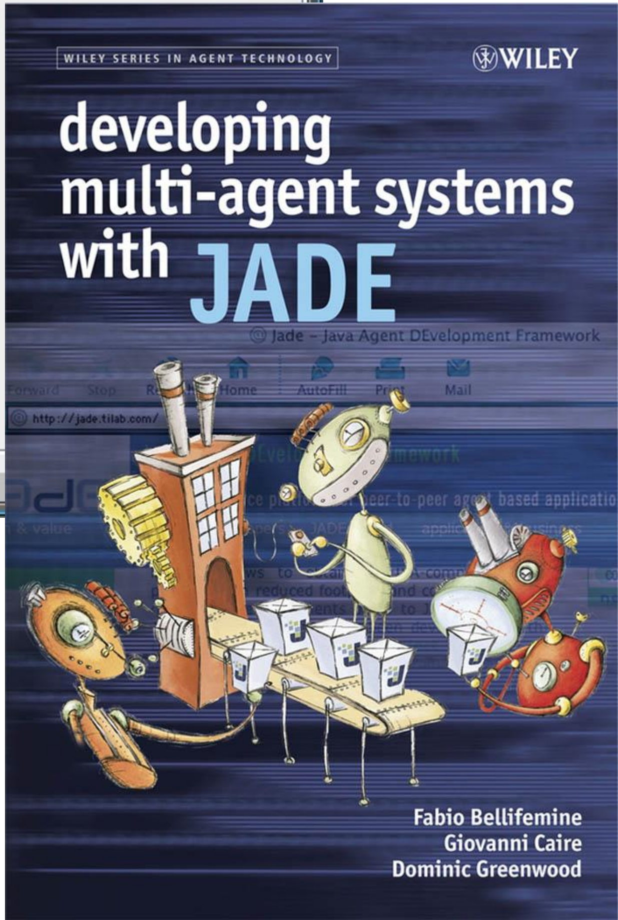
CFP:0 (949 9_1)
CFP:0 (949 2_2)
PROPOSE:0 (949 001 2_2)
PROPOSE:0 (949 011 2_0)
PROPOSE:0 (949 051 9_1)
REJECT-PROPOSAL:0 (949 070 001)
ACCEPT-PROPOSAL:0 (949 2_0 011)
REJECT-PROPOSAL:0 (949 070 051)
INFORM:0 (949 092 2_0)
No Message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developing multi-agent systems with JADE
Jade – Java Agent DEvelopment Framework
Fabio Bellifemine
Giovanni Caire
Dominic Greenwood

Cooperation = communication for coordination and sharing

Sharable: information, knowledge, data, result, conclusion, hypothesis, …
generally „homogenous” organizations,
task, goal, ...
more structured organizations (specializations)

Protocols depend on organization type

closed, more close organization (hierarchy, team, society, ...)
message sequence: stiff, non-expandable („fixed”)
organization highly structured, boss role, task sharing,
organization less structured, asymmetric manager role, task sharing
open, more open organization (coalition, market, ..., web, e-commerce, ...)
belief-, goal-based, flexible, egalitarian society, app. symmetric
interactions: information, result sharing,
weakly structured societies with conflicts, arbiter role
information sharing: conflict resolution with special protocols

Task sharing: Contract Nets

1. Manager receives a task. It decomposes it into smaller chunks, „subtasks” .
2. Manager seeks contractors for the subtasks.
   It broadcasts the descriptions of the subtasks, possibly with the requirements regarding the solutions and waits for the offers.
3. Contractor agents compare the description of the subtasks and the requirements with their solving capacity and stay put or send back the proposals with the conditions and the estimated quality of the solutions.
4. Manager agent choses the best offers and assigns the subtasks to the contractors.
5. Contractor agents solve the tasks and send the solutions to the manager.
6. Manager integrates the arriving solutions into the full solution of the global task and sends it back to the user.

The identity of the task solving agents is not known in advance.
Differences in knowledge.
Contractors must evaluate their own capabilities.
Manager can learn.
Fault tolerance and gracefull degradation.

Voting agents – unanimous opinion among rational competitive agents

Correct, satisfying aggregating of competitive preferences into a joint social decision.

autonomous agents (voters)
alternatives (outcomes, candidates)
preferences (ordering of the outcomes)
(group)profile

aggregating function
  social choice function
  social welfare function

Agent rationality

Transitivity of preferences:
basic aspect of human rationality,
proper environment interpretation

Transitive preference

$$x \succ_i y, \; y \succ_i z \;\Rightarrow\; x \succ_i z$$

Important questions

How to interpret the (individual/group) rational decision?
What are the properties of a good aggregating function?
Which properties can be guaranted simultaneusly?
How difficult is the computation of a group voting?
Are voters better off if they do not vote truthfully?

Widely used

Plurality rule: candidate with the most votes wins (noncommittals do not count)

$$|\{i \in N : x \succ_i y\}| > |\{i \in N : y \succ_i x\}| \quad \rightarrow \quad x \succ_P y$$

Majority rule: candidate with more than half of the votes wins (noncommittals do count as against)

$$|\{i \in N : x \succ_i y\}| > n/2 \quad \rightarrow \quad x \succ_M y$$

May theorem

If there are 2 candidates, the plurality rule is the only decision process to assure the following basic requirements (**Kenneth May,** 1952):

The group decision function treats each voter identically (**anonymity**) .
Reversing each set of preferences reverses the group preference (**neutrality**).
If x was the winner and a voter changes its vote for x, x remains the winner (**positive responsiveness**).

Everything is OK for 2 candidates, but what about more candidates?

Typical extensions:
- **plurality rule**: the winner has the highest number of votes (even $<$ 50%).
- **run-off**: majority winner, if none, then the best two with plurality.

	1 cs	2 cs	3 cs	4 cs
	20	24	26	30
1.	z	y	x	w
2.	x	z	y	z
3.	y	x	z	x
4.	w	w	w	y

Problems with plurality rule

PR: w wins with 30 votes (minority winner!)

w is weaker against every other candidate one by one, yet it wins.

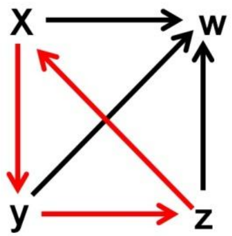
RO: no majority, two best are: w (30), x (26)
In 2nd round: x (70), w (30), **x** is the winner.

But those, who supported **z** may complain, why just x?
The majority prefers z to x! $z \succ_i x$!?

Voting paradoxes

(1) Sensible algorithms and sensible criteria do not meet.

(2) Despite the transitivity of the individual preferences the group preference computed by plurality voting is not necessarily transitive (cycles in majority graph) (Condorcet-winner).



	1 cs	2 cs	3 cs	4 cs
	19	24	27	30
1.	z	y	x	w
2.	x	z	y	z
3.	y	x	z	x
4.	w	w	w	y

Conclusions - **Arrow theorem** (Kenneth J. Arrow, 1963), (also others)

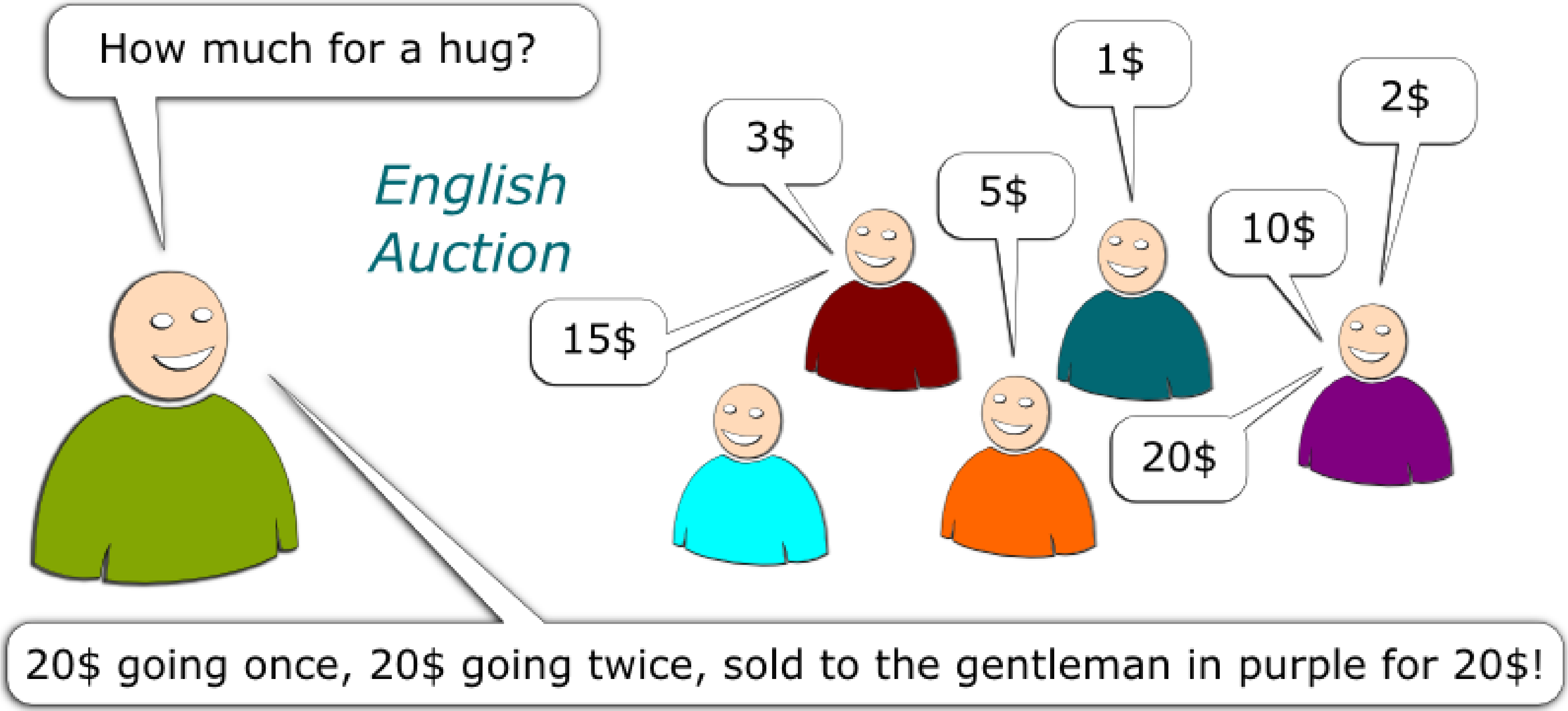
There is no voting algorithm which would warrant the minimal requirements defined as follows.

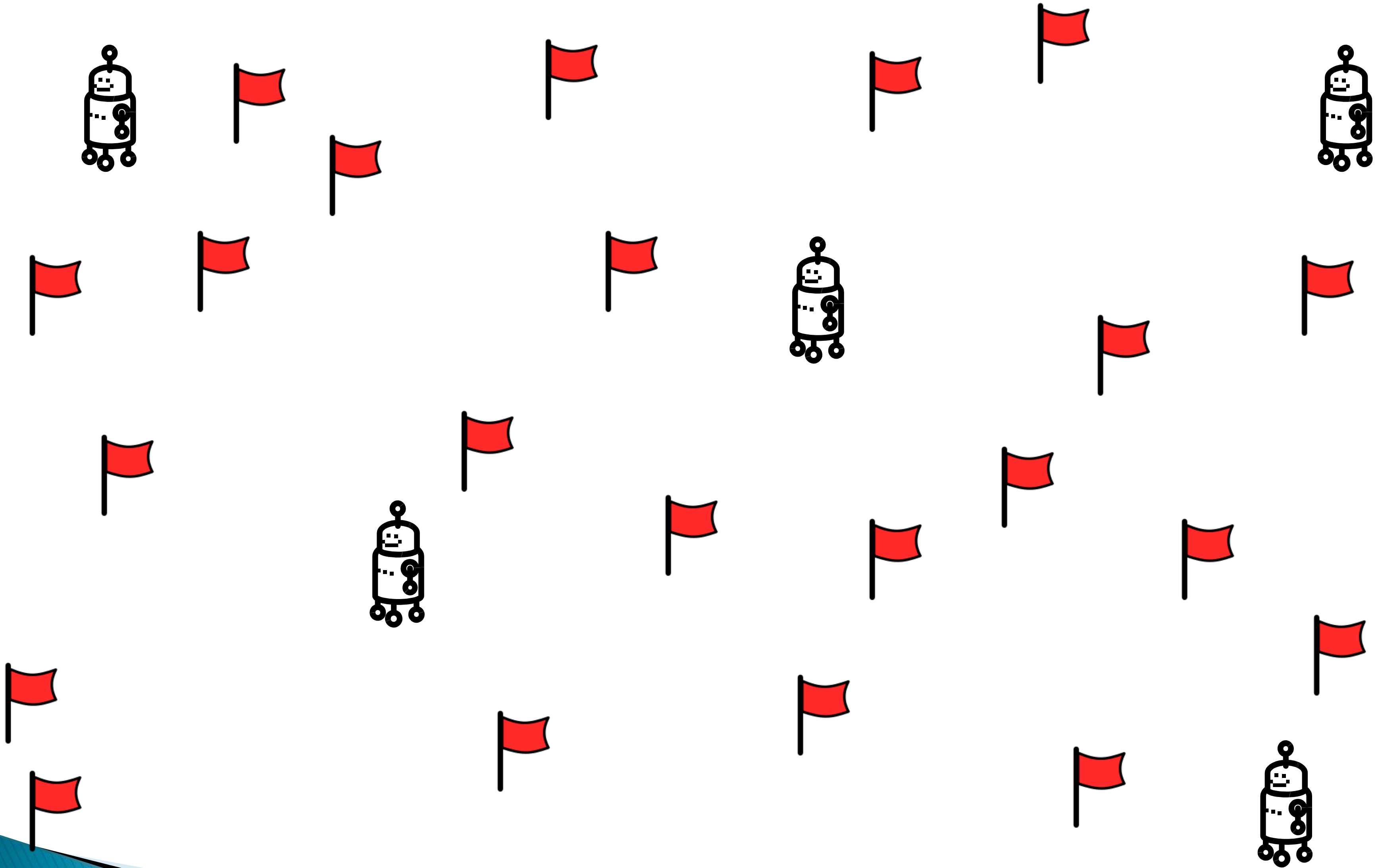
Let the voting system be: **Nondictatorial** and **Pareto-efficient.**

If a voting system is nondictatorial and Pareto-efficient, then there exist such preference profiles, that the voting result has cycles (social preference is intransitive), and/or the criterion of the independency of the irrelevant alternative is violated.

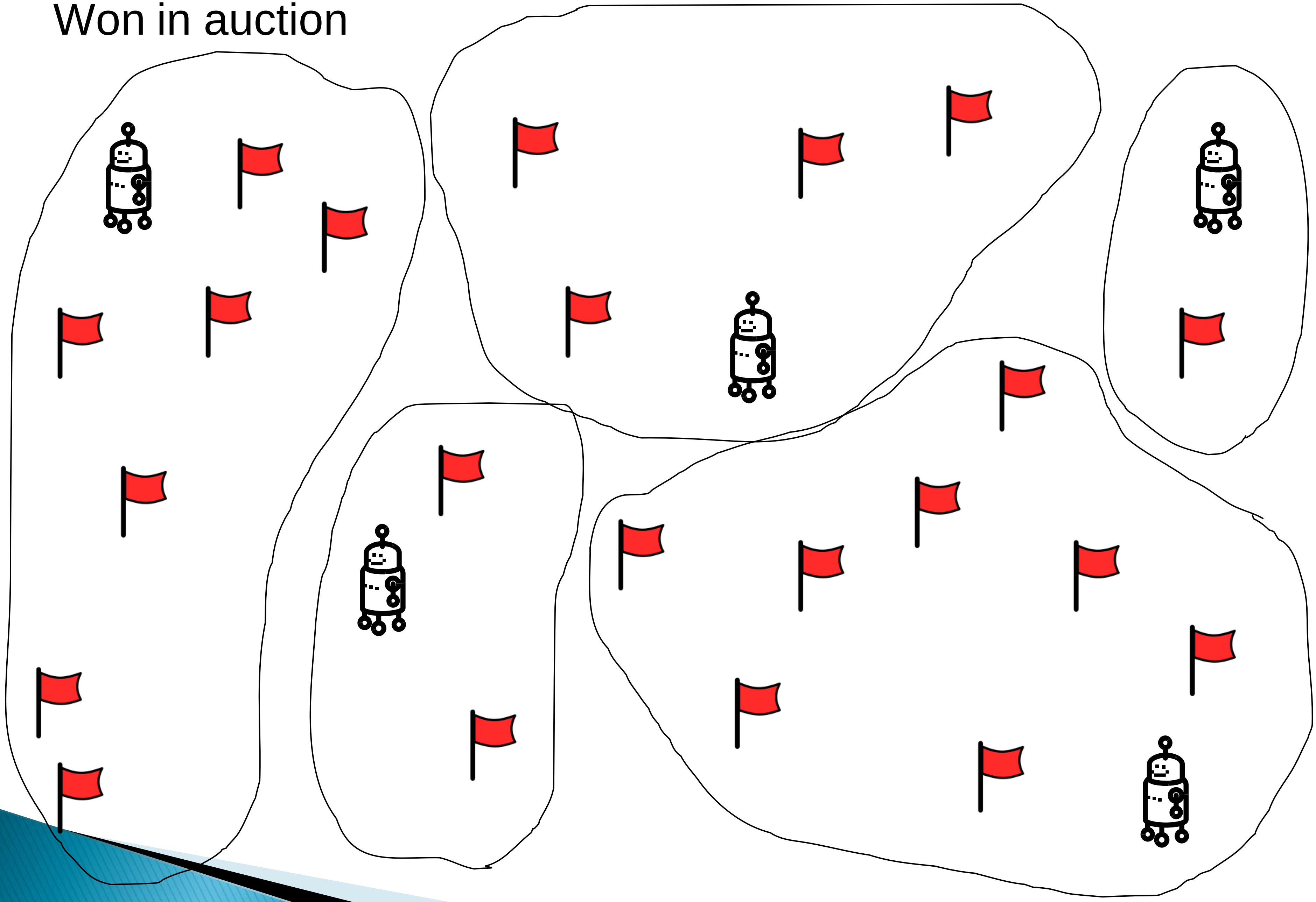
Which voting system to use? That one which problems are less visible in actual practice.

Coordination and task sharing with auctions

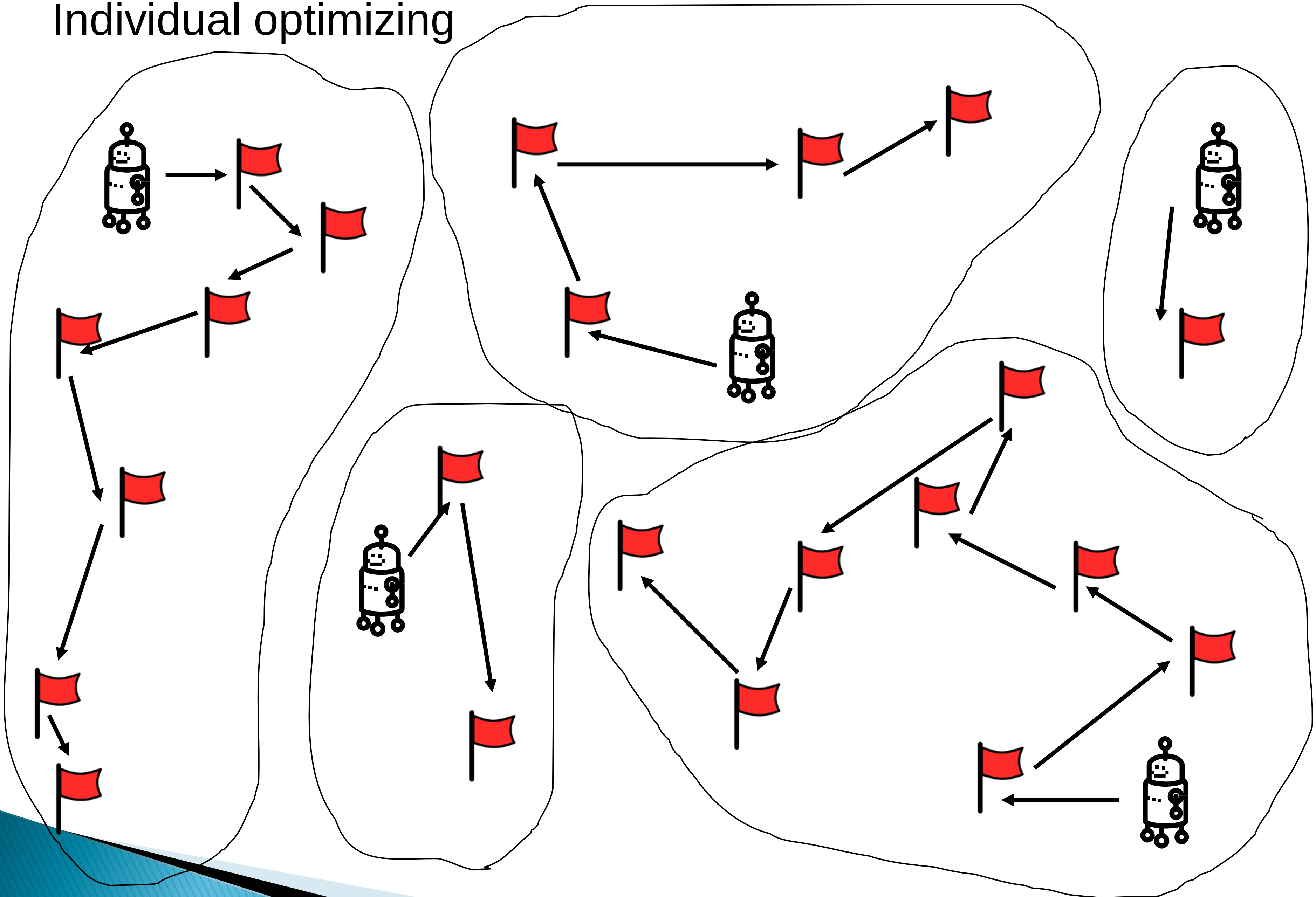




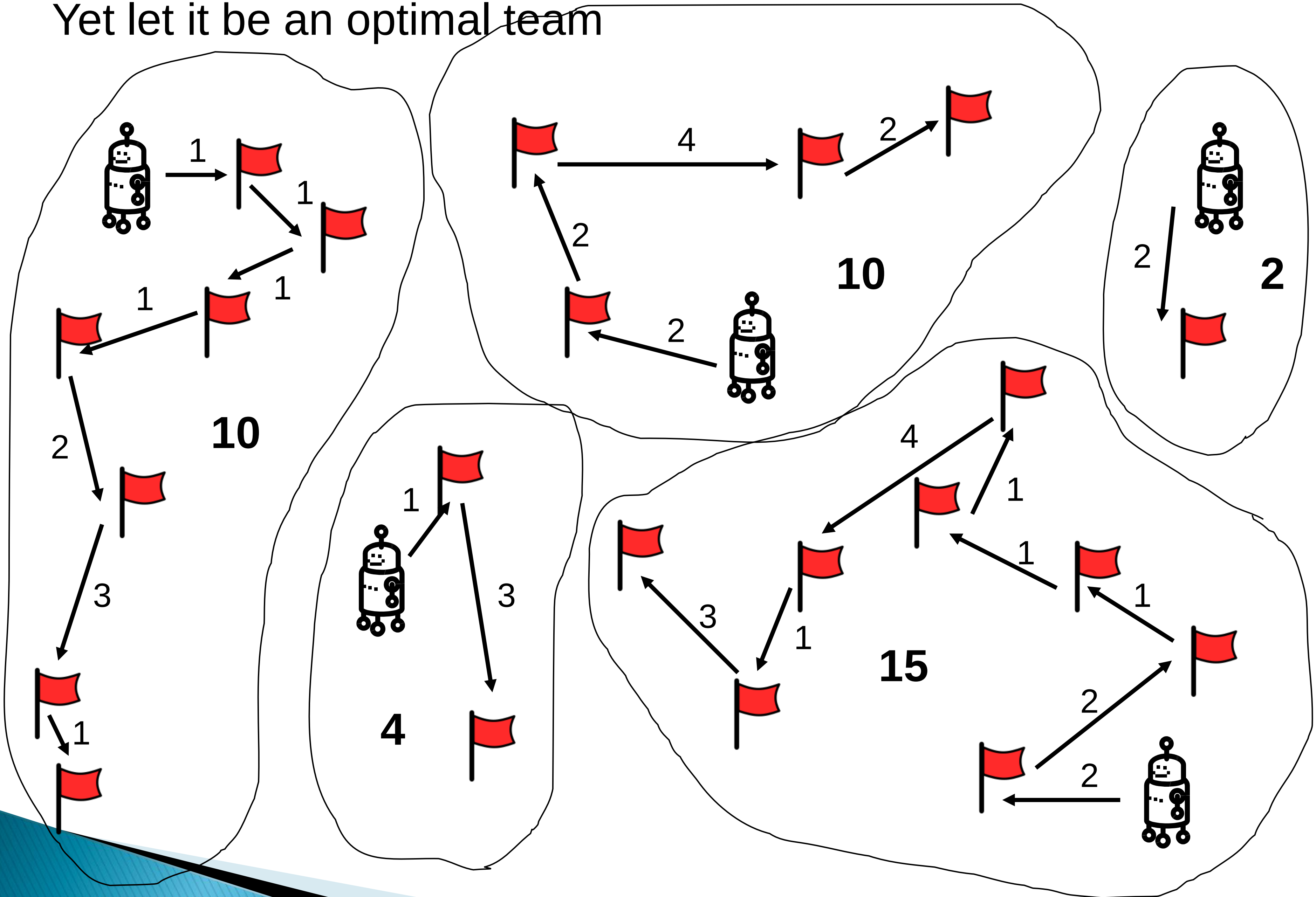
Won in auction



Individual optimizing



Yet let it be an optimal team



Why an auction?

Objects of unknown value
Can be automated
„Fair" solution

Coordinating with auctions

agent	bidder
task	bidded object
„cost"	money

Advantages: auctions are

short,
communication-efficient,
computation-efficient
results in **cost optimal** teams,
can be used even if the environment is **changing**.

Designing auction protocols

FORMAT Open or closed
Ascending or descending
Simultaneous or sequential
One turn or many turns
BID RULES
PROCEDURES
PARTICIPATION RULES
INFORMATION

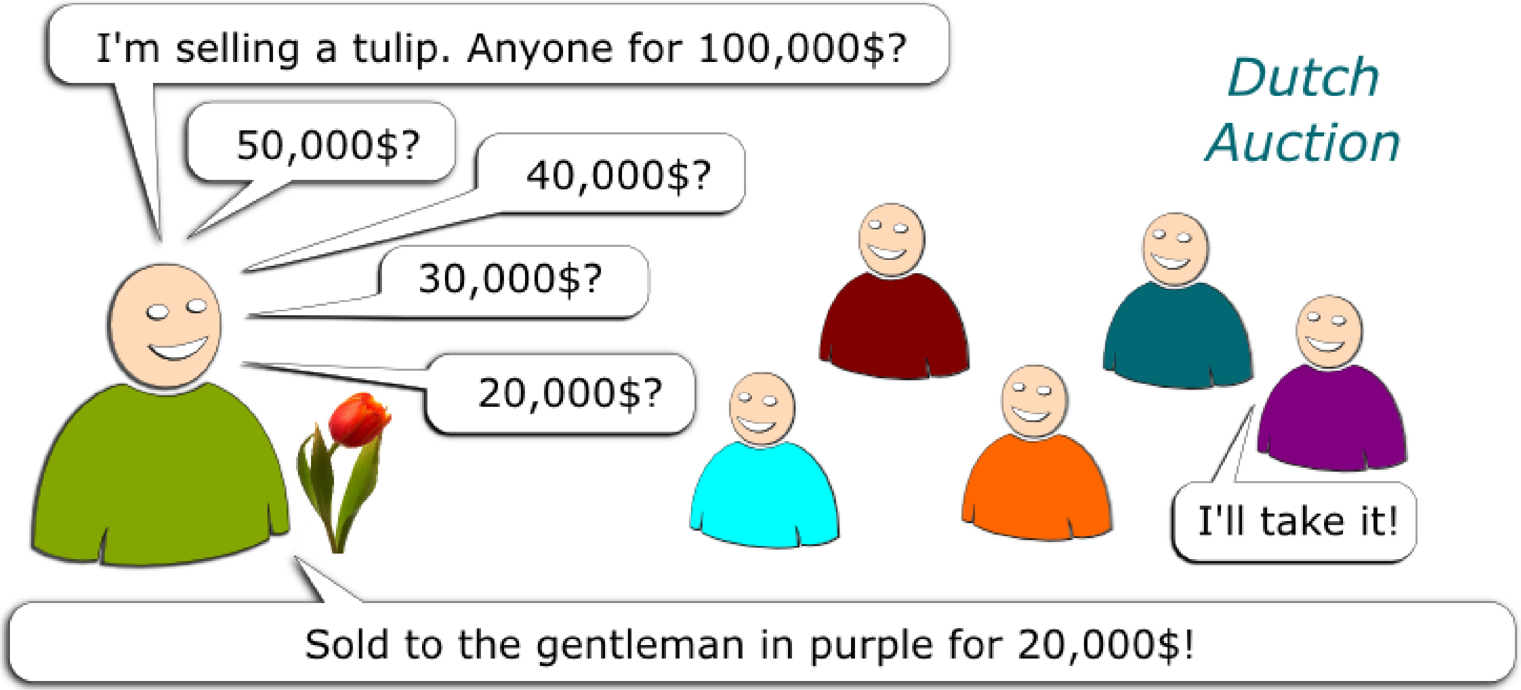
Usual auction types

Single item auction
Group auction
Combinatorial auction

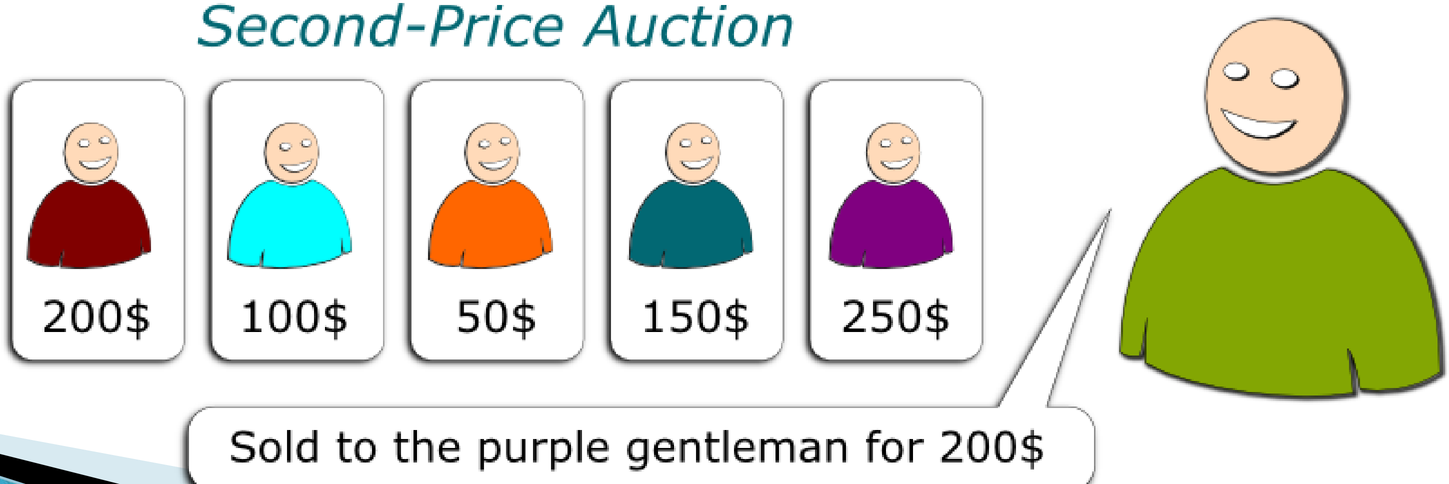
Single item auction →

- **English** (ascending)
- **Japanese** (ascending)
- **Dutch** (descending)
- **Sealed first-price**
- **Vickrey (**sealed-bid second-price)

Dutch Auction



Second-Price Auction



Combinatorial auction

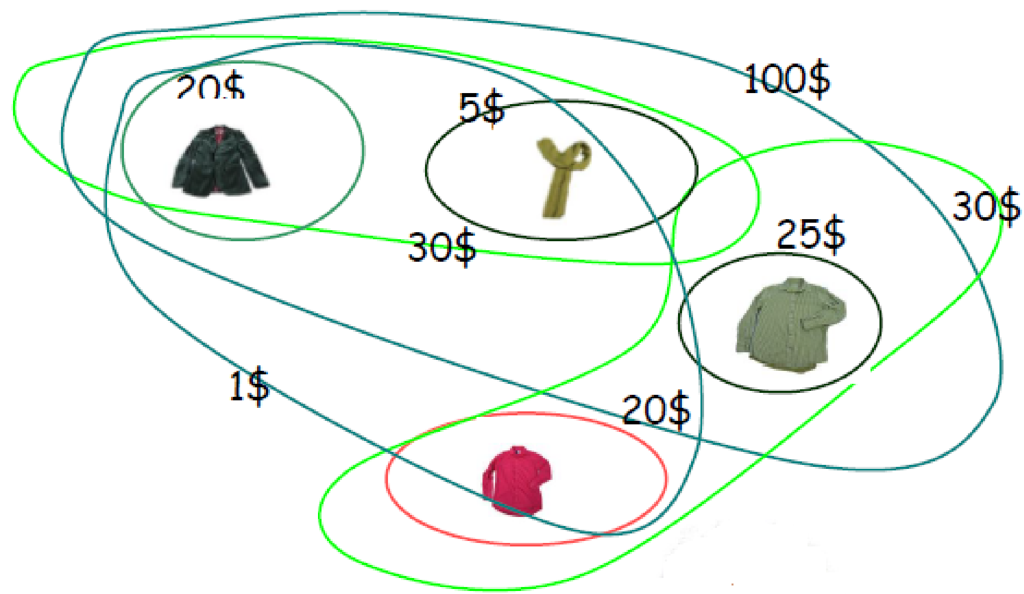
T item set.

Each bidder bids for an arbitrary set of bundles (subsets of T).

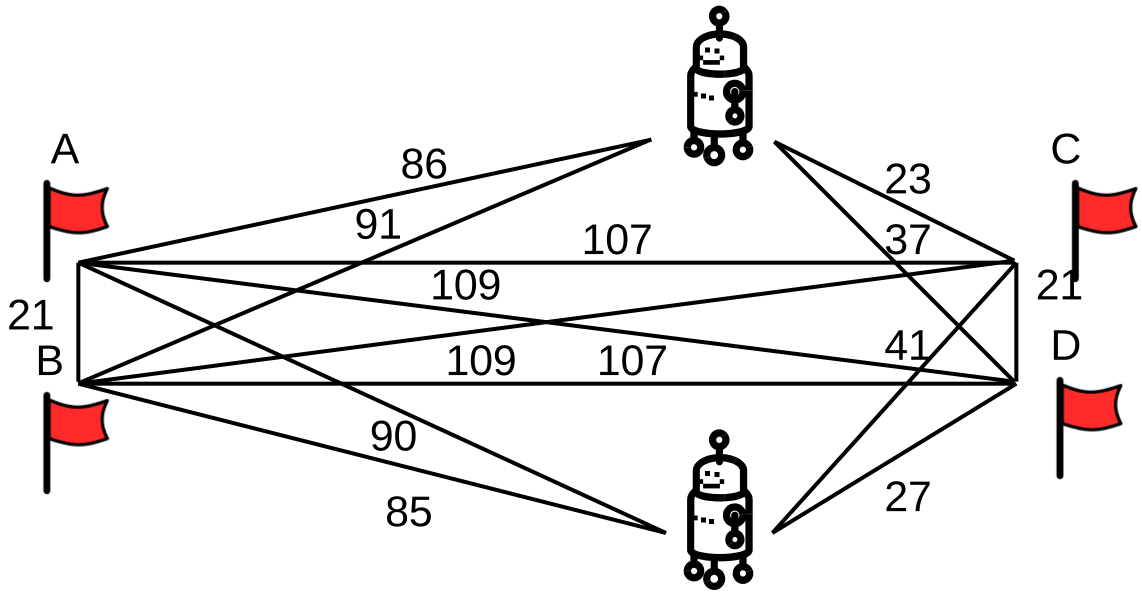
Nuber of bundles $2^{|T|}$. Computing the winner is NP-complete.

Fast computation possible, if the bundle set is sparce.

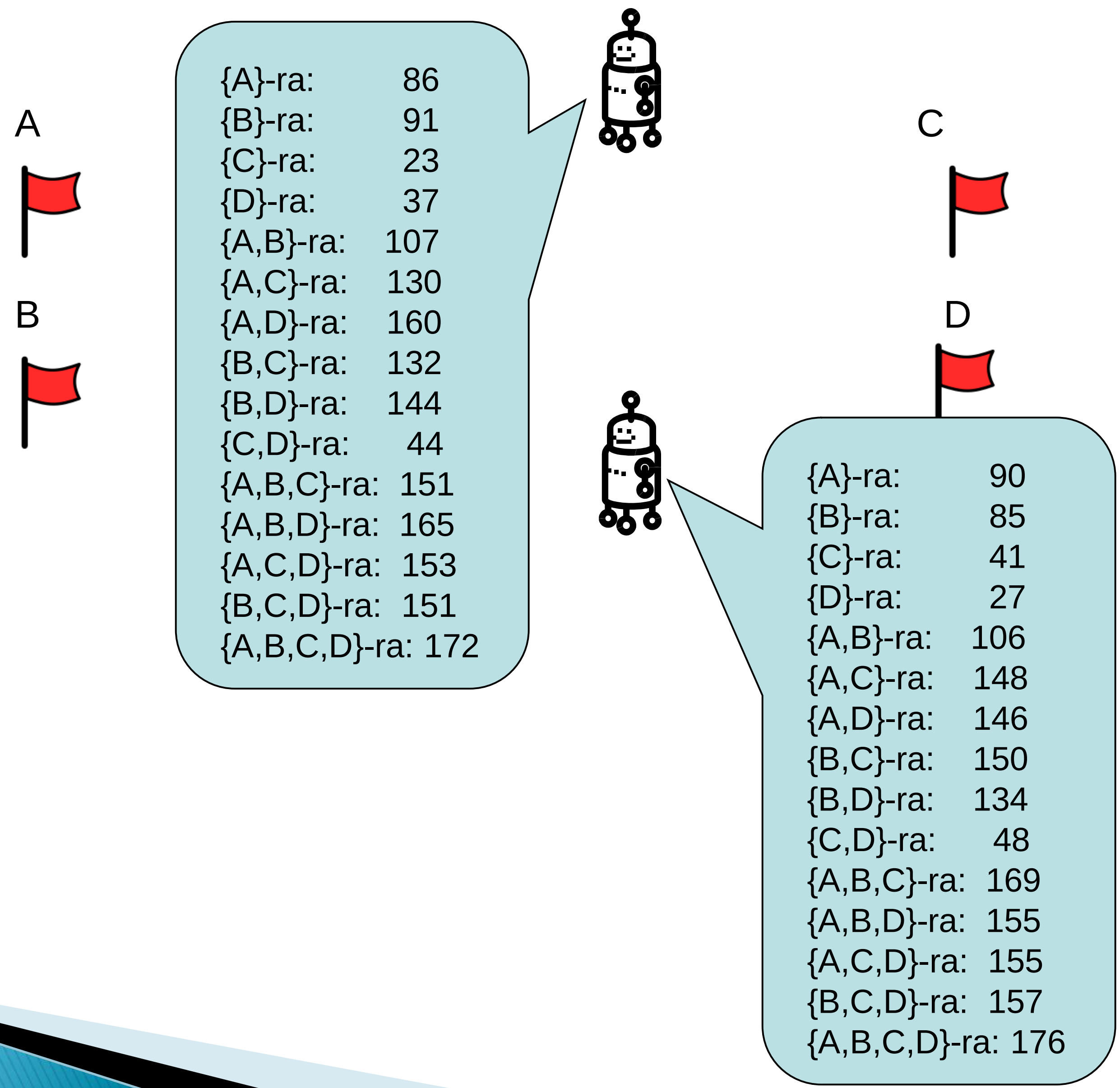
- Reduced bundle number
- Bundle clusters
- Small size bundles
- …



Coordinating with auctions



Ideal combinatorical auction



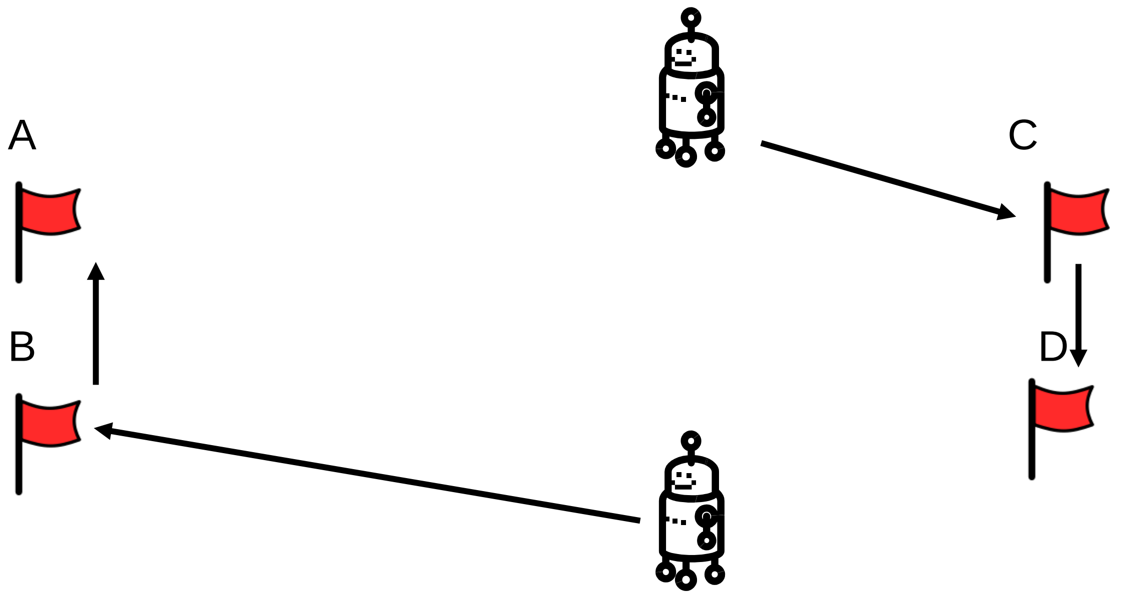
Ideal combinatorical auction

{A}-ra:	**86**
{B}-ra:	91
{C}-ra:	**23**
{D}-ra:	37
{A,B}-ra:	107
{A,C}-ra:	**130**
{A,D}-ra:	160
{B,C}-ra:	**132**
{B,D}-ra:	144
{C,D}-ra:	**44**
{A,B,C}-ra:	**151**
{A,B,D}-ra:	165
{A,C,D}-ra:	**153**
{B,C,D}-ra:	**151**
{A,B,C,D}-ra:	**172**

{A}-ra:	90
{B}-ra:	**85**
{C}-ra:	41
{D}-ra:	**27**
{A,B}-ra:	**106**
{A,C}-ra:	148
{A,D}-ra:	**146**
{B,C}-ra:	150
{B,D}-ra:	**134**
{C,D}-ra:	48
{A,B,C}-ra:	169
{A,B,D}-ra:	**155**
{A,C,D}-ra:	155
{B,C,D}-ra:	157
{A,B,C,D}-ra:	176

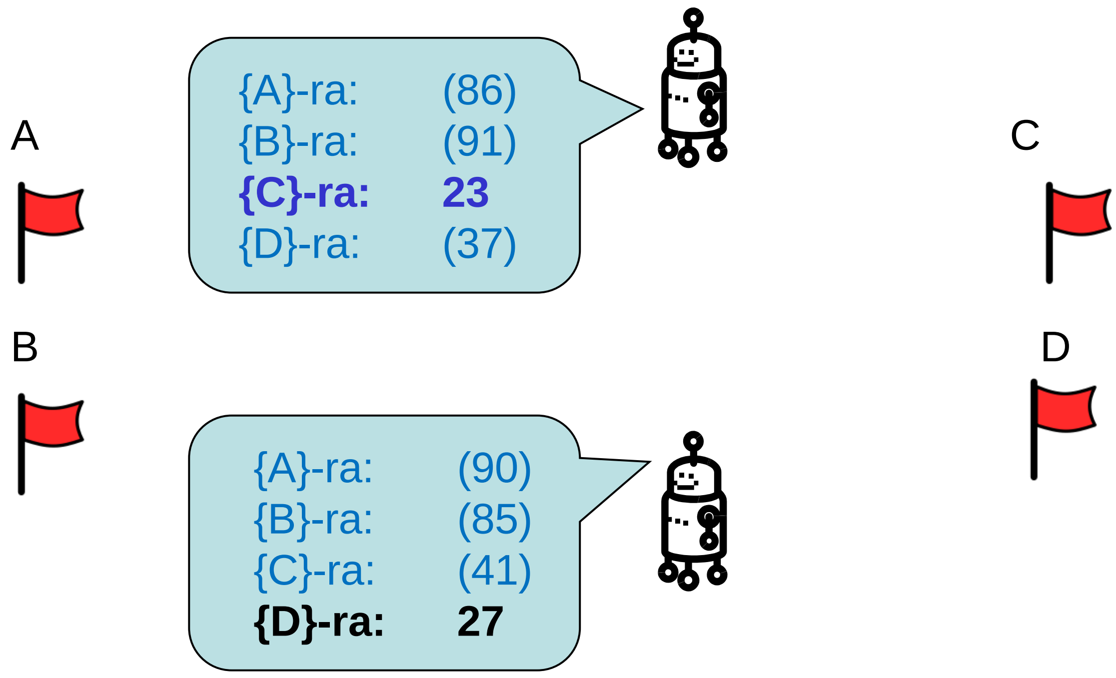
-	{A,B,C,D}	176
{A}	{B,C,D}	243
{B}	{A,C,D}	246
{C}	{A,B,D}	178
{D}	{A,B,C}	206
{A,B}	**{C,D}**	**155**
{A,C}	{B,D}	264
{A,D}	{B,C}	310
{B,C}	{A,D}	278
{B,D}	{A,C}	288
{C,D}	**{A,B}**	**150**
{A,B,C}	{D}	178
{A,B,D}	{C}	206
{A,C,D}	{B}	238
{B,C,D}	{A}	241
{A,B,C,D}	-	172

Ideal combinatorical auction

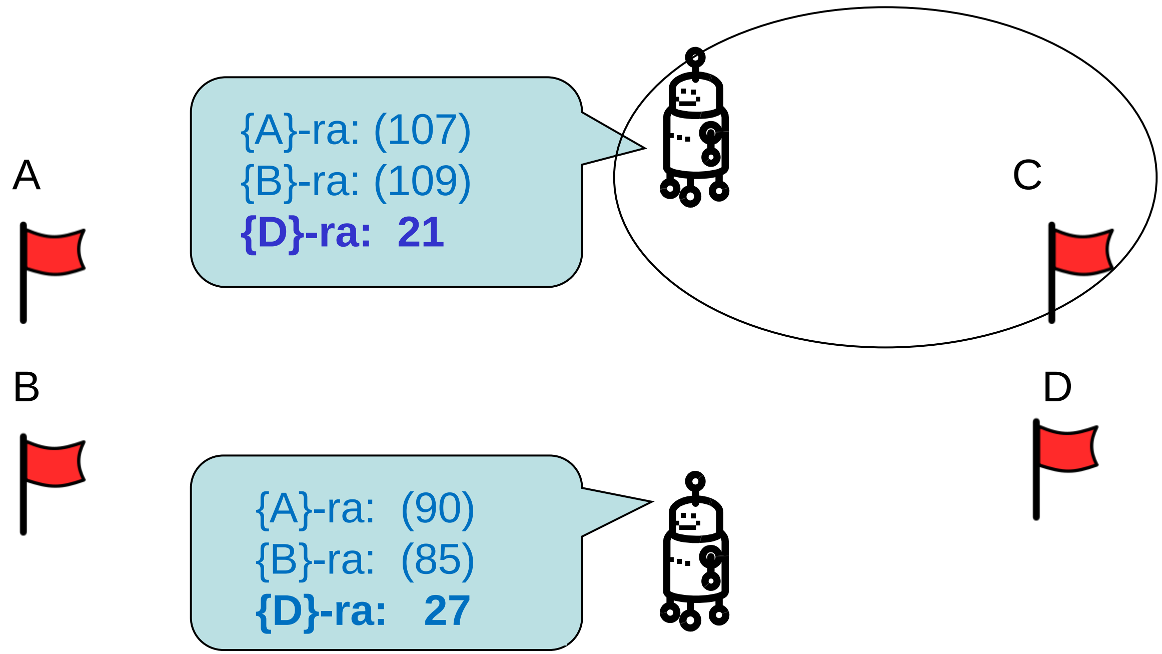


Team cost minimal
Winner solution NP-complete
Exponential bid number

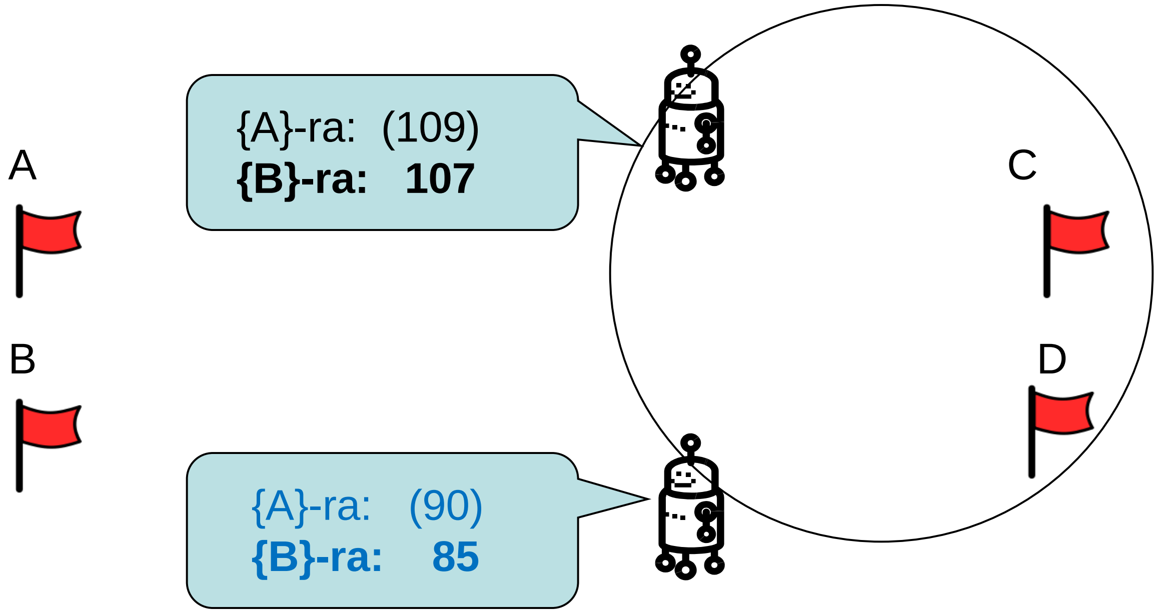
Sequential auction



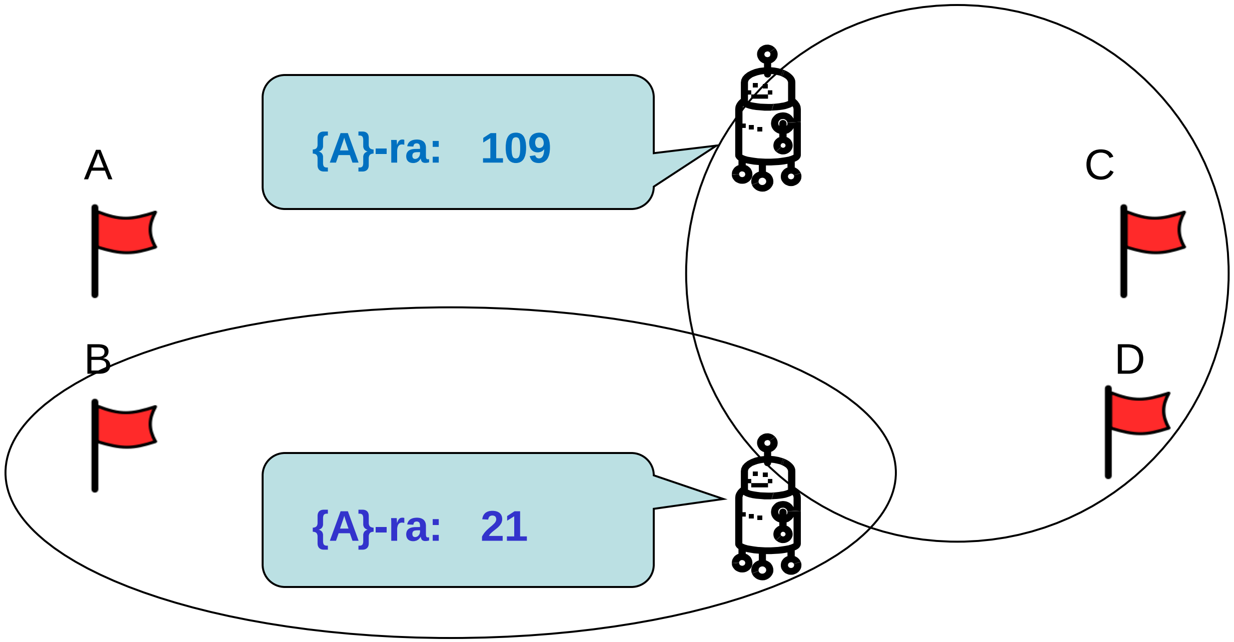
Sequential auction



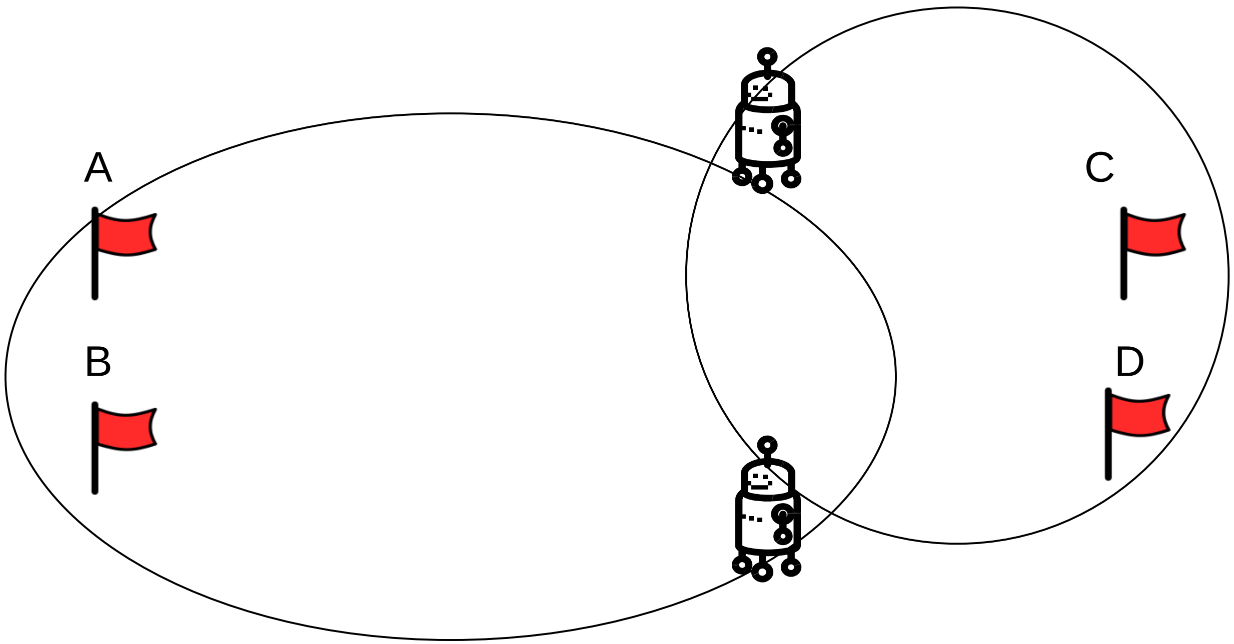
Sequential auction



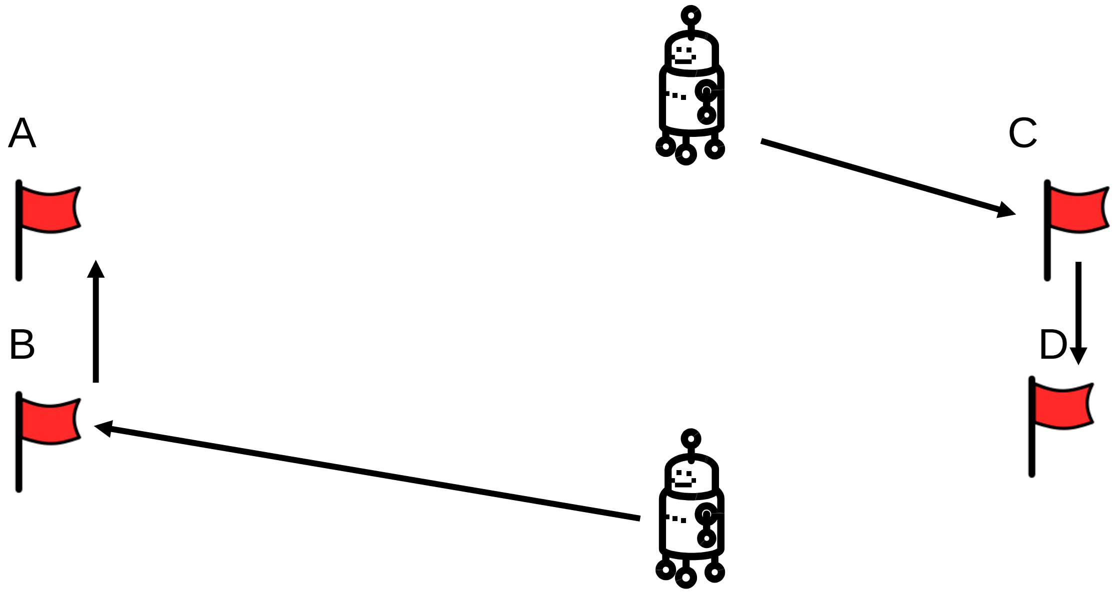
Sequential auction



Sequential auction



Sequential auction



Bids

{A}-ra: (86)	{A}-ra: (90)
{B}-ra: (91)	{B}-ra: (85)
{C}-ra: 23	{C}-ra: (41)
{D}-ra: (37)	**{D}-ra: 27**

{A}-ra: (107)
{B}-ra: (109)
{D}-ra: 21

{A}-ra: (109)
{B}-ra: 107

{A}-ra: 21

Wins

Upper agent	Lower agent
C = 23	
D = 21	
	B = 85
	A = 21

Each agent bids at most once in a round.
The number of rounds equals the number of items.

Sequential auction

Suitable bid design:

MiniSum

summary efforts minimized for the whole team
(energy, distance, resource, …) (eg. Planetary exploration)

MiniMax

maximal individual cost minimized
minimizing the full task solution time (makespan)
(eg. objektum/ area guarding, clearing the mine)

MiniAve

minimizing the average arrival time to the destination
minimizing the average service time (flowtime)
(eg. sarch and rescue)

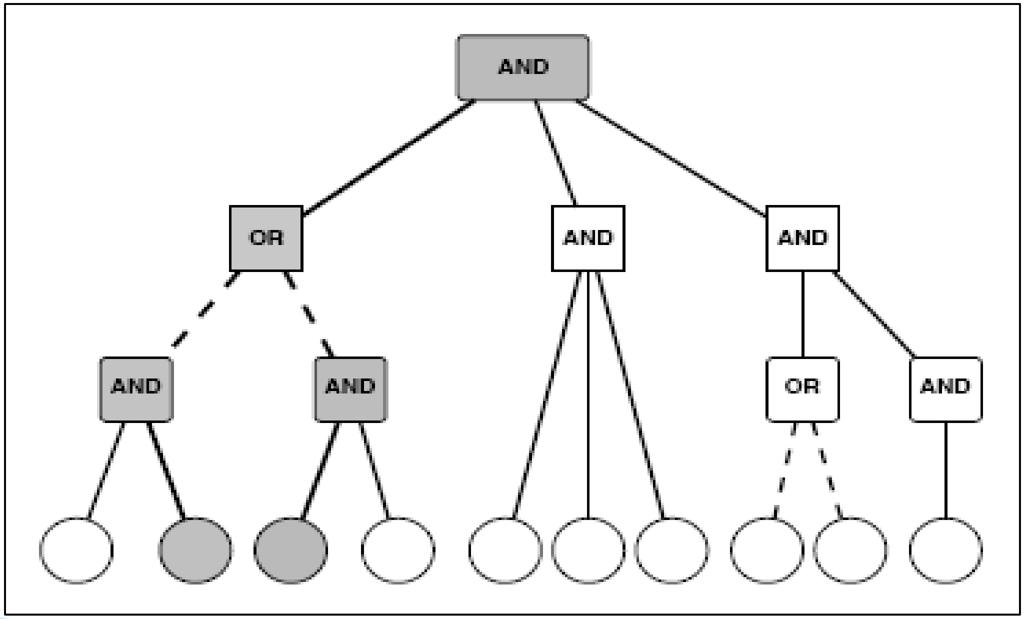
Handling complex tasks

Elementary task
Decomposable task
Composite task
Complex task

Strategies:
Decomposition now - assignement later
Assignement now – decomposition later

Task AND-OR trees

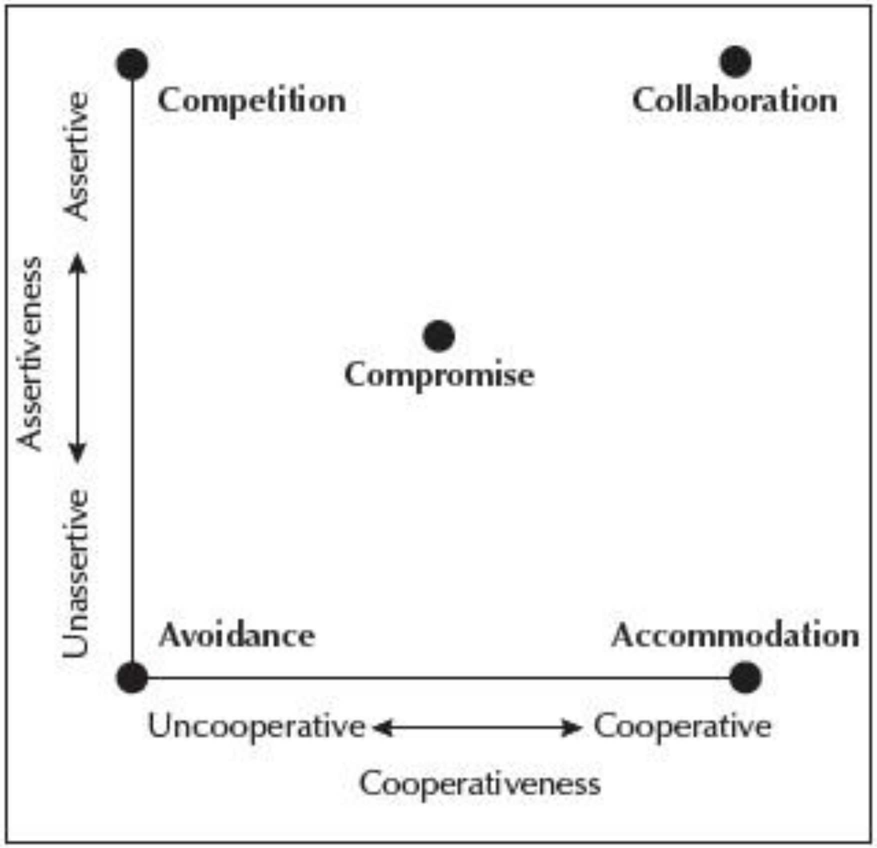
Bid languages for trees



Conflicts (Universal phenomenon in agent systems)

Not passing over resources
(due to **local autonomy**)
No agreement who should do what
(**weak problem decomposition**)
Differences in opinions about decisions
(**different perspective**)

(what is an advantage/ disadvantage for a **single agent**, it is disadvantage/advantage for the **group**)



Conflict classes

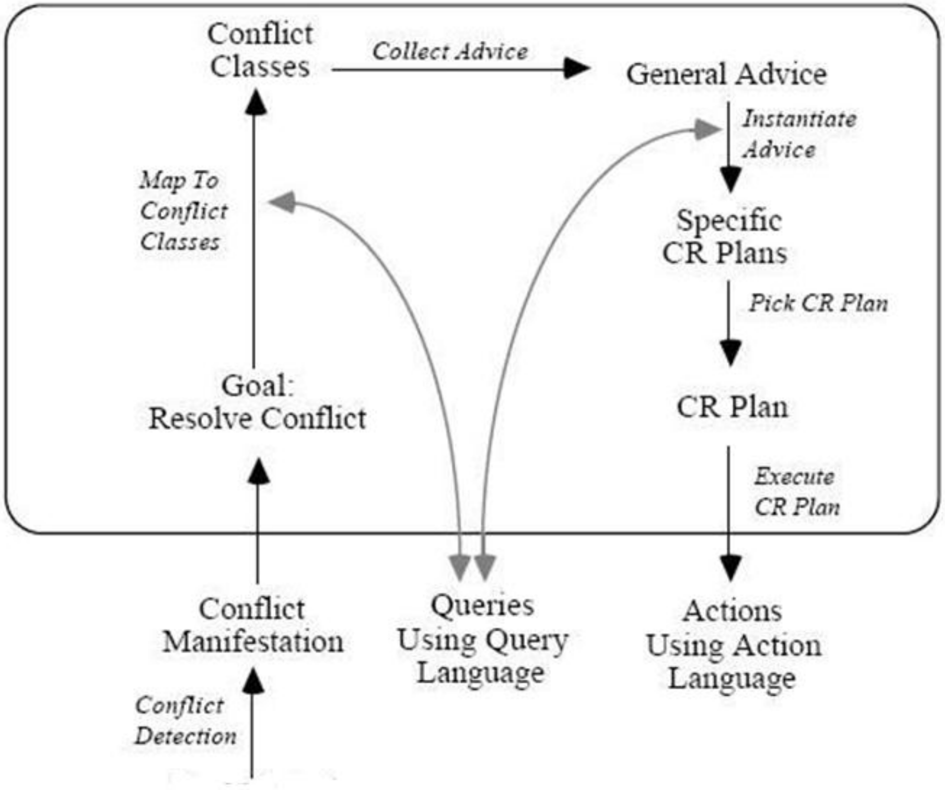
Conflict recognition (type, hierarchy, ...)
Identifying conflict resolution strategy (type, hierarchy, ...)
Applying conflict resolution strategy (protocols, ...)

Depends on:
coperative MAS (hierarchy, team, ...)
non-cooperative MAS (congregation, markets, ...)

during **task sharing**
during **result sharing**

positive (abundance of …)
negative (something is missing …)

General scheme of conflict resolution



Conflict classes – cooperative agents

Knowledge management of the two agents differs

- in data,
- in rules,
- in knowledge sources,
- in preferences,
- in activities,
- in .... (any symbolically expressible information)

Conflict types

schema conflict – different notions (names, predicates, ontology, ...)
data conflict - incorrect, inconsistent data (units, accuracy)
knowledge conflict – different reasoning capability

In BDI model

Goal conflict
Plan conflict
Belief conflict

Conflict resolving subprotocols

INQUIRY
ARBITRATION
PERSUATION
ACCOMODATION

Conflicts of competetive agents – Game theory

Components

- Normal form, extensive form
- Players, strategies, utilities, pay-off
- Symmetric/ asymmetric
- Zero-sum, Non-zero-sum
  - (Σ=0, maxmin=minmax, egyensúly, Neumann, 1928)
- Dominating strategy
- Pure, mixed strategies
- Nash-equilibrium
  - (every finite game has at least one (mixed) equilibrium, Nash, 1951):
- …

1 \ 2	x	y	z
u	(6, 3)	(1, 5)	(0, 6)
v	(1, 7)	(2, 8)	(2, 6)

Battle of sexes

1 \ 2	Comp	Coop
Comp	(1, 1)	(3, 2)
Coop	(2, 3)	(0, 0)

Chicken

1 \ 2	Brave	Cowd
Brave	(0, 0)	(3, 1)
Cowd	(1, 3)	(2, 2)

Matching pennies

1 \ 2	Head	Tail
Head	(1, -1)	(-1, 1)
Tail	(-1, 1)	(1, -1)

Leader

1 \ 2	Goes	Waits
Goes	(0, 0)	(3, 2)
Waits	(2, 3)	(1, 1)

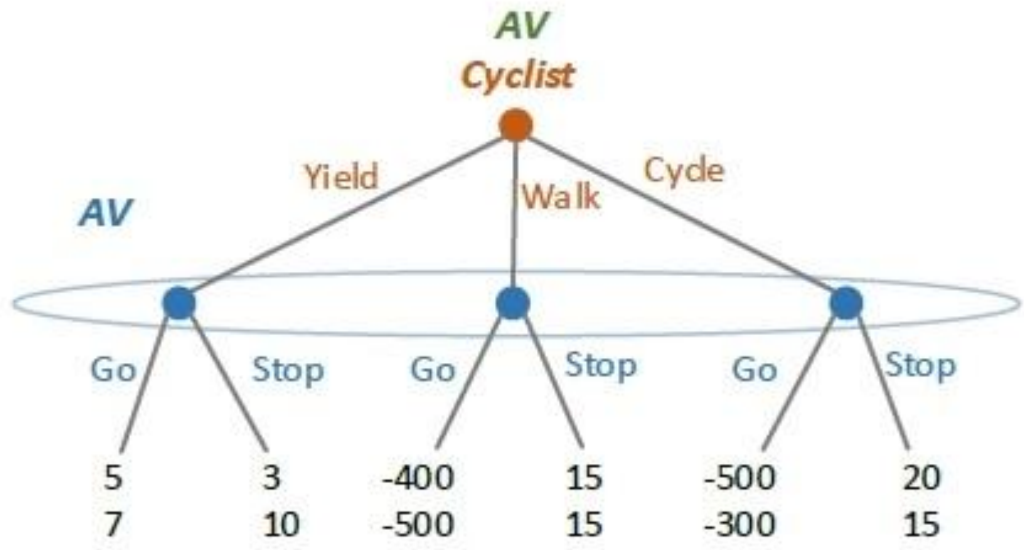
Prisoner's dilemma

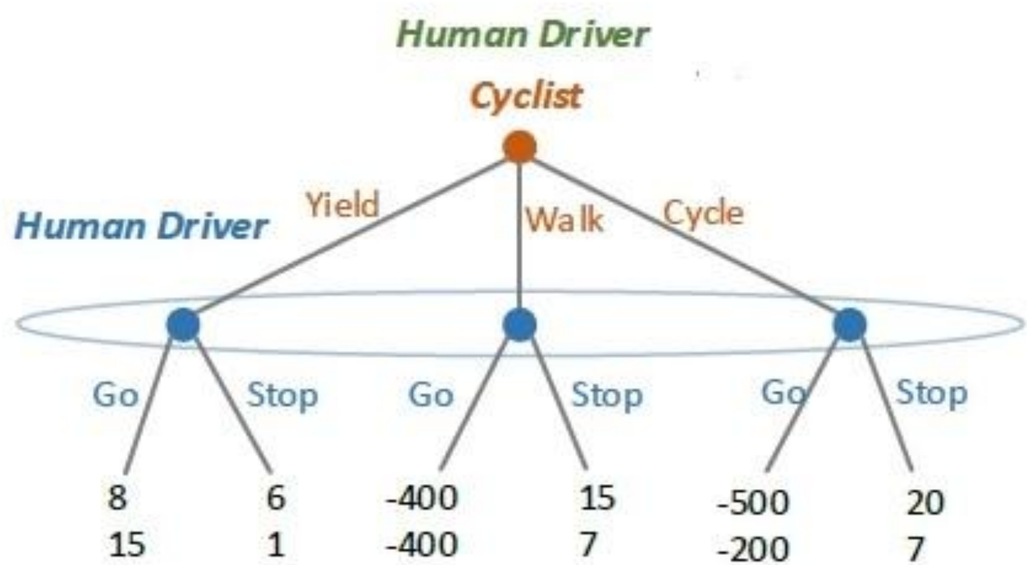
(D,D) = NE
D – dominating strategy
all (x,y), beside (D,D) is Pareto optimal
(C,C) is maximizing the social welfare function

1 \ 2	D	C
D	(2, 2)	(4, 1)
C	(1, 4)	(3, 3)

When already every car in the streets will be Tesla!?

Dynamic (sequential) games in extensive form





Dynamic (sequential) games in extensive form

Cyclist

AV		y	w	c
	s	10, 3	15, 15	15, 20
	g	7, 5	–400, –500	–500, –300

Cyclist

HV		y	w	c
	s	1, 6	7, 15	7, 20
	g	**15, 8**	–400, –400	–500, –200

Mechanism design: social welfare function

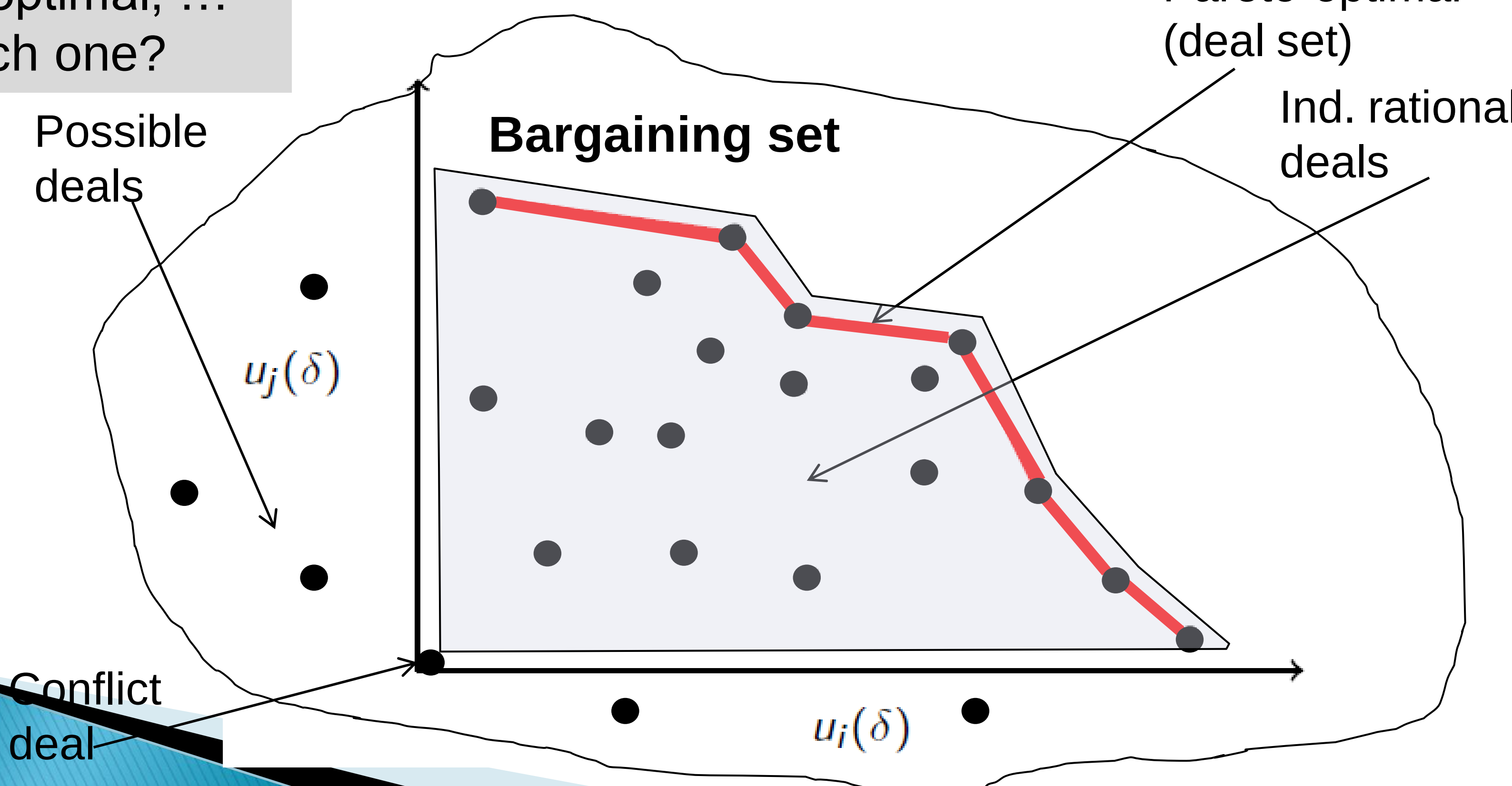
(Voting)

(Auction)

Seeking agreement: **Negotiation (protocols)**

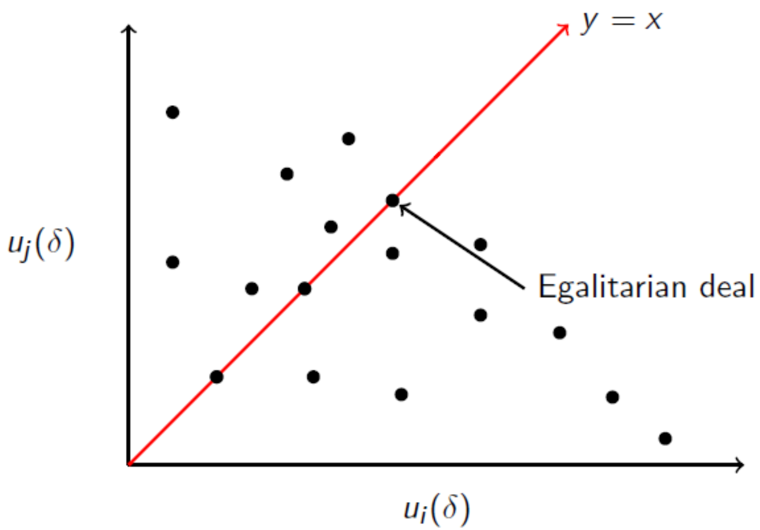
(Arguing)

Strategic solution
Pareto-optimal, …
But which one?



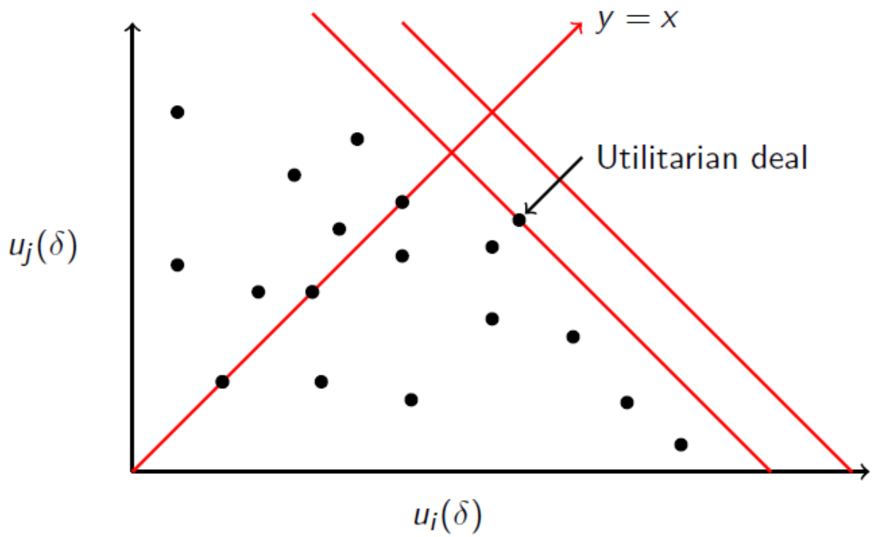
Egalitarian

$$\delta = \arg\max_{\delta' \in E} \sum_i u_i(\delta'), \quad E = \left\{ \delta \mid \forall_{i,j}\ u_i(\delta) = u_j(\delta) \right\}$$

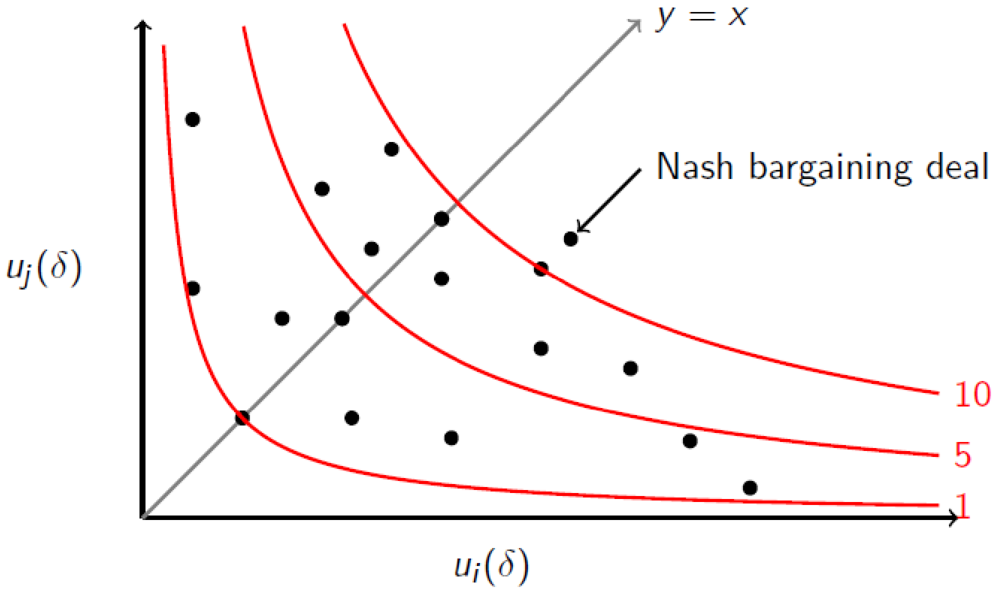


Utilitarian

$$\delta = \arg\max \sum_i u_i(\delta)$$



Nash-bargaining deal $\delta = \arg\max_{\delta'} \prod_i u_i(\delta')$



Monoton Concession Protocol – Zeuthen strategy (1930)

What to offer in the first round? Everybody its best (preferred) deal.

Who should concess in a given round?

That agent, which is the least inclined to risk the conflict deal. (*)

When concessing, how much? Just so much that it ceases to be (*).

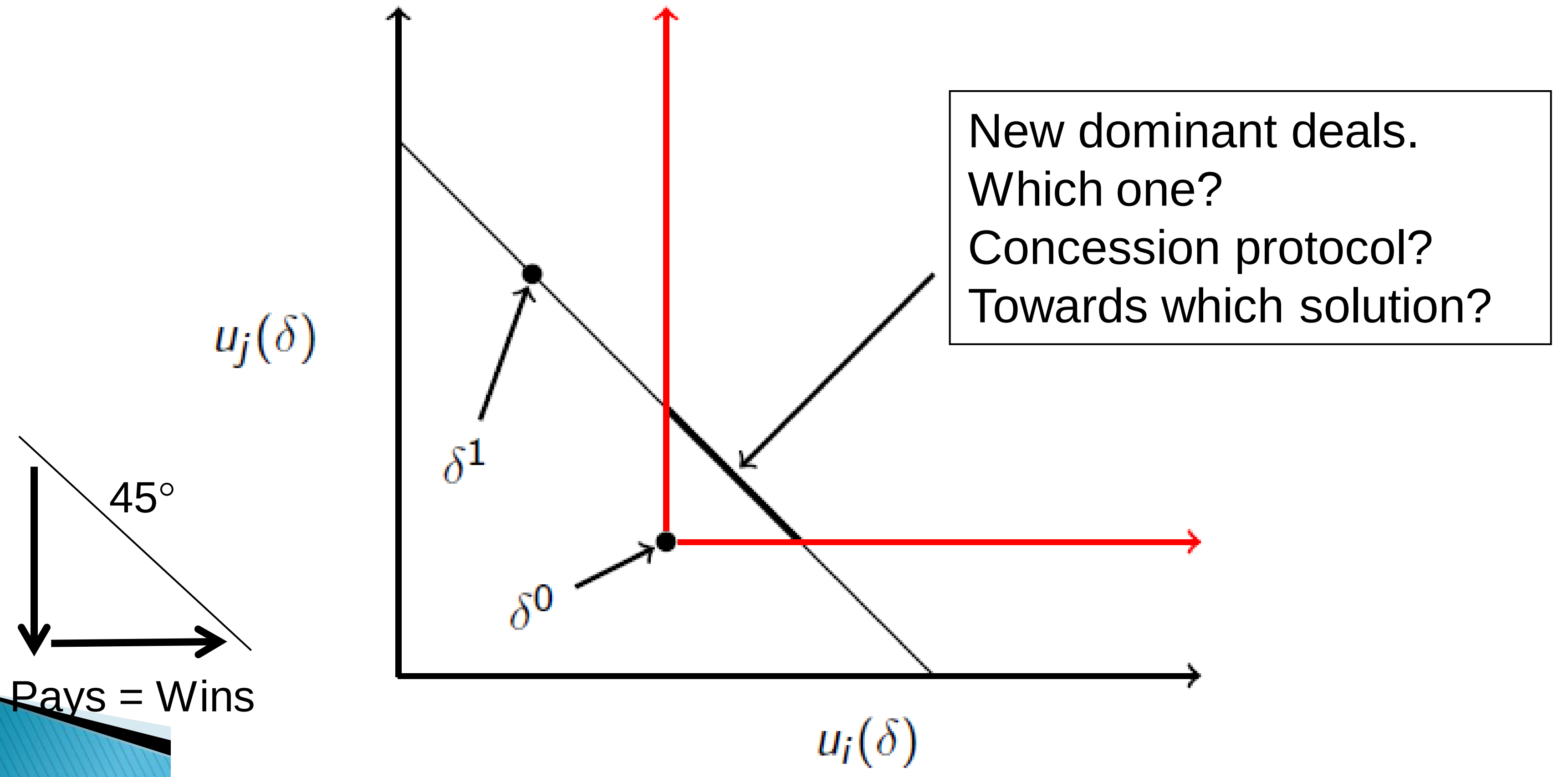
If less: it must concess anew - not efficient.

If more – utility is lost.

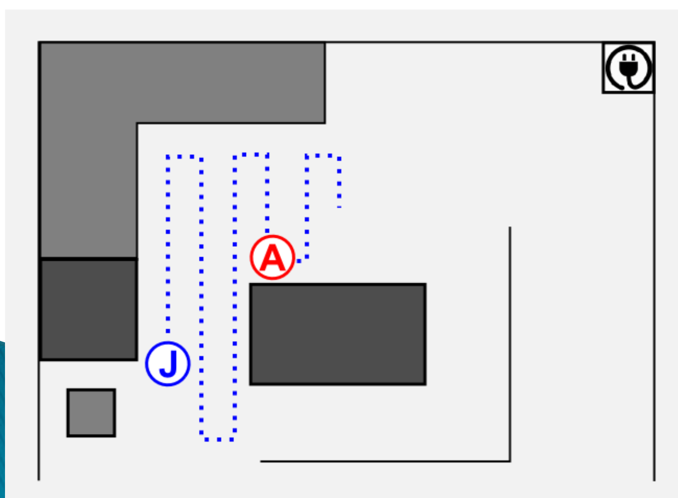
Negotiating with payments

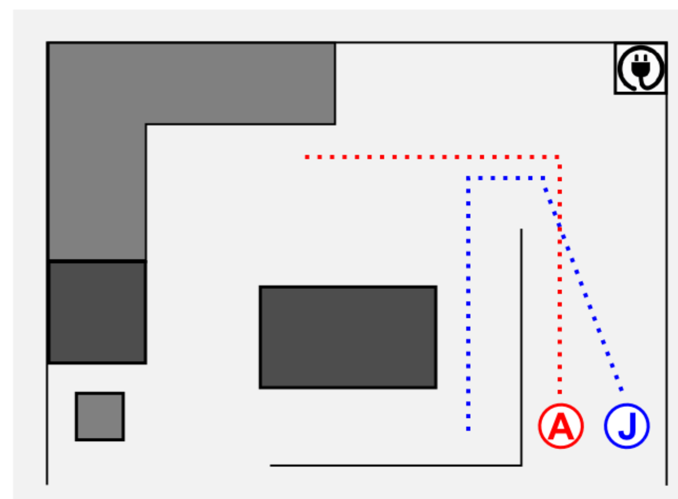
What if there is no really good deal to offer or to accept?

Payments: Introducing (financial) payments – increasing possible deals



Case study – Conflicts between Amigo and Jaguar (R5COP)





Measuring the severity of conflicts

Level of self-harm
Importance and urgency of the task
Waiting time and its uncertainty
Need for human interaction

Robot states

Being on charger
Waiting for a task
Moving towards a destination
Cleaning low (Jaguar only)
Cleaning high (Amigo only)
Waiting for human operator
Communicating with human operator
Picking up a tool from its storage location (e.g. vacuum cleaner)
Using a tool
Putting back a tool to its storage location
Waiting for human personnel
Communicating with human personnel

Issue-Alert (new ACL performatives)

<i, issue-alert (j, f)>

FP: Bi ser(f) $\wedge$ Bi α $\wedge$ Bi β $\wedge$ Bi alarm(f)

RE: (1) Bj Bi ser(f) $\wedge$ Bij alarm(f)

(2) Bj Bi ser(f) $\wedge$ Bj ser(f) $\wedge$ Ij solv(f) $\wedge$ Bij alarm(f)

where:

ser(f) - f is a serious situation

solv(f) - f is solvable

alarm(f) – f is an alarm situation

α = Bj $\neg$ser(f) $\vee$ Uj $\neg$ser(f) $\vee$ $\neg$Bj ser(f)

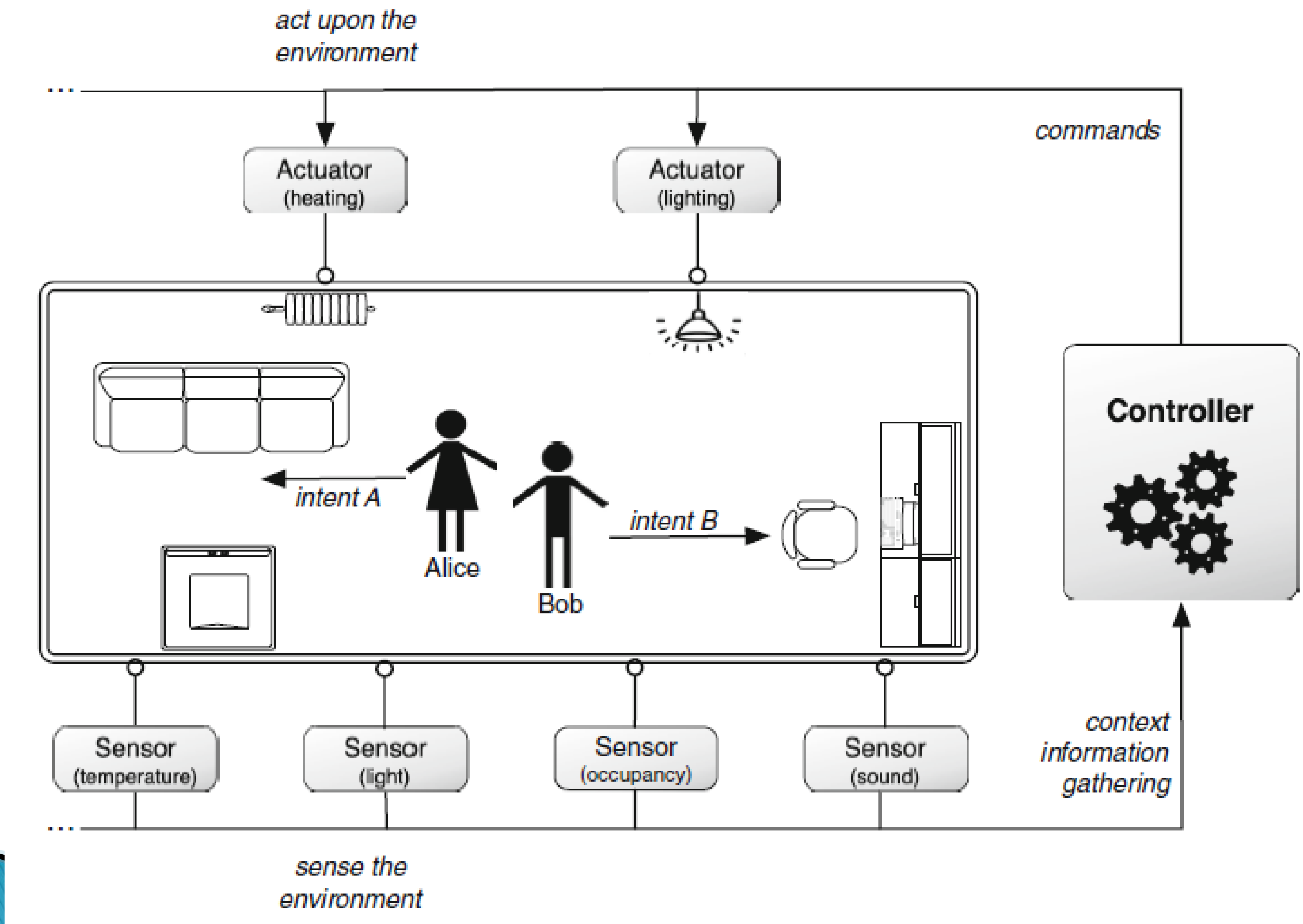
β = $\exists$x. feasible x solv(f) (for some action of robot j)

Bij w = Bj Bi w $\wedge$ Bi Bj w

The two versions of the RE mean a weaker and a stronger response (and obligation taking) on behalf of the hearer. To issue an alert the speaker must believe that the issue is important and worth alarming, and that the hearer deas not consider it that way. Also that the hearer will be able to do something about it, when getting the message. For a less cooperative hearer the result of receiving alert means solely an information that the speaker considers it important (almost no illocutionary force).

		Jaguar										
		A	B	C	D	F	G	H	I	J	K	L
Amigo	A	01^{7}	-	-	-	-	-	-	-	-	-	-
	B	-	-	-	-	-	-	-	-	-	-	-
	C	-	-	02^{1}	03^{2}	04^{2}	05^{2}	06^{2}	07^{2}	08^{2}	-	-
	E	-	-	09^{2}	10^{3}	11^{3}	12^{3}	13^{3}	14^{3}	15^{3}	-	-
	F	-	-	16^{2}	17^{3}	-	18^{4}	-	-	-	-	-
	G	-	-	19^{2}	20^{3}	21^{4}	22^{4}	-	-	-	-	-
	H	-	-	23^{2}	24^{3}	-	-	25^{5}	26^{5}	27^{2}	-	-
	I	-	-	28^{2}	29^{3}	-	-	31^{5}	32^{5}	33^{2}	-	-
	J	-	-	34^{2}	35^{3}	-	-	36^{2}	37^{2}	38^{2}	-	-
	K	-	-	-	-	-	-	-	-	-	39^{6}	40^{6}
	L	-	-	-	-	-	-	-	-	-	41^{6}	

Conflict detection and resolution in home and building automation systems



Conflict detection and resolution in home and building automation systems