Questions for a cooperative robot: what, who, where, when, how?

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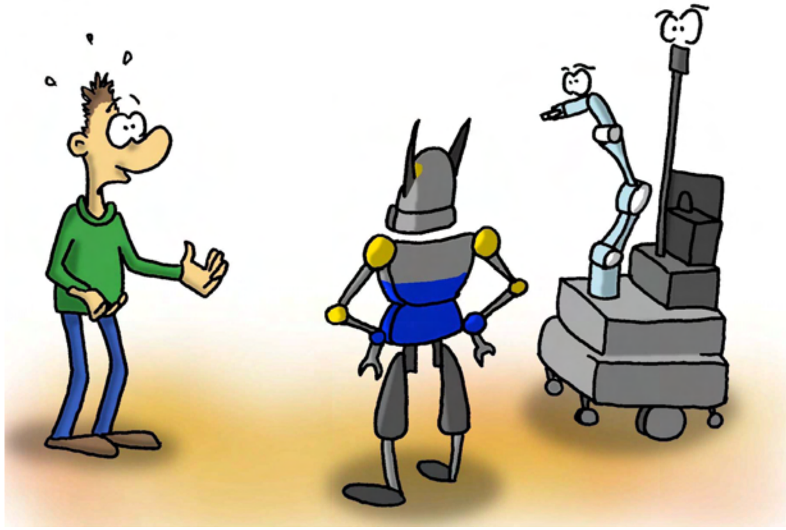


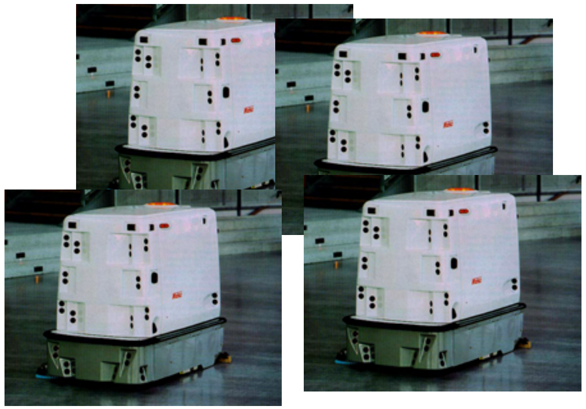
What is sure

- The autonomous robots, when they will be really used, will very seldom be alone

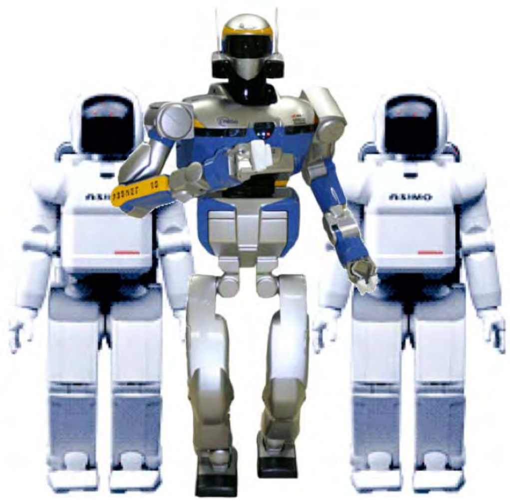
A prediction: “20xy – in a mall”

A group of service robots

Several semi-autonomous wheelchairs



A team of cleaning robots



Several assistive or companion robots

Two types of interactions

- domain and task dependent interaction that will be necessary within a team of robots e.g. perform cooperatively a cleaning task, or a surveillance mission

and also

- generic interaction abilities, when a robot “encounters” a robot that is dedicated to another activity e.g. efficient avoidance and space sharing, between a cleaning robot and a surveillance robot

A shift in the perspective: From a single robot to human-robot teams

Autonomous Robotics

- a dream and a challenge

- The robot was alone

a hero

  - Very capable
  - Very intelligent
  - You give it a goal/task
  - It does the job
  - ... end it is ready for a new adventure

Human Robotic teamwork

The robot companion / assistant

COGNIRON

http://www.cogniron.org

Participating labs:
LAAS, Toulouse
EPFL, Lausanne
IPA, Stuttgart
KTH, Stockholm
U. Karlsruhe
U. Bielefeld
U. Hertfordshire
U. Amsterdam
VU. Brussels
GPS, Stuttgart

Information Society Technologies

Human-Robot Exploration

EVA Assistant Tasks

- Robots carrying equipment (mules)
- Robots in advance of humans (scouts)
- Robots maintaining services (data connectivity)

- Interactive
- Dialogue intensive
- Robots need to keep up with humans

Robonaut: cooperative deployment of equipment

Toward the collaborative robot

- Task oriented Interaction
- Task involves another partner
- Questions of task decomposition, task allocation, task achievement
- Reporting and acting on a task while it is executed

- Reasoning abilities and models of the robot of the others
- Collaborative schemes, Communication, Social behaviour, space and activity sharing

- Questions for a cooperative robot: what, who, where, when, how?

Contributions / Bricks for the collaborative abilities of a robot

- Plan-merging protocol (when and how)
- Task allocation protocol (who)
- Opportunistic behaviour enhancement (who, what and how)
- An architecture for multi-robot cooperation (all..)
- Cooperation through assistance (who and how)

- Multi-robot manipulation: the IKEA problem (how and where)
- Adaptive Formation of UAVs in a hostile environment (who and how)

- SHARY: collaborative human-robot task achievement (what, how and when.)

- Proactive and safe motion in a dynamic environment (how)
- Navigation in presence of humans … user studies (how)
- Guiding a person (how and when)
- Manipulation in presence/interaction with humans ..(where and how)
- Perspective taking (where)
- HATP: a Human Aware Task Planner (what, who and how)

List of co-authors

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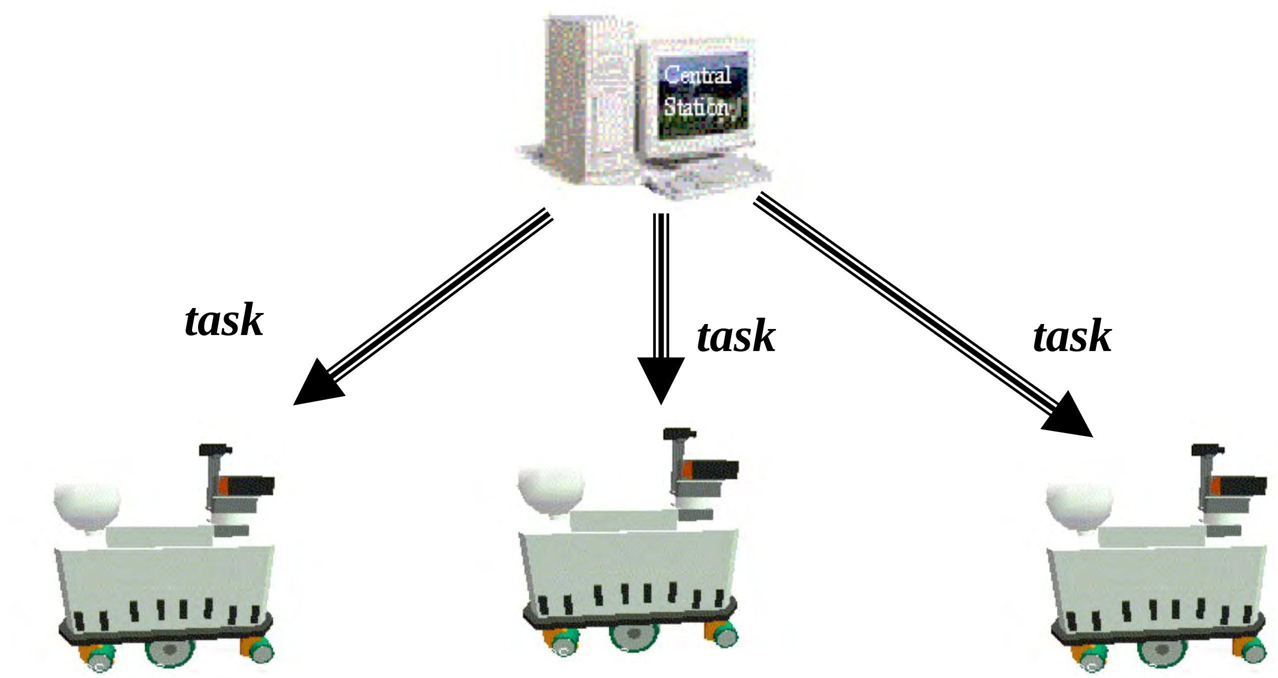
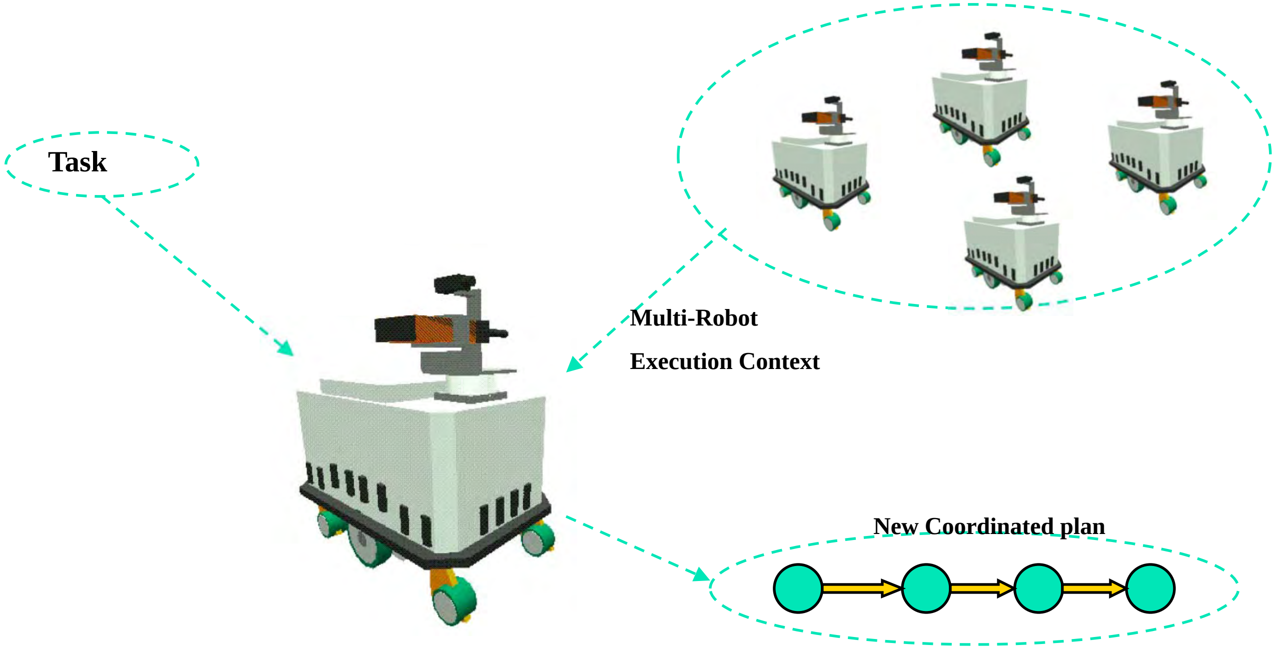
1 - Plan-merging protocol (when and how)

- In multi-robot context
- How to deal with resource conflicts in a distributed way in a dynamic environment ?

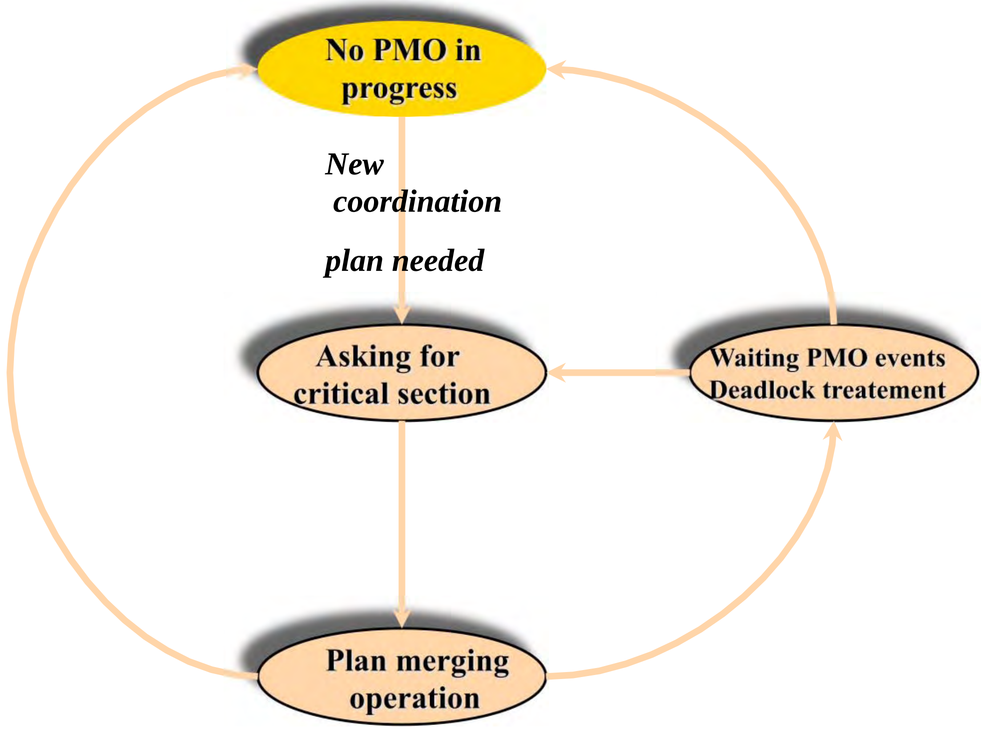
The central station allocates (incrementally) individual tasks to robots



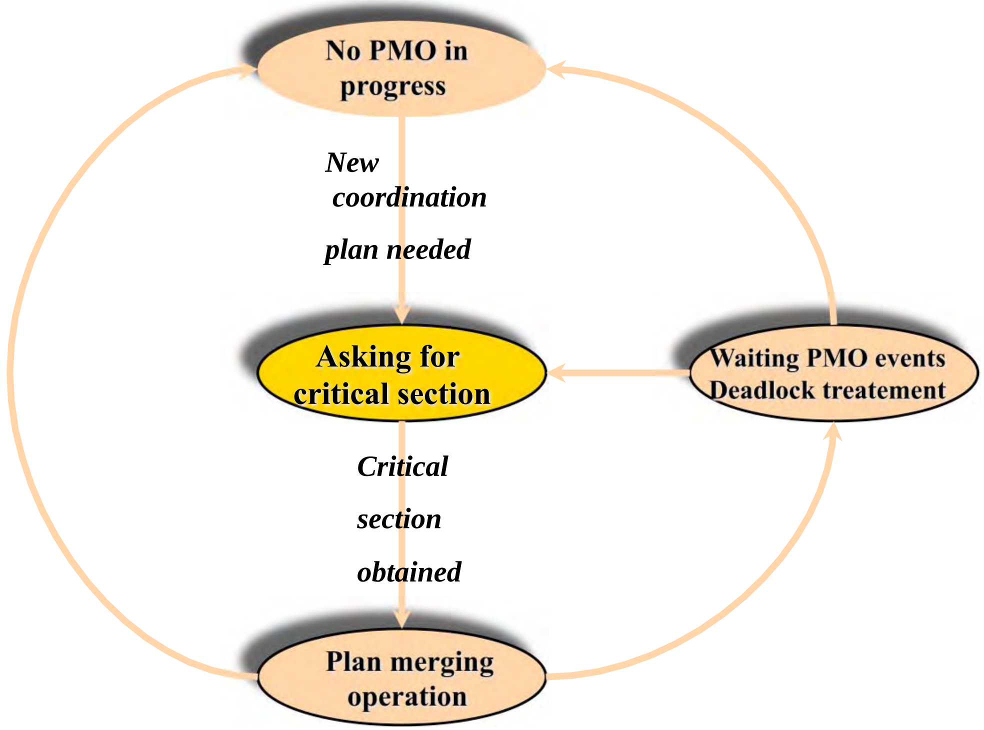
Plan-Merging: Each robot adapts incrementally its plan to comply with the multi-robot context



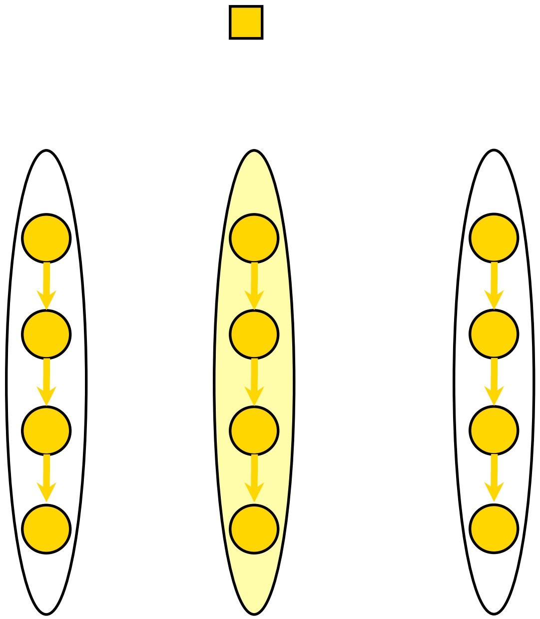
Plan Merging Protocol

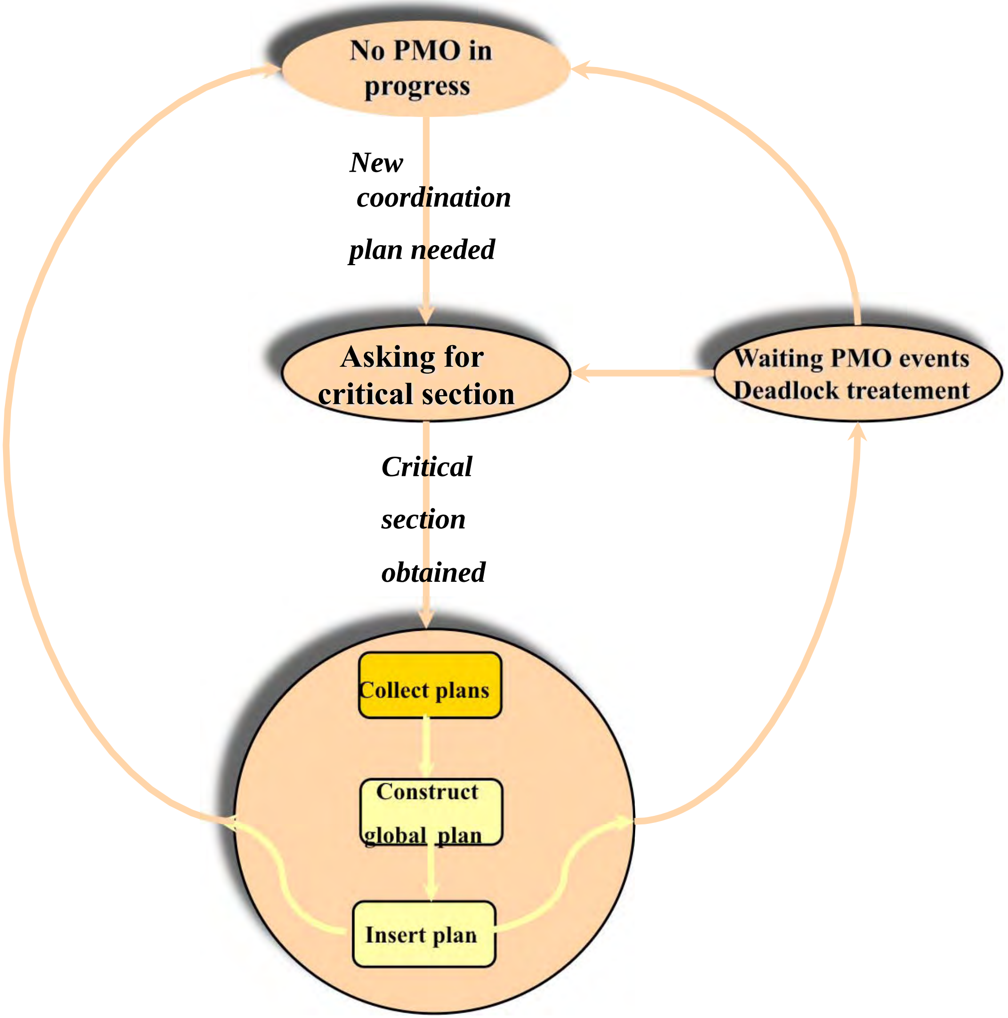


Plan Merging Protocol

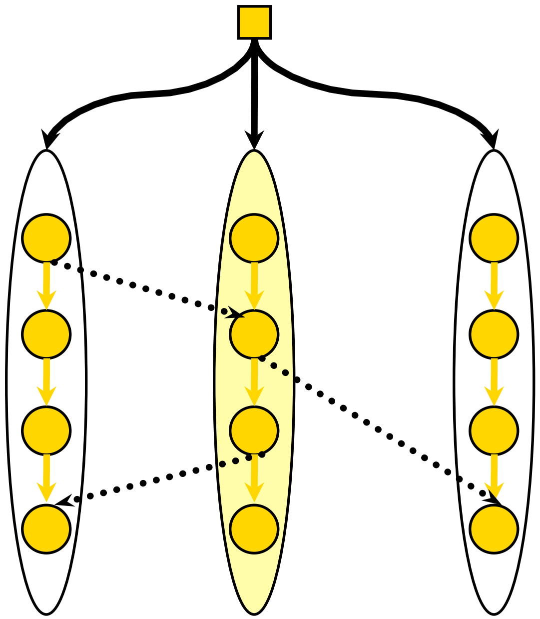


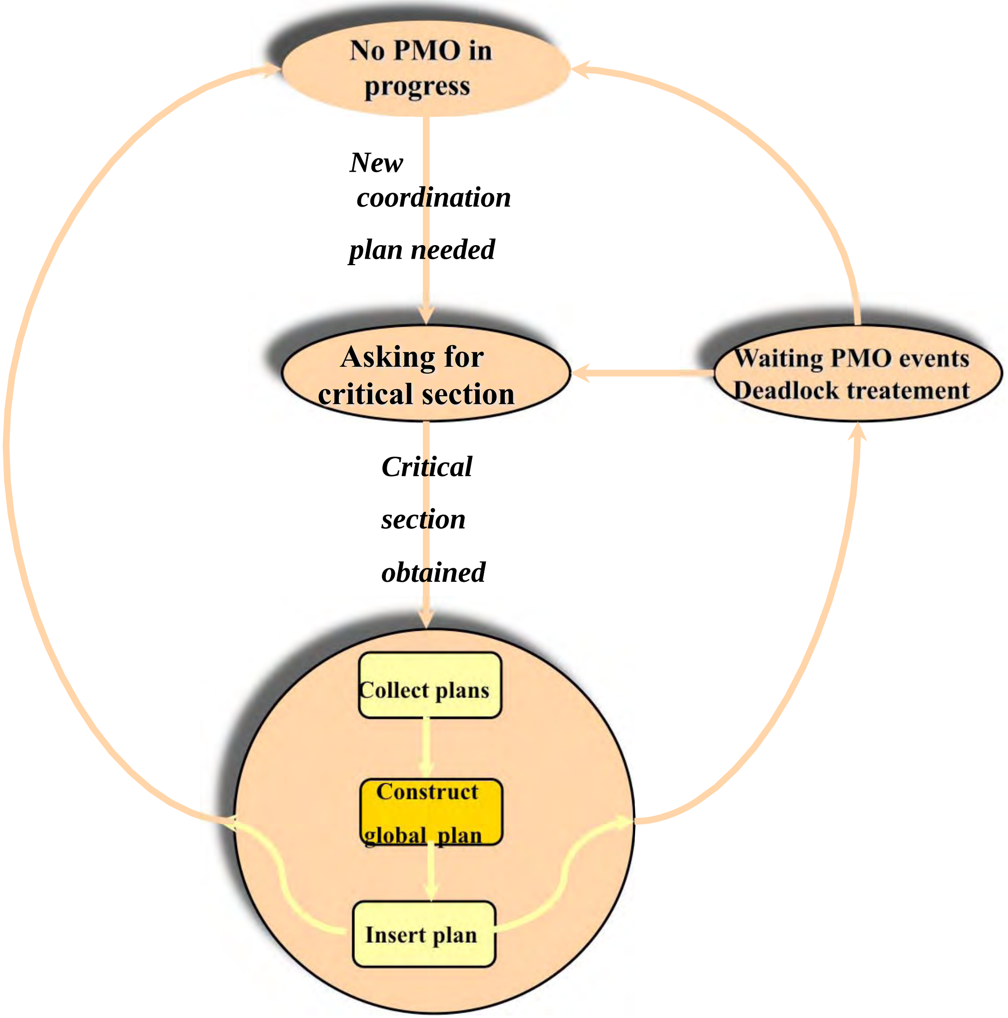
Plan Merging Protocol



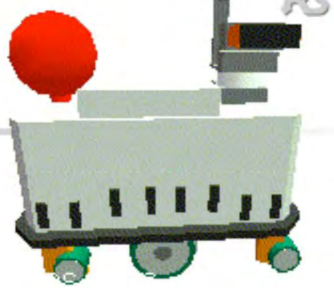


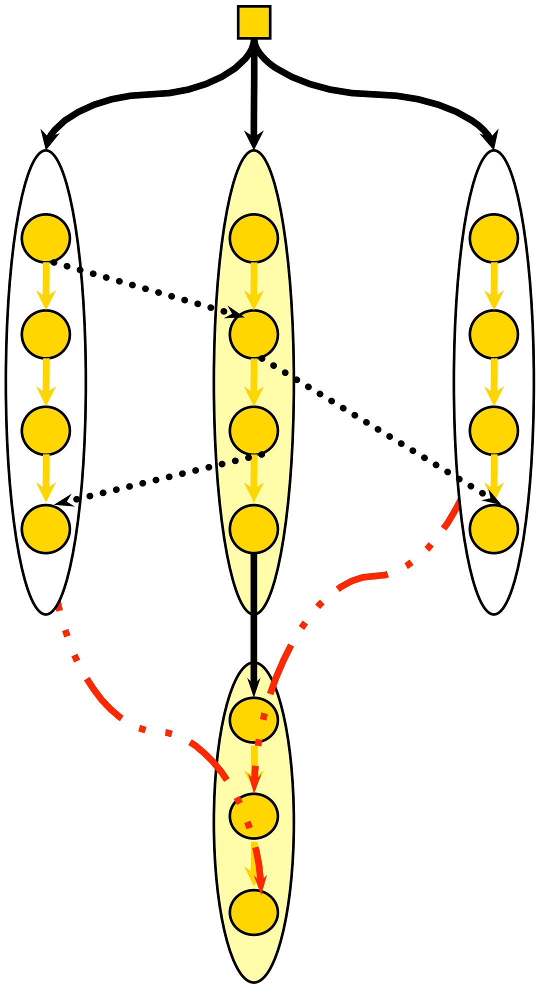
Plan Merging Protocol

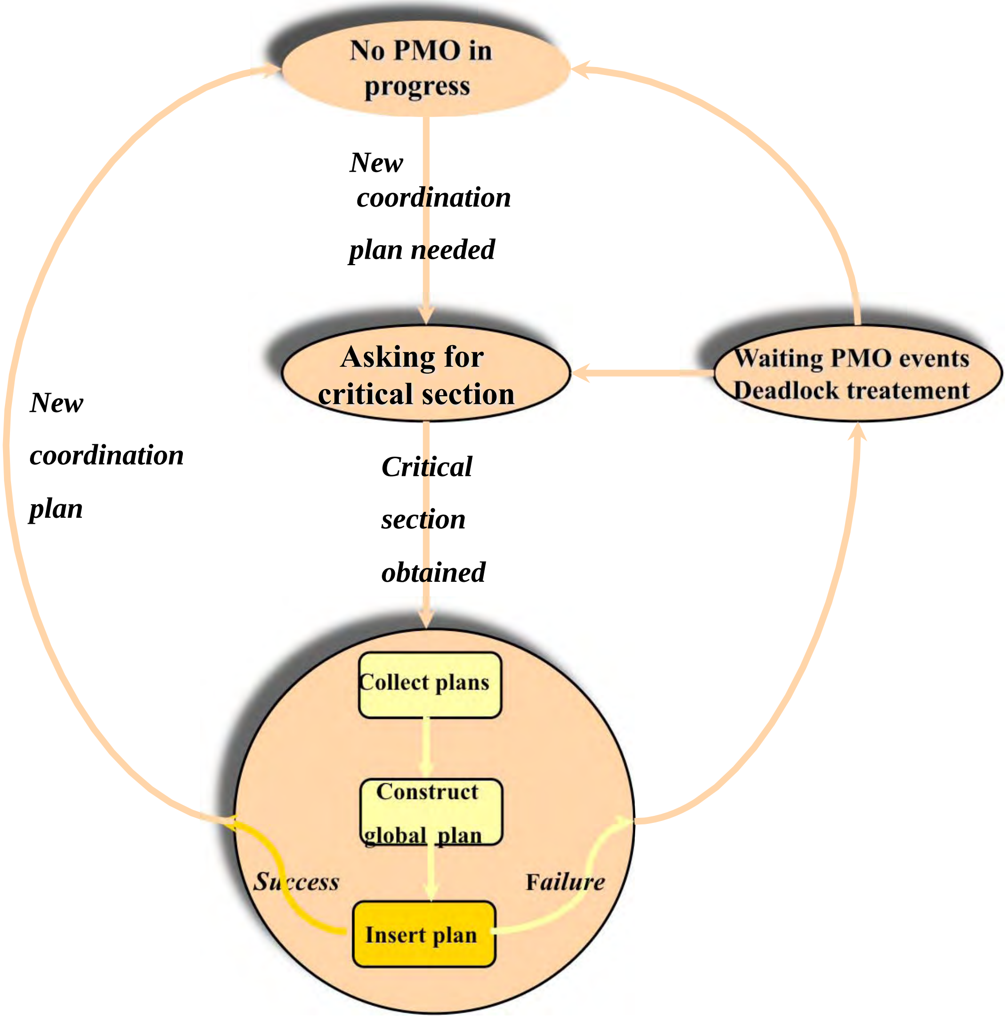




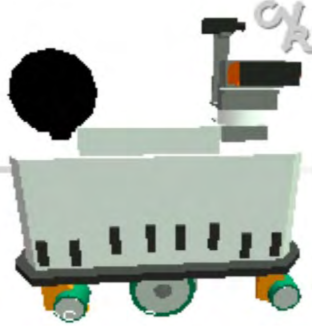
Plan Merging Protocol

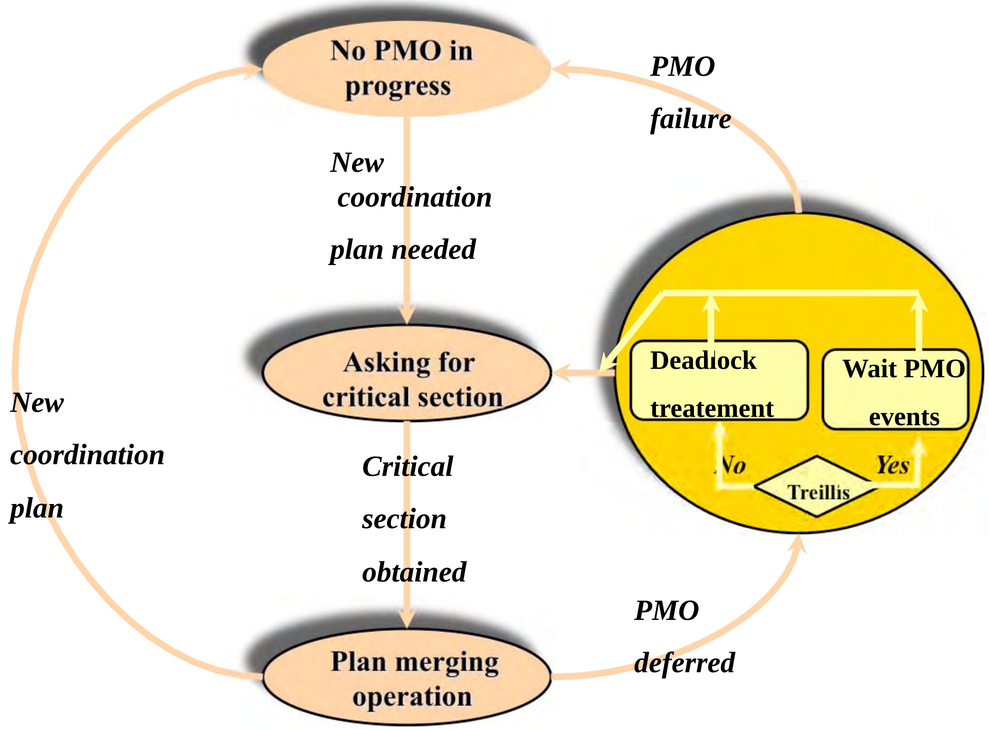




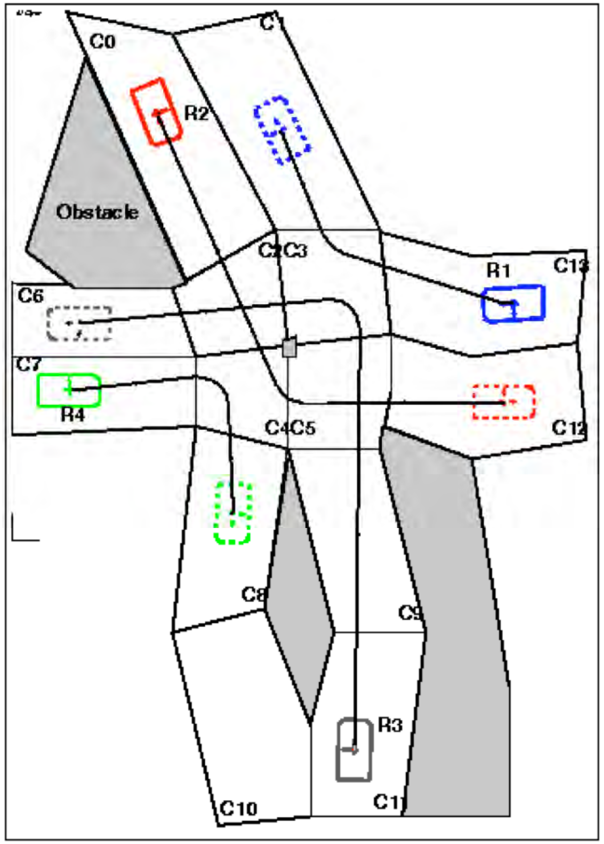


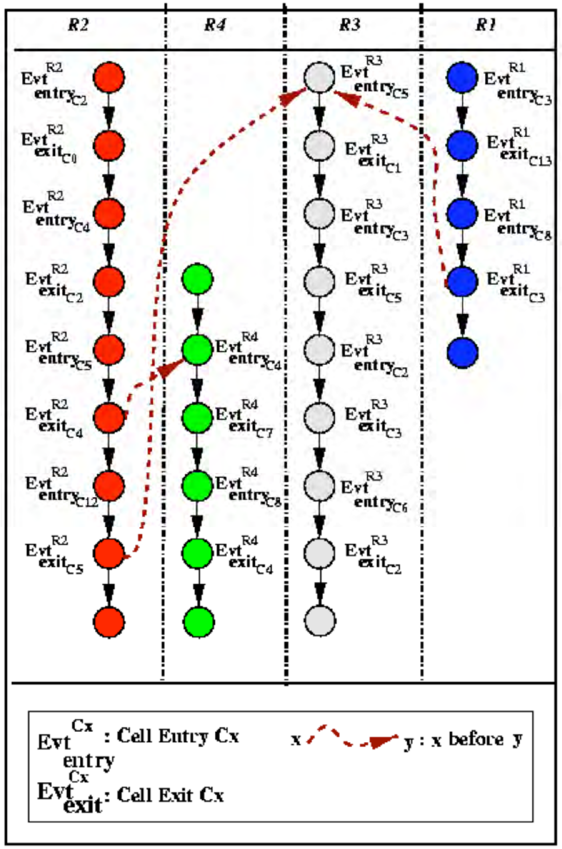
Plan Merging Protocol

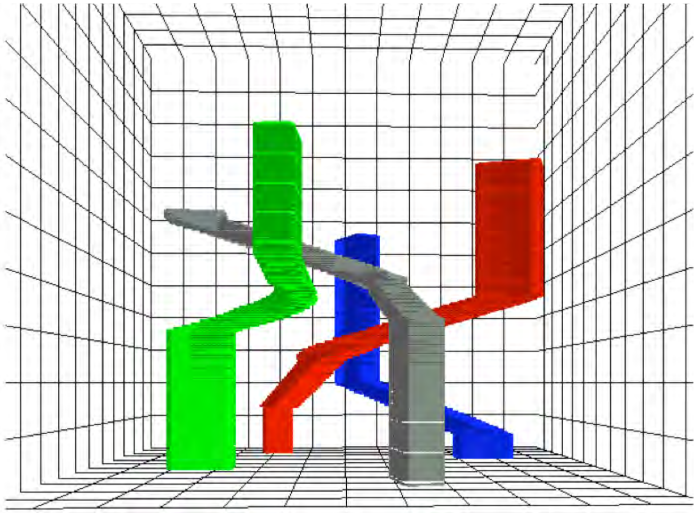




Plan-merging at a crossing

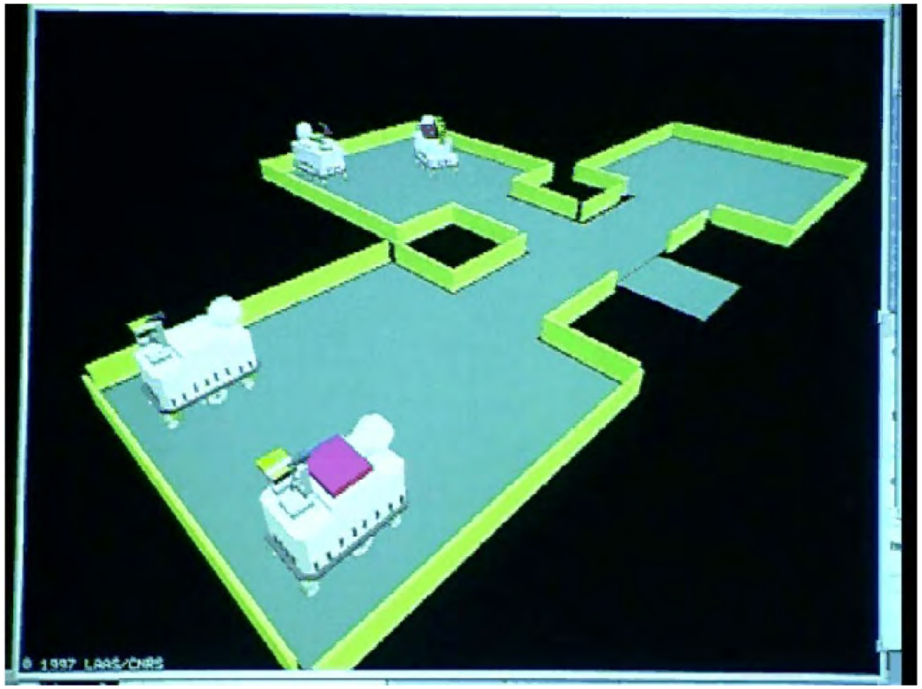


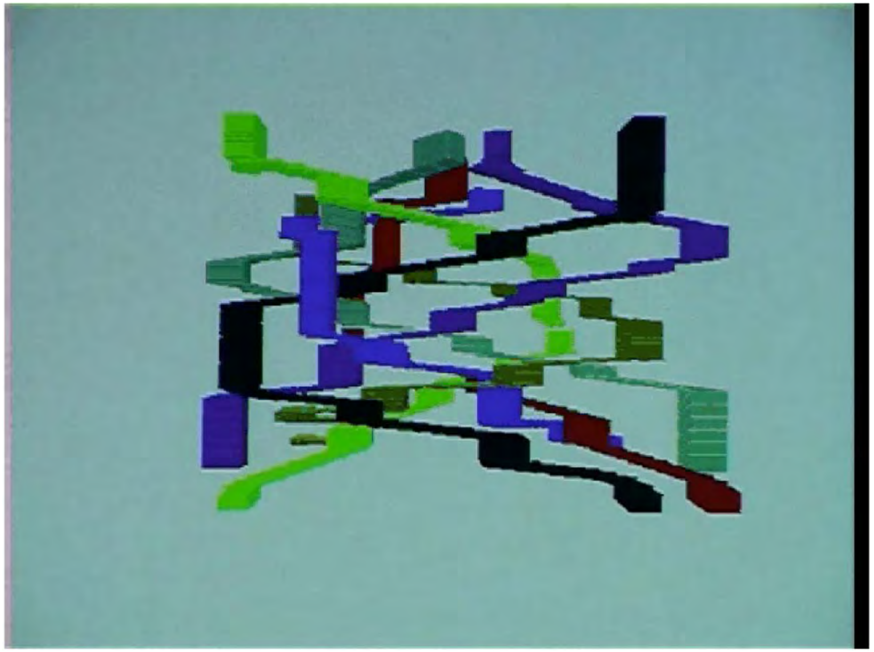




Four trajectories in Space-Time

Intricate motion coordination



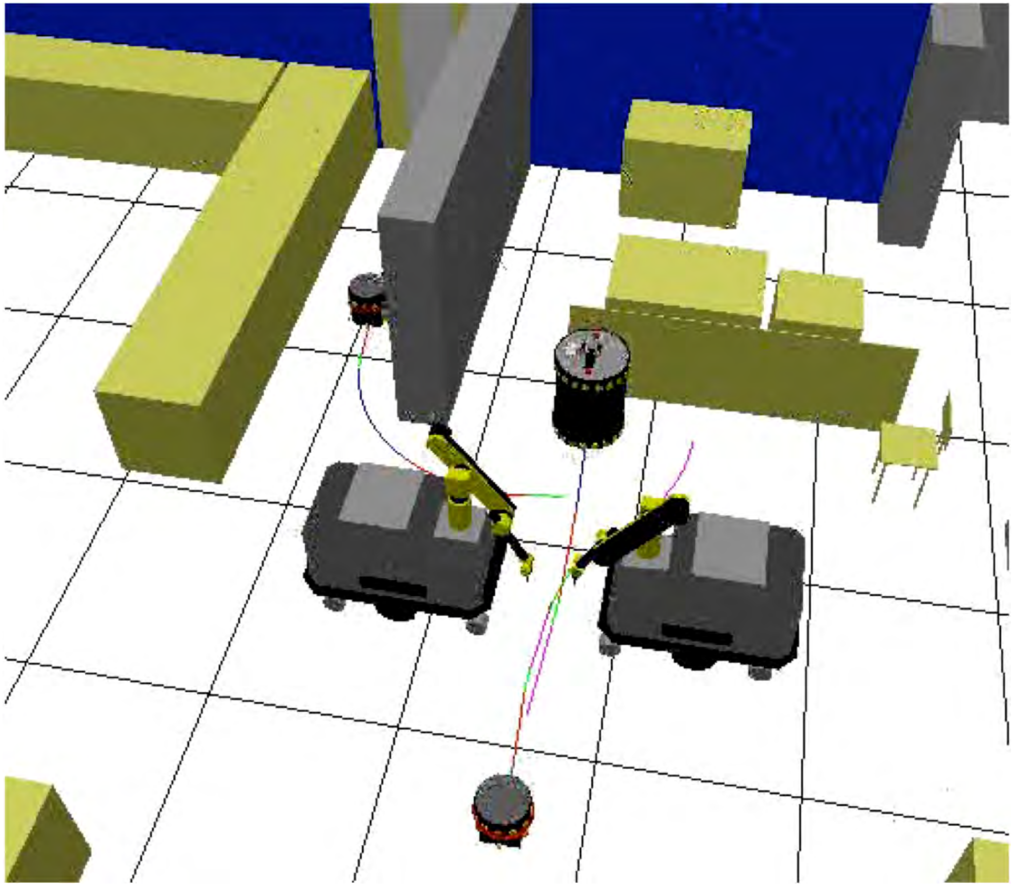


Thesis of F. Robert and Samer Qutub (1996)

Multi-robot hétérogènes

Paradigme
d'Insertion
de Plan Etendu

3D – Robots hétérogènes
Nombreux ddl - Priorités
(F. Gravot)



Variants

- Insert
- Insert_Modify
- Insert_Replan
- Priorities
- Discrete (Crossing paths)
- Continuous (Convoy mode)

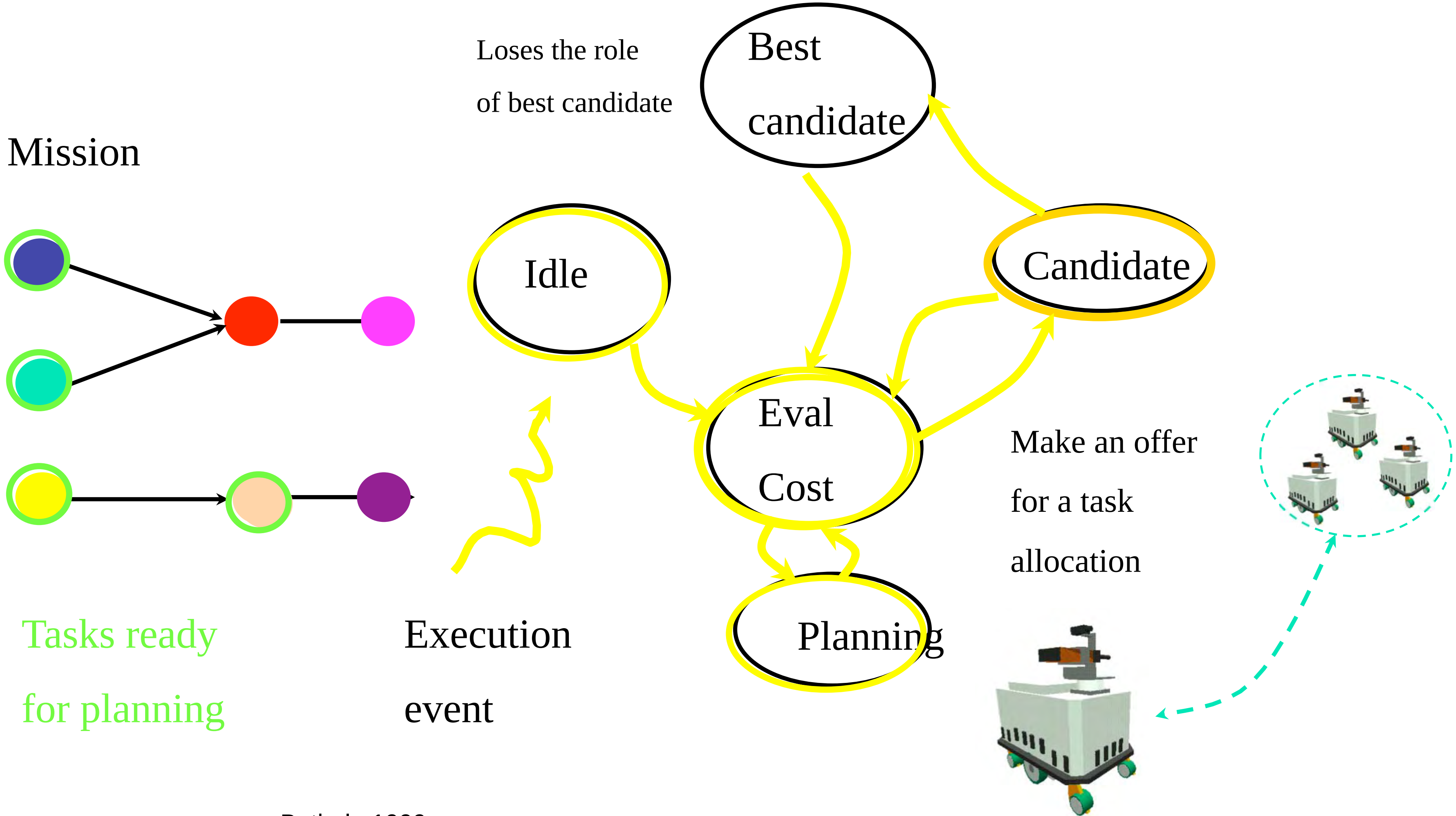
2 - Task allocation protocol (who)

- How to distribute a set of partially ordered task to a set of autonomous robots ?

Task allocation

- A mission is a set of partially ordered tasks, defined as set of goals to be achieved.
- Tasks should/are allocated to the robots based on their capabilities and on their execution context.
- Not necessarily distributed. However, task allocation is essentially based on proper or local information.
- → Negotiation process

Task Allocation process

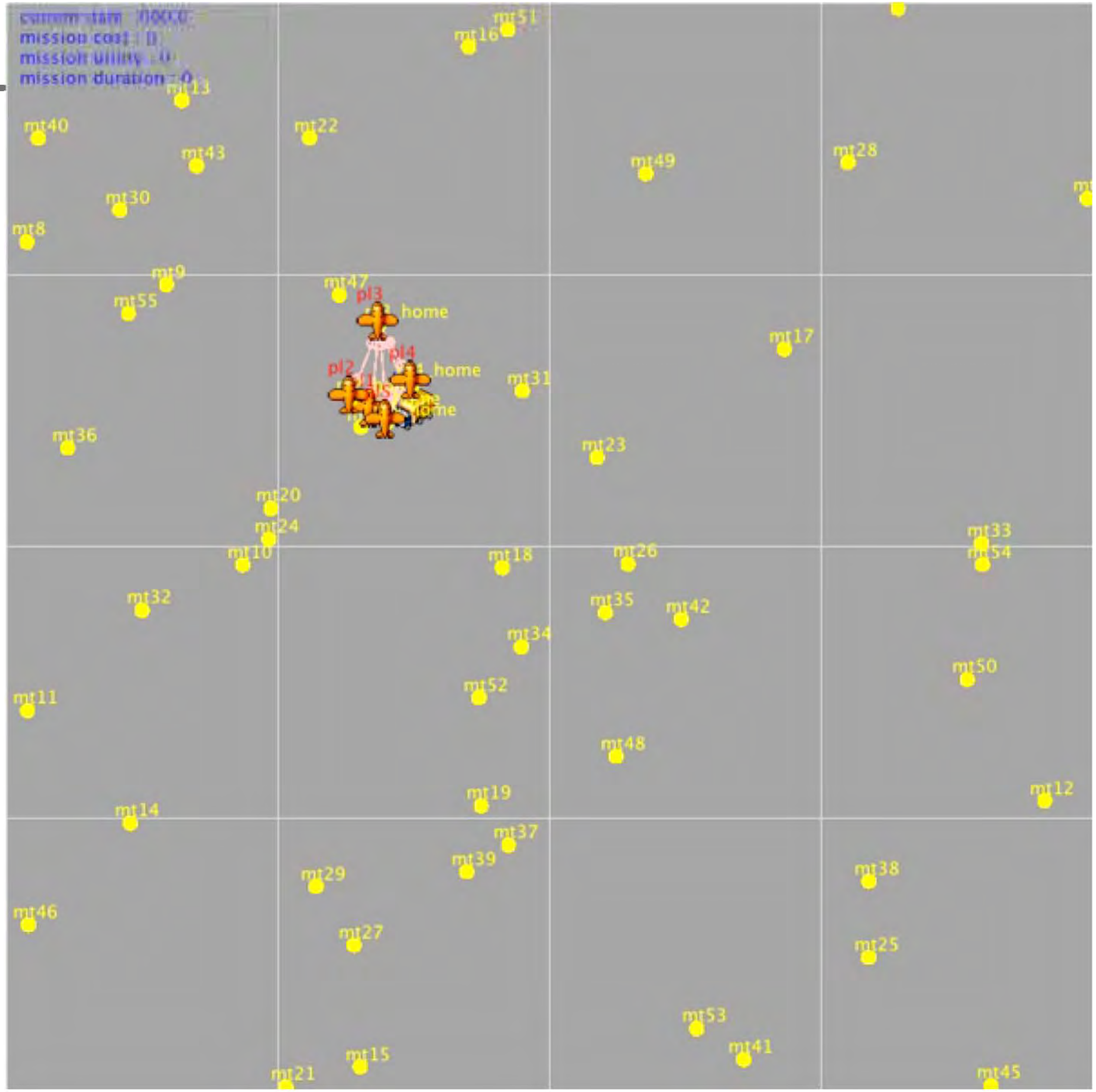


Bothelo 1999

Task Planning based Task allocation

- Tasks may be allocated (and re-allocated when necessary) incrementally through a negotiation process between robot candidates.
- This negotiation is combined with a task planning and cost estimation activity which allows each robot to decide its future actions taking into account:
  - its current context and task,
  - its own capacities
  - as well as the capacities of the other robots.

Distributed Incremental Task Allocation



[Lemaire-2004] Distributed task allocation based on auction

Set of places to visit with temporal and communication constraints

Incremental re-evaluation based on the robots « load »

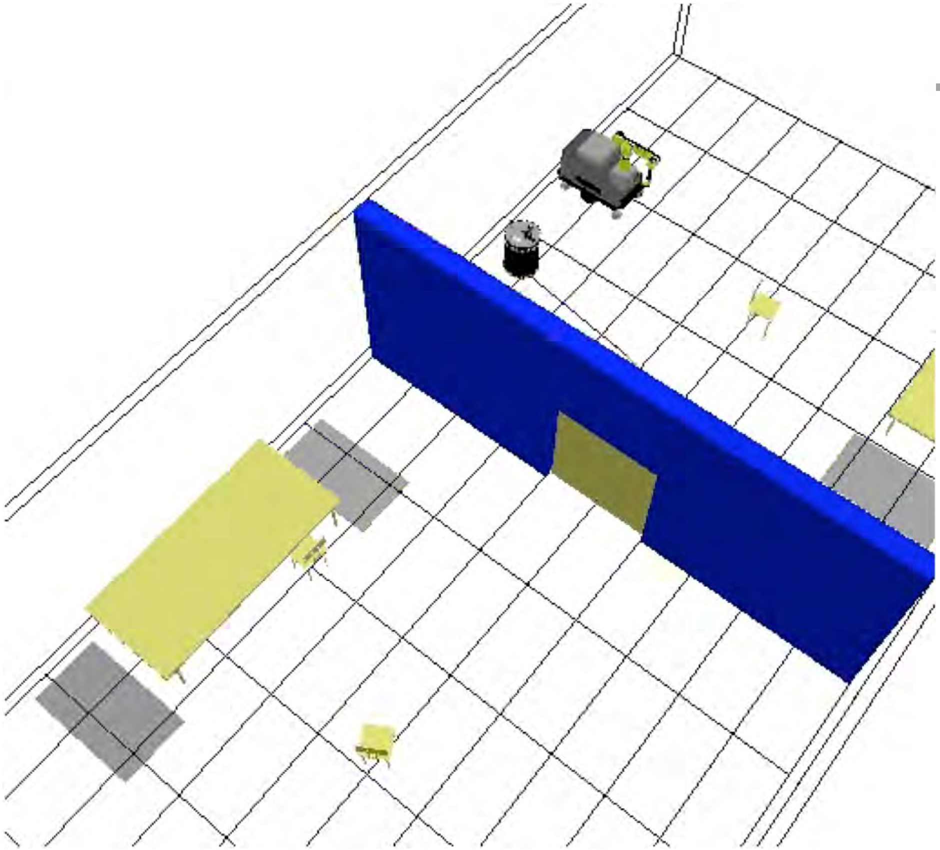
3 - Opportunistic behaviour enhancement (who, what and how)

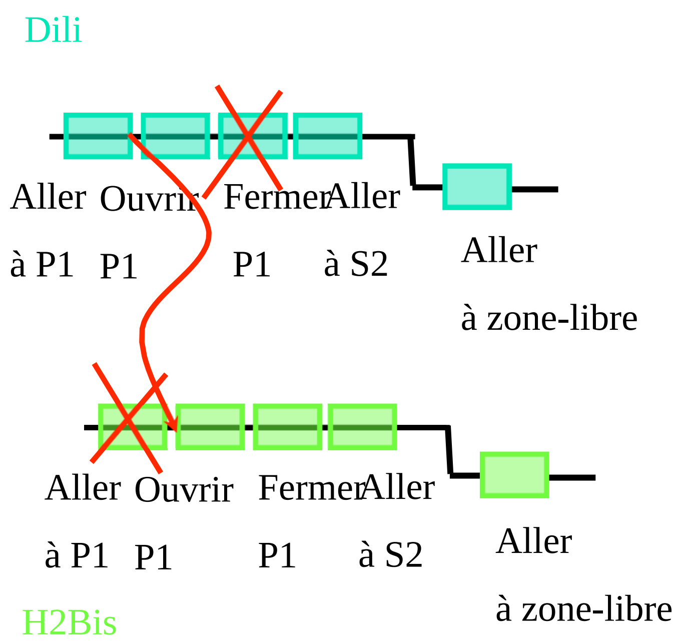
- In a multi-robot context
- Observing a set of incrementally refined plans and detecting potential sources of inefficiency

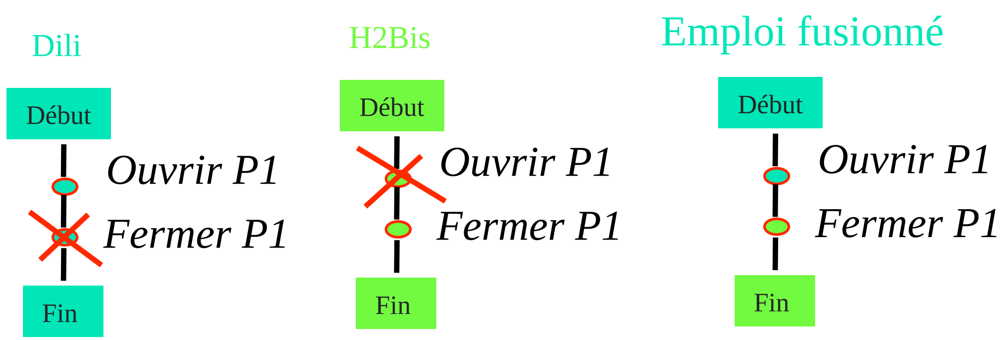
Task achievement in a multi-robot context

- The tasks cannot be directly « executed » but require further refinement
- Each robot synthesizes its own detailed plan.
- We identify two classes of problems related to the distributed nature of the system:
  1. coordination to avoid and/or solve conflicts and
  2. cooperation to enhance the efficiency of the system.

Utilisation Coopérative d ’une étape







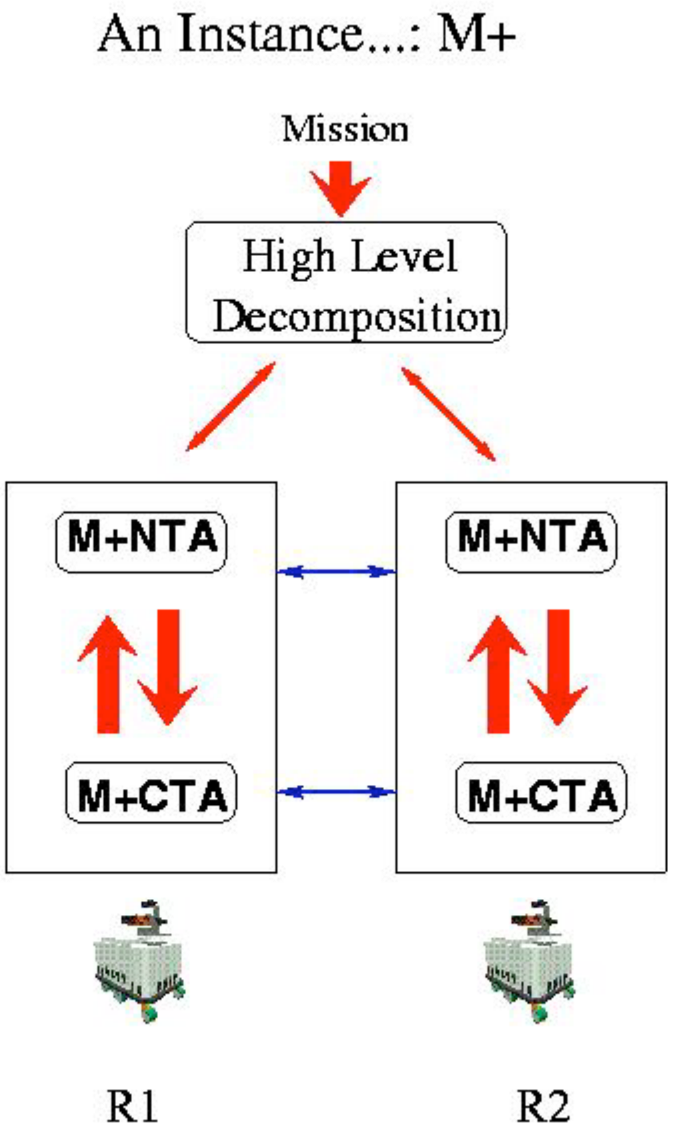
Botelho, DARS 2000

4 - An architecture for multi-robot cooperation

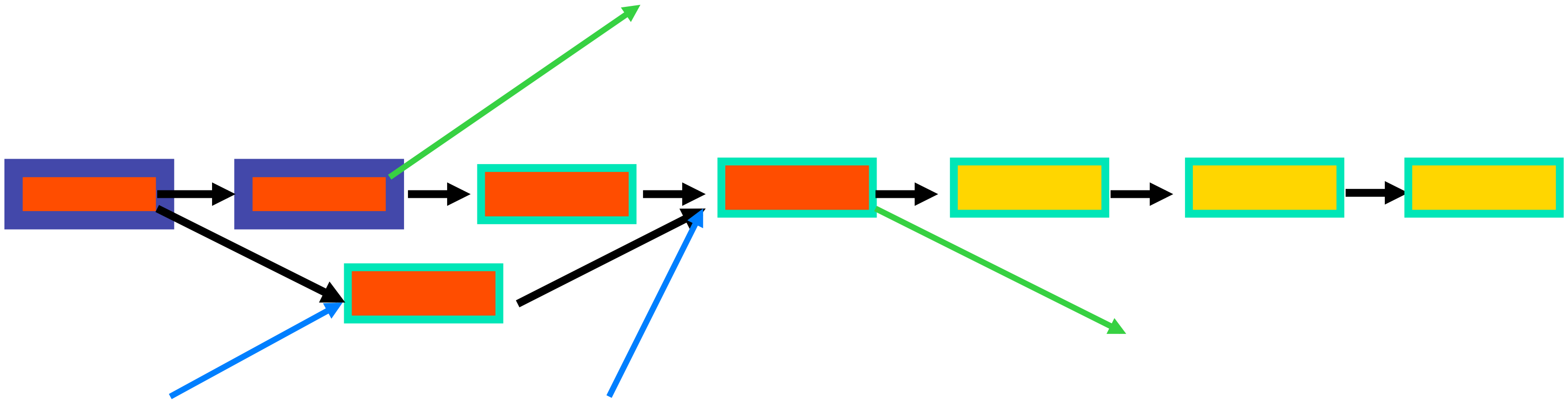
Multi-robot control cooperation

- What decisional levels ?
- What models, protocols and algorithms at each level ?
- What consequences on the robots and on the tasks to perform ?

An architecture for multi-robot cooperation



Evolution of a robot plan



Coordinated plan (partially freezed)

Actions not yet validated in the multi-robot context

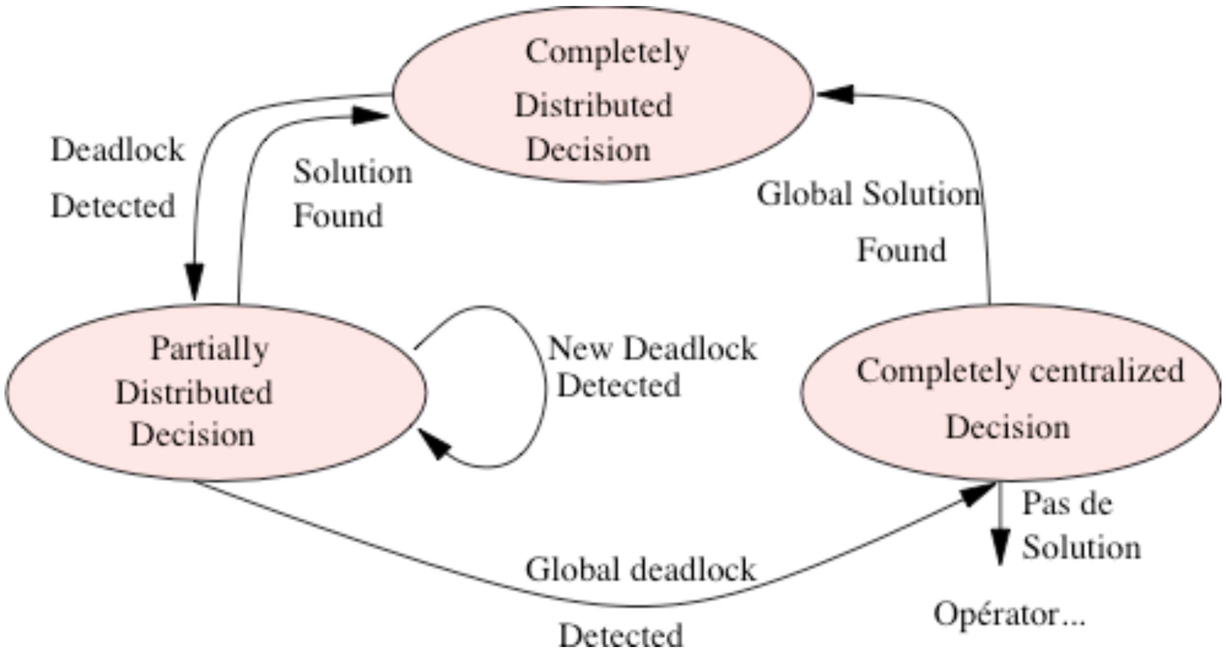
Signals to other robots

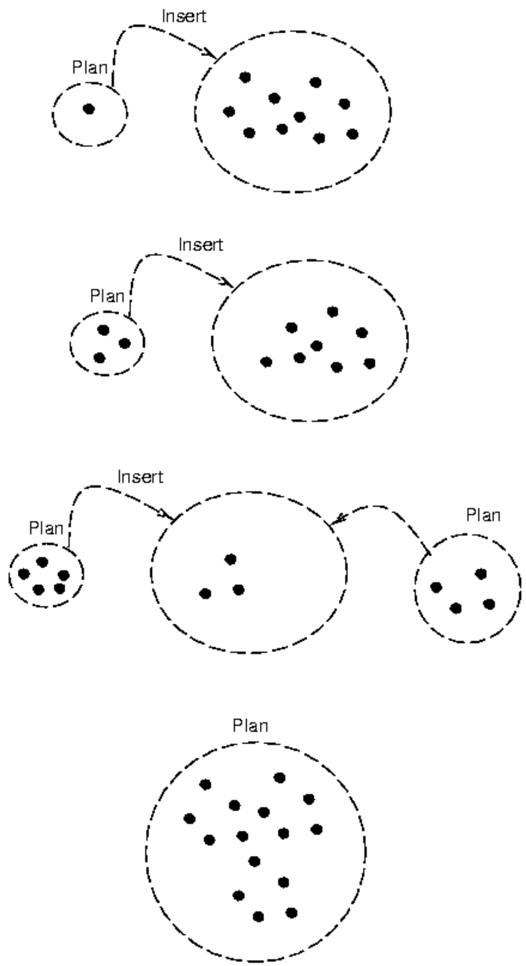
Signals from other robots

Operations on Plans

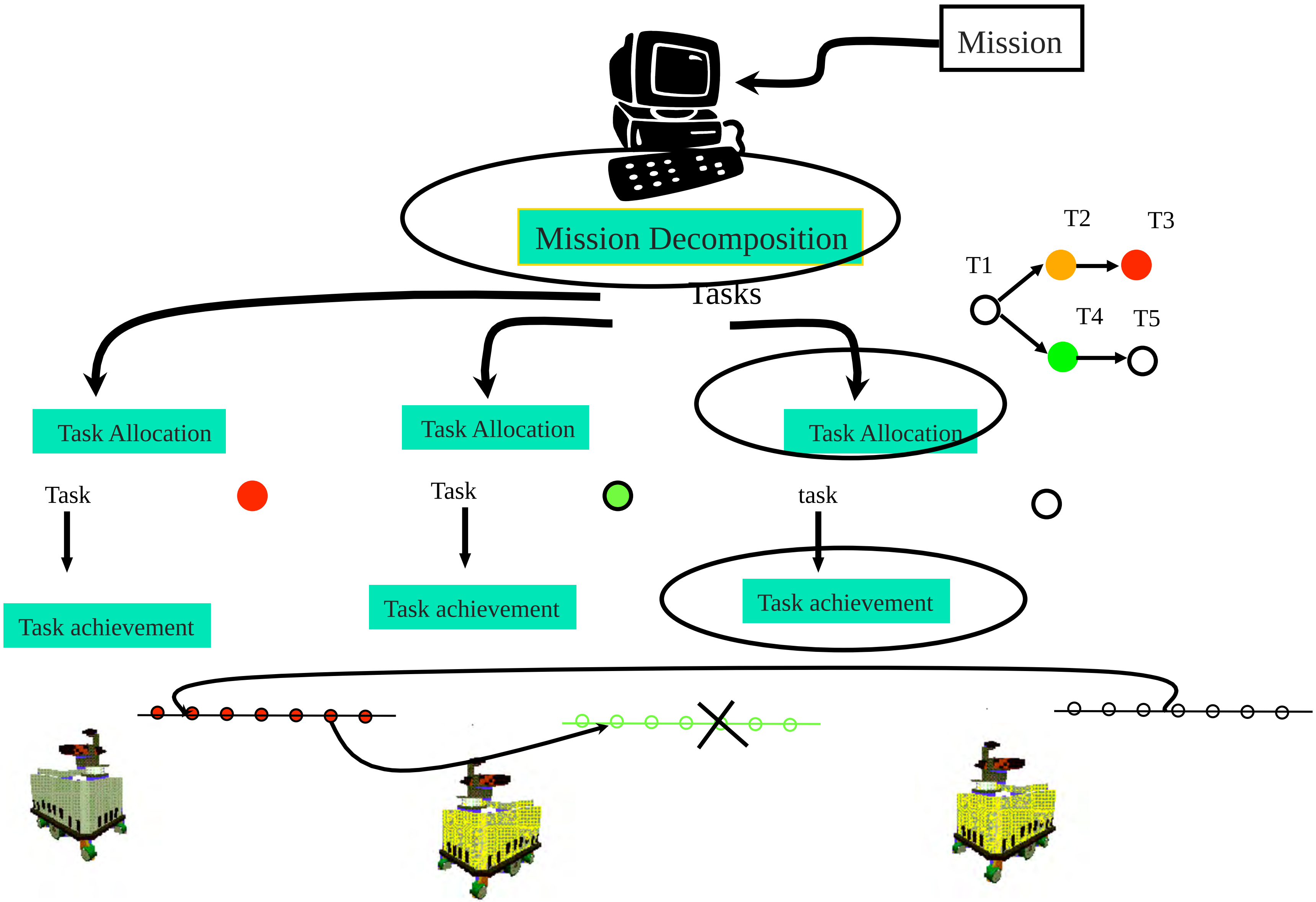
- Updating the plan when an event occurs: start actions, signal events to other robots: $CP_i^{k+1} = \mathrm{UPDATE}(e, CP_i^k)$
- Incremental planning for Robot i: $IP_i^{k+1} = \mathrm{PLAN}(CP_i^k, G_i^{k+1})$
- Collecting Coordinated Plans $GP_i^k = \bigcup_{j \neq i} CP_j^k$
- Plan Merging Operation $CP_i^{k+1} = \mathrm{PMO}(GP_i^k, IP_i^{k+1})$

Adaptative move from completely distributed to centralized decision

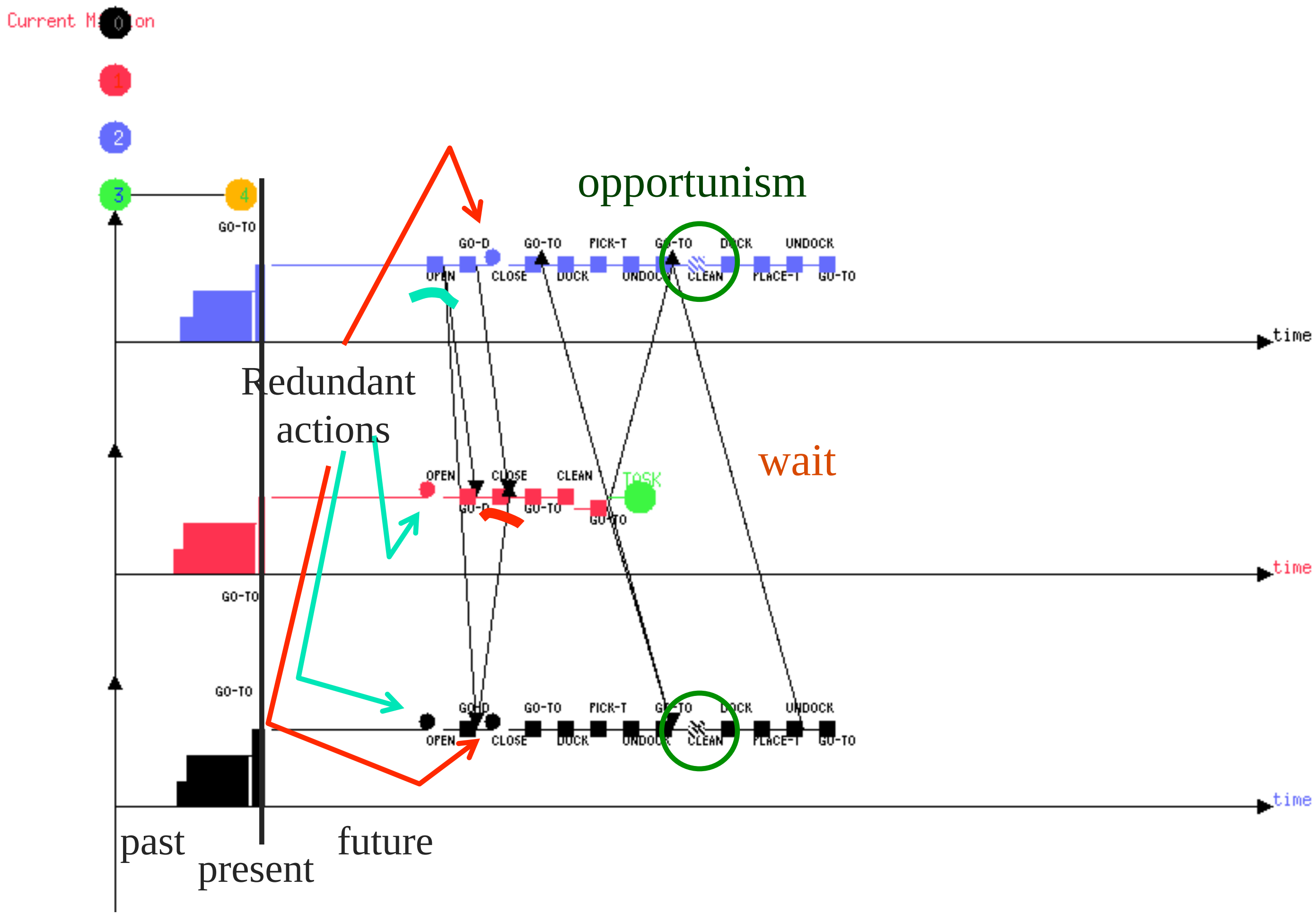


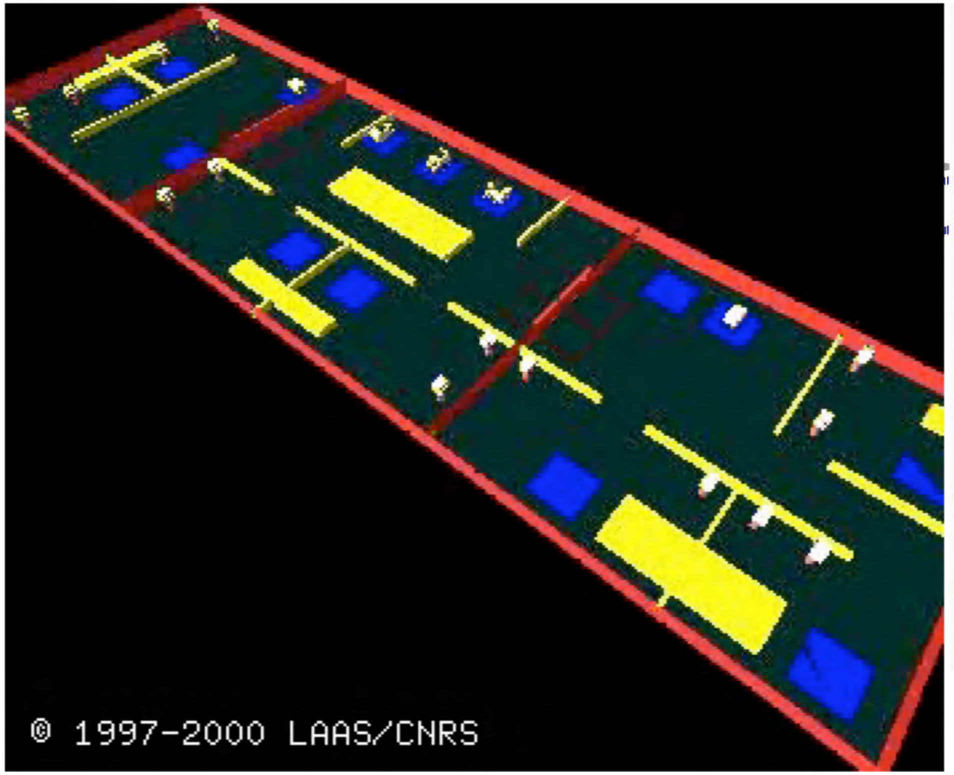


An example

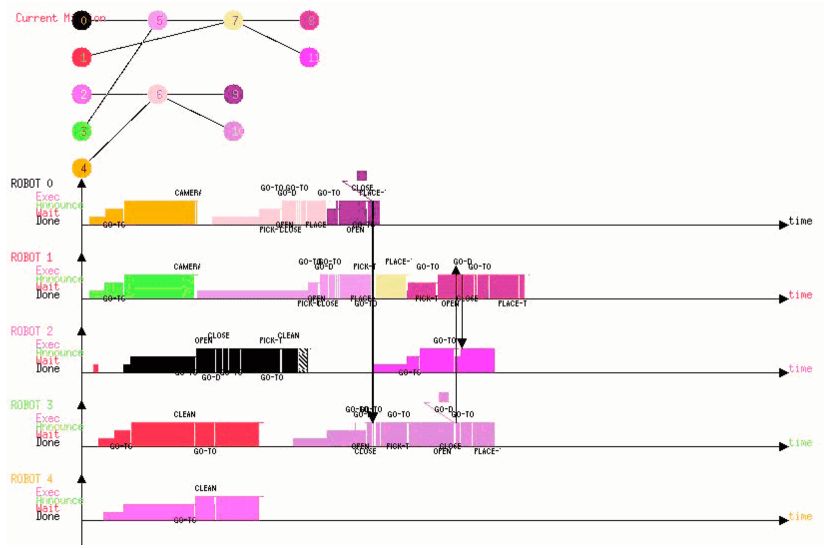

Mission
Mission Decomposition
Tasks
T1
T2
T3
T4
T5
Task Allocation
Task Allocation
Task Allocation
Task
Task
task
Task achievement
Task achievement
Task achievement

Distributed Decisional activity display



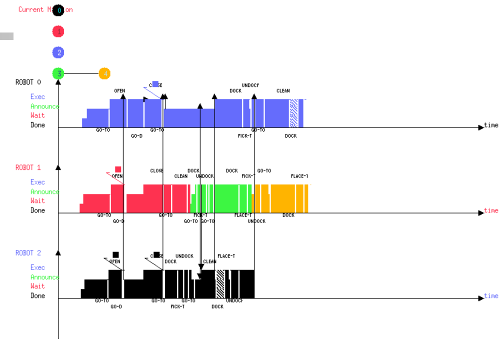

© 1997-2000 LAAS/CNRS

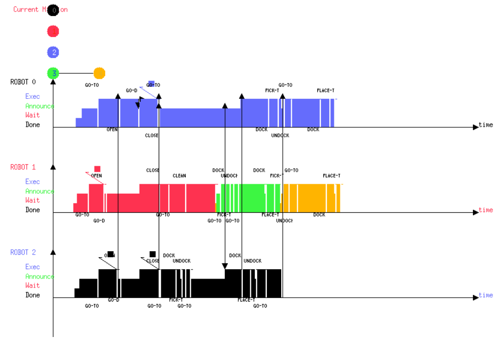

Current Mission
ROBOT 0
ROBOT 1
ROBOT 2
ROBOT 3
ROBOT 4
Exec
Announce
Wait
Done
time


Current Mission
ROBOT 0
ROBOT 1
ROBOT 2
ROBOT 3
ROBOT 4
Exec
Announce
Wait
Done
CAMERA
CLEAN
GO-TO
time

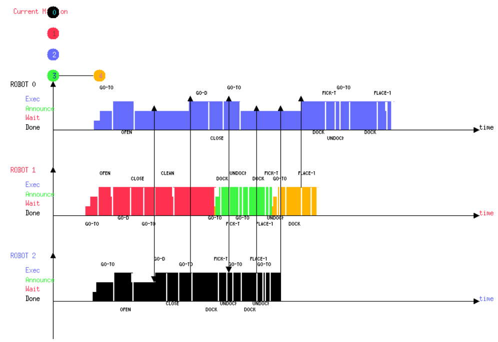
Other examples

- R0 and R2 are slower. They decide not to help R1 to clean ROOM1

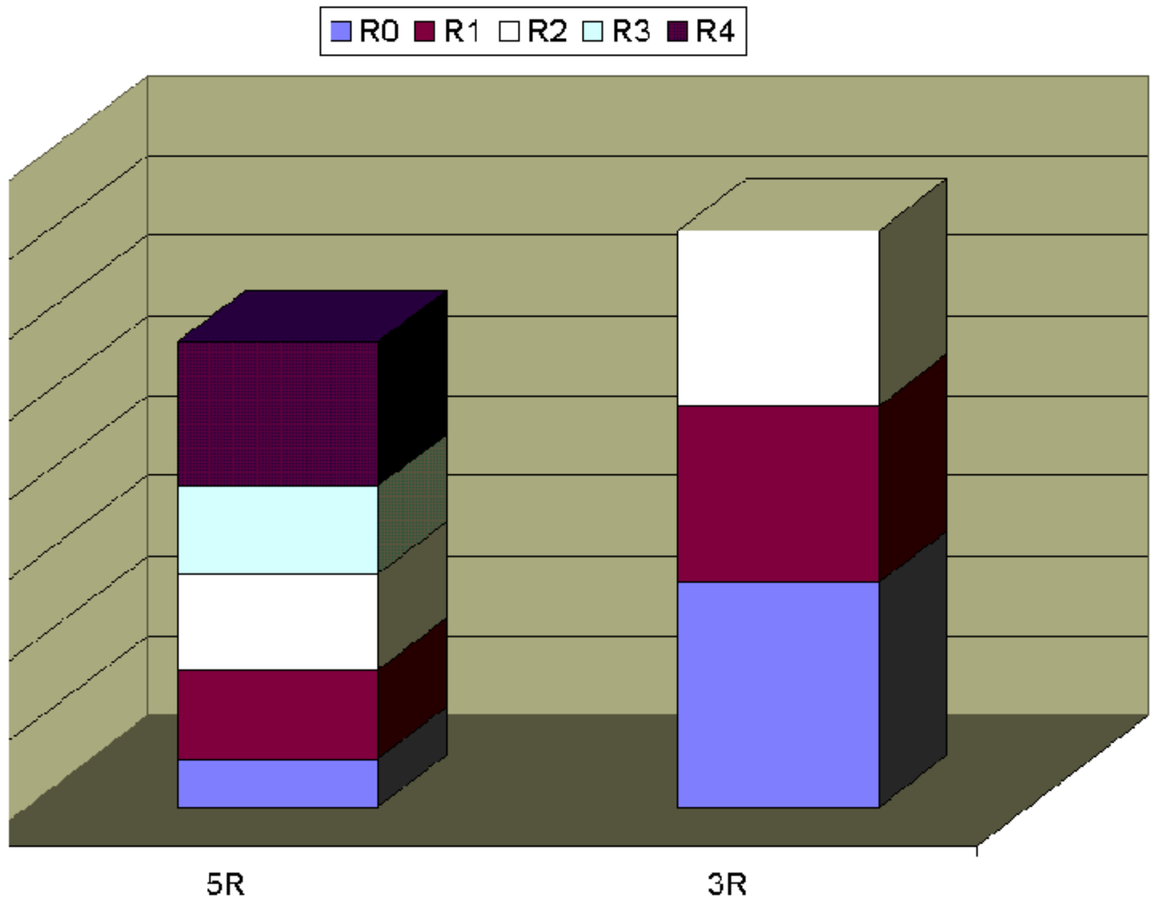




- The cooperative mechanisms are inhibited. The robots only COORDINATE.



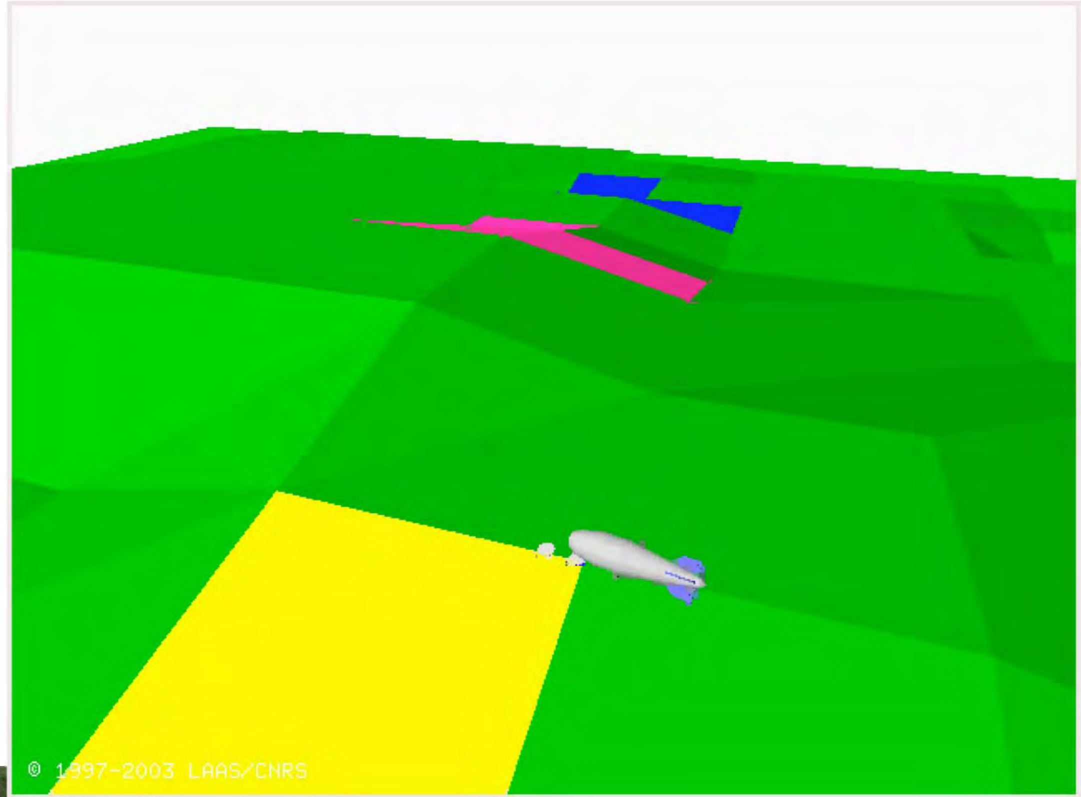
Workload for each robot



COMETS: Real time coordination and control of multiple heterogeneous Unmanned Aerial Vehicles (UAV)

Environment surveillance:

- Forest fire alarm detection
- Alarm confirmation / fire monitoring
- Mapping



The COMETS fleet


Marvin (TUB)


Karma (LAAS)

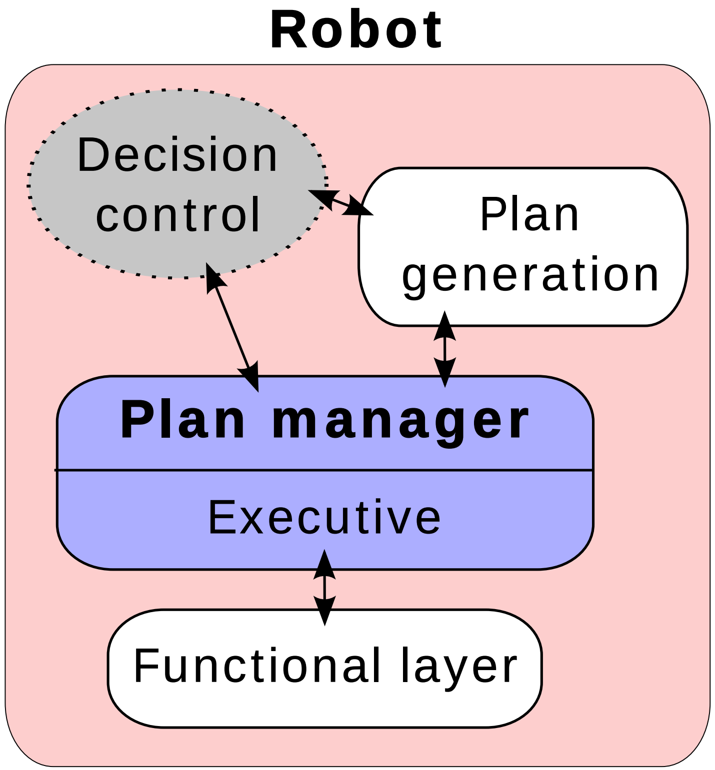

Heliv (Helivision)

(Work of Gancet, Lacroix)

5 - Cooperation through assistance

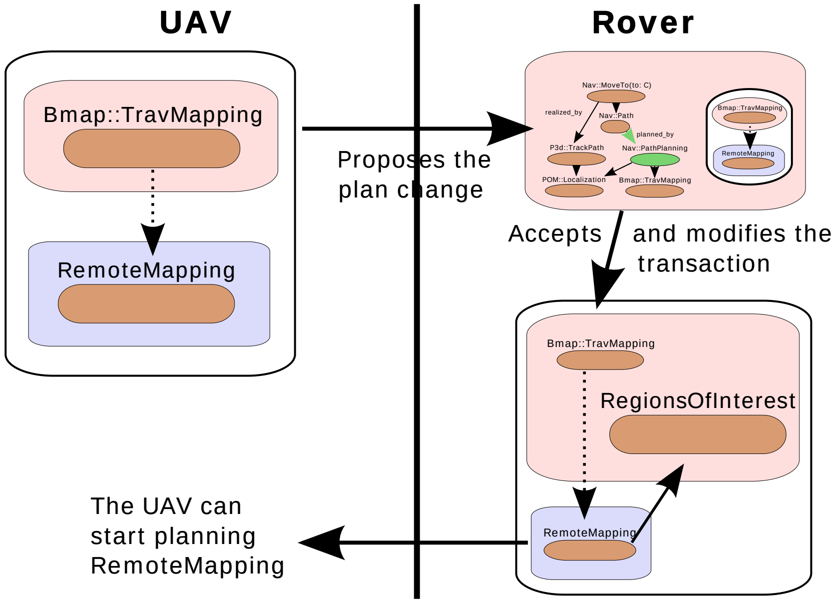
A plan management component

- **a plan model**
  - generic enough to represent planner results
  - expressive enough for intricate execution & incremental plan refinement
- **a plan management component**
  - execution and adaptation of plans



Thesis of Sylvain Joyeux (2006)

A UAV for traversability mapping of a terrestrial robot

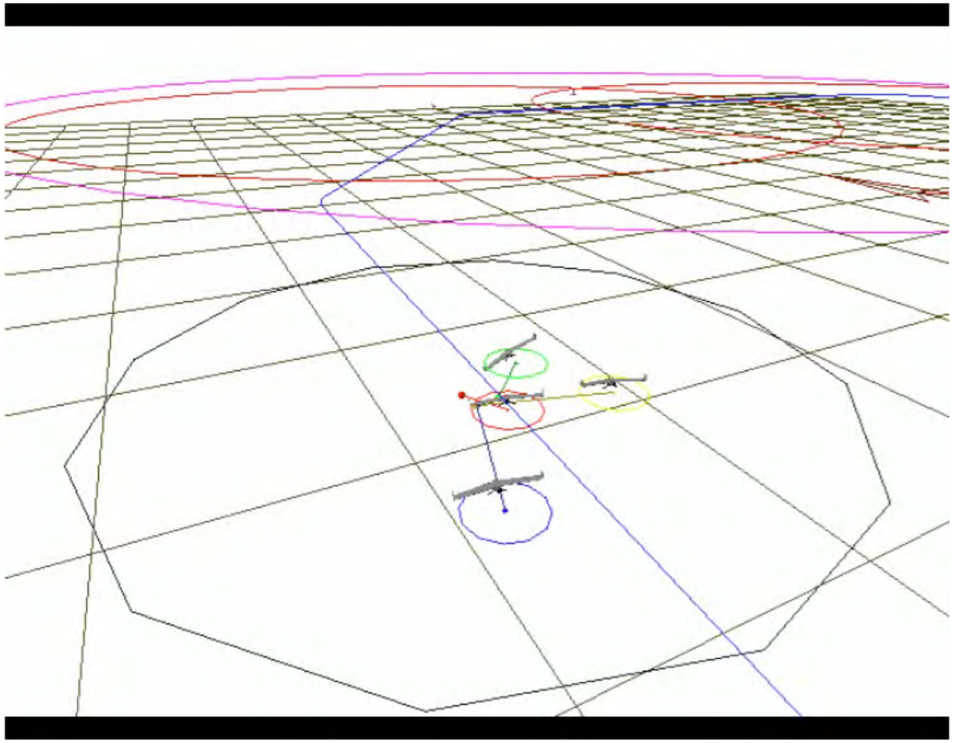


Collaborative task achievement involving close interaction

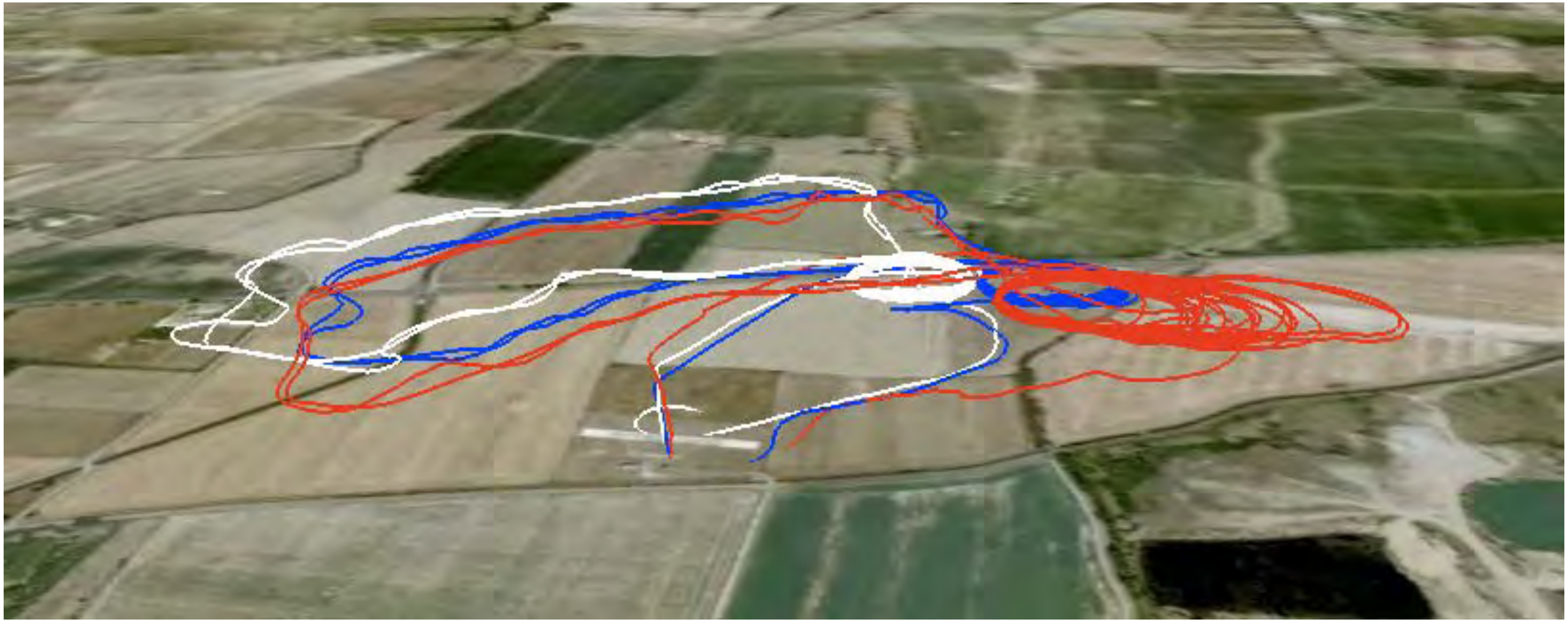
6 - Adaptive Formation of UAVs in a hostile environment (who and how)

Task “internal” to the team:

- Choose an adequate configuration (position and role) based on the current context (threats, path) and to the UAVs abilities
- Plan and coordinate spatial reconfiguration of the formation



Thesis of Gautier Hattenberger 2007

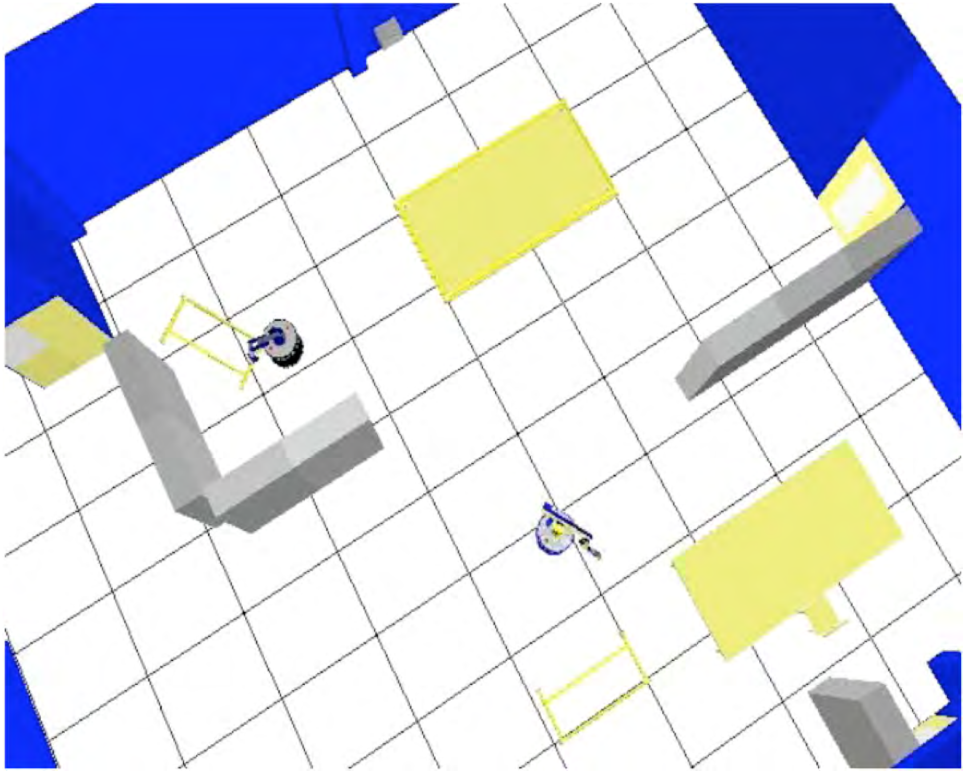


7 - Asymov: A planner for Cooperative assembly

Plan:

- "transit" and "transfer" motions
- Individual (synchronized) or cooperative motion
- Choose graps and placements (how and where)

- Based on a general formulation of the manipulation
- Formal link between geometric and symbolic reasoning



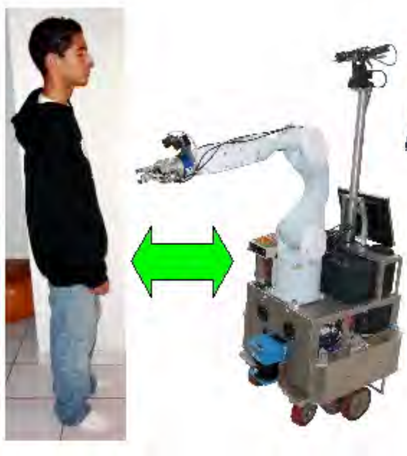
The IKEA problem

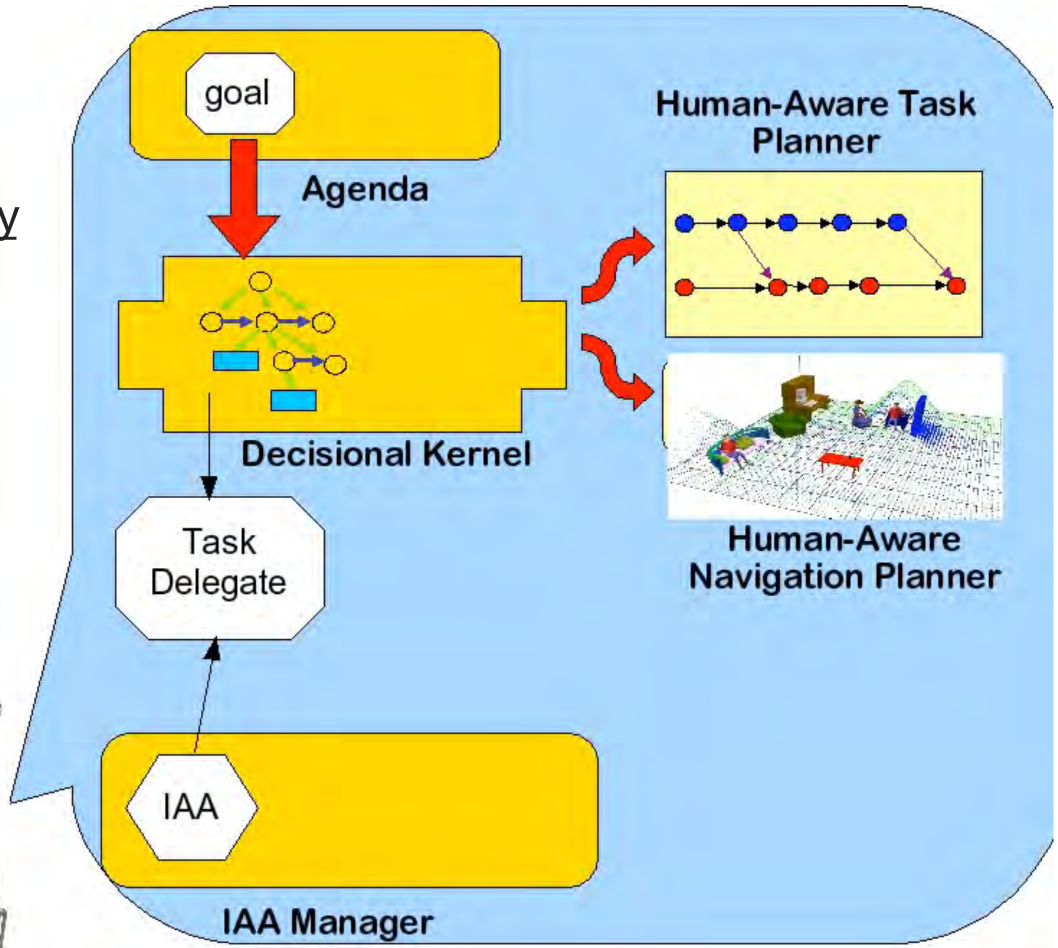
(Thesis of Gravot and Cambon – based on work of Simeon, Laumond, Cortes)

8 - A task-oriented architecture for an interactive robot

- **Task-Oriented**
- How to perform a task, in presence or in interaction with humans, <u>in the best possible way</u>
  - Efficiency, Safety, Acceptability, Intentionality

- **Planning and On-Line Deliberation**
  - **Anticipation, Reasoning**





the IAA (InterAction Agent) represents the human state, abilities and preferences.

HRI Robot Decisional Abilities

- Planners and Interaction Schemes that will allow the robot:
  - to elaborate plans
  - and to perform its tasks
- While taking into account explicitly the constraints imposed by:
  - the presence of humans,
  - their needs and preferences.

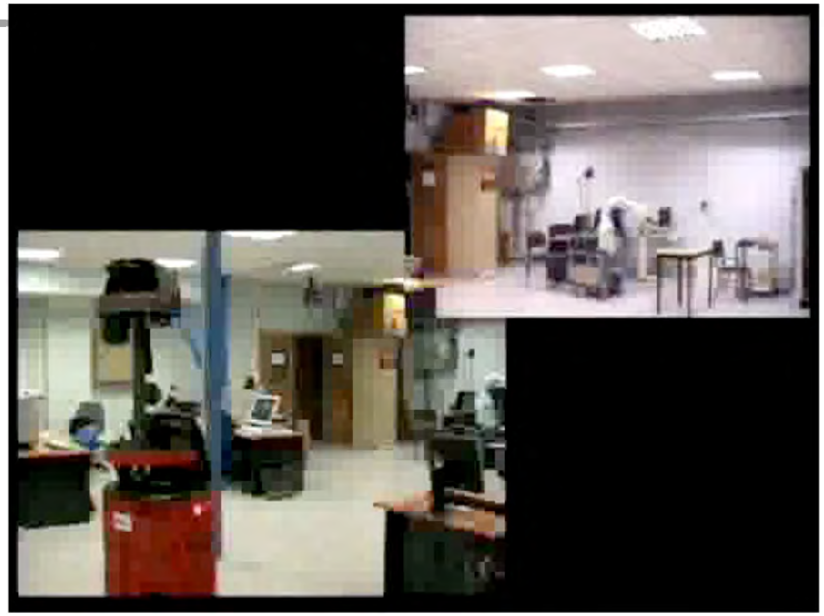
Supervision of H/R task achievement

Robot Searches for interaction when left alone

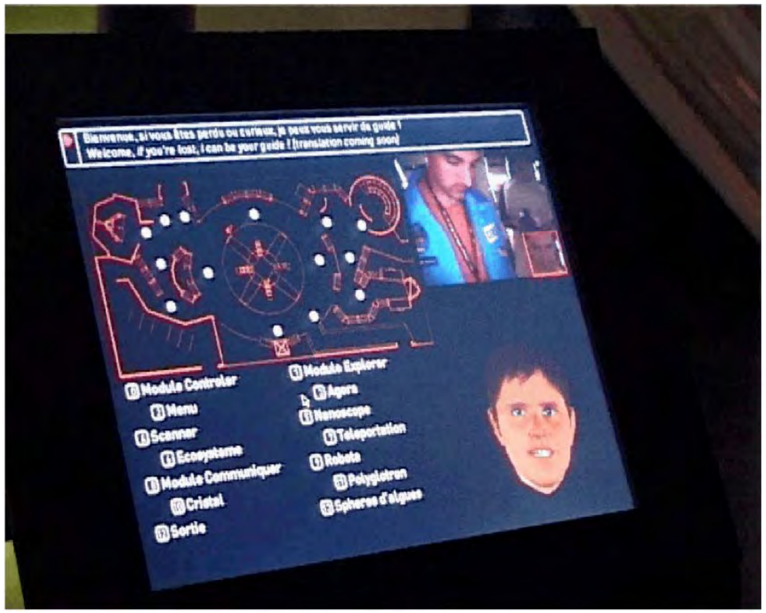
Establishes a common task

Programming a H/R task involving several perception and interaction modalities

Abandons mission if guided person stops following



Rackham at « Cité de l'Espace »:



Integrative approach for a robot that acts in interaction with humans

- Work on Collaborative / Interactive task achievement
  - based on a study of human-robot interaction
  - inspired from Joint activity / Teamwork
  - concretized as a set of robot decisional abilities

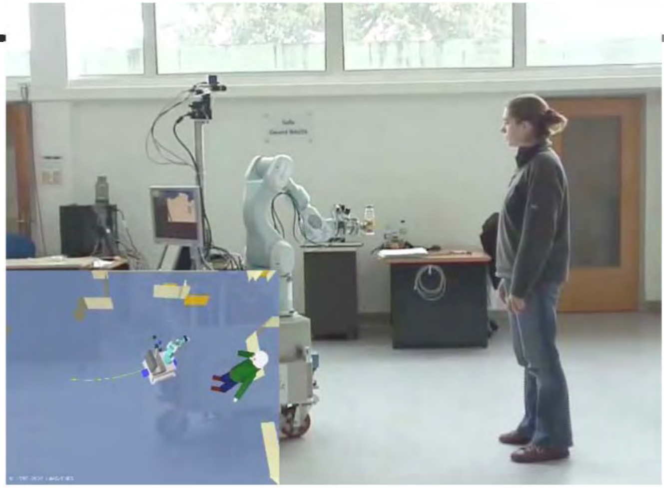
- is progressively producing a coherent basis for **Joint Human-Robot Activity**

SHARY
Supervisor for Human Aware Robot « Ynteraction »

- Continuous planning: Context dependent task refinement
- Joint tasks (joint activity / teamwork)
  - Joint Goal
  - Task refinement: plans / recipes
- Maintains common ground through a set of communication acts that support the interactive task achievement:
  - deciding who speaks when
  - establishing facts that must be agreed upon ..
- Monitors human performance and commitment

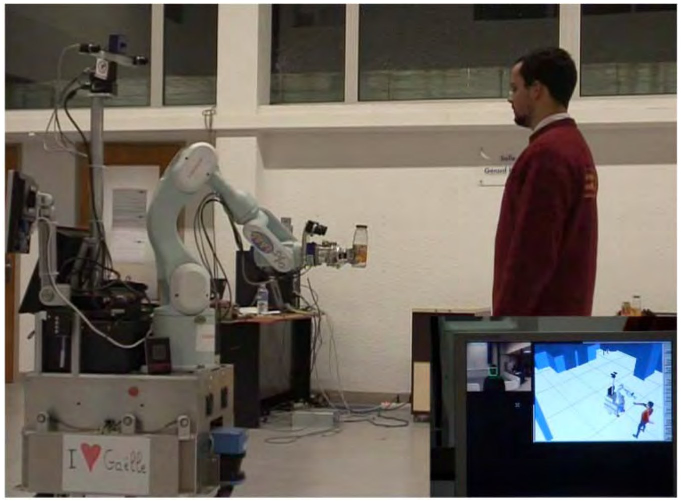
- Thesis of Aurelie Clodic (2007)

Handing an object to a person



tvb

Where is Thierry ?

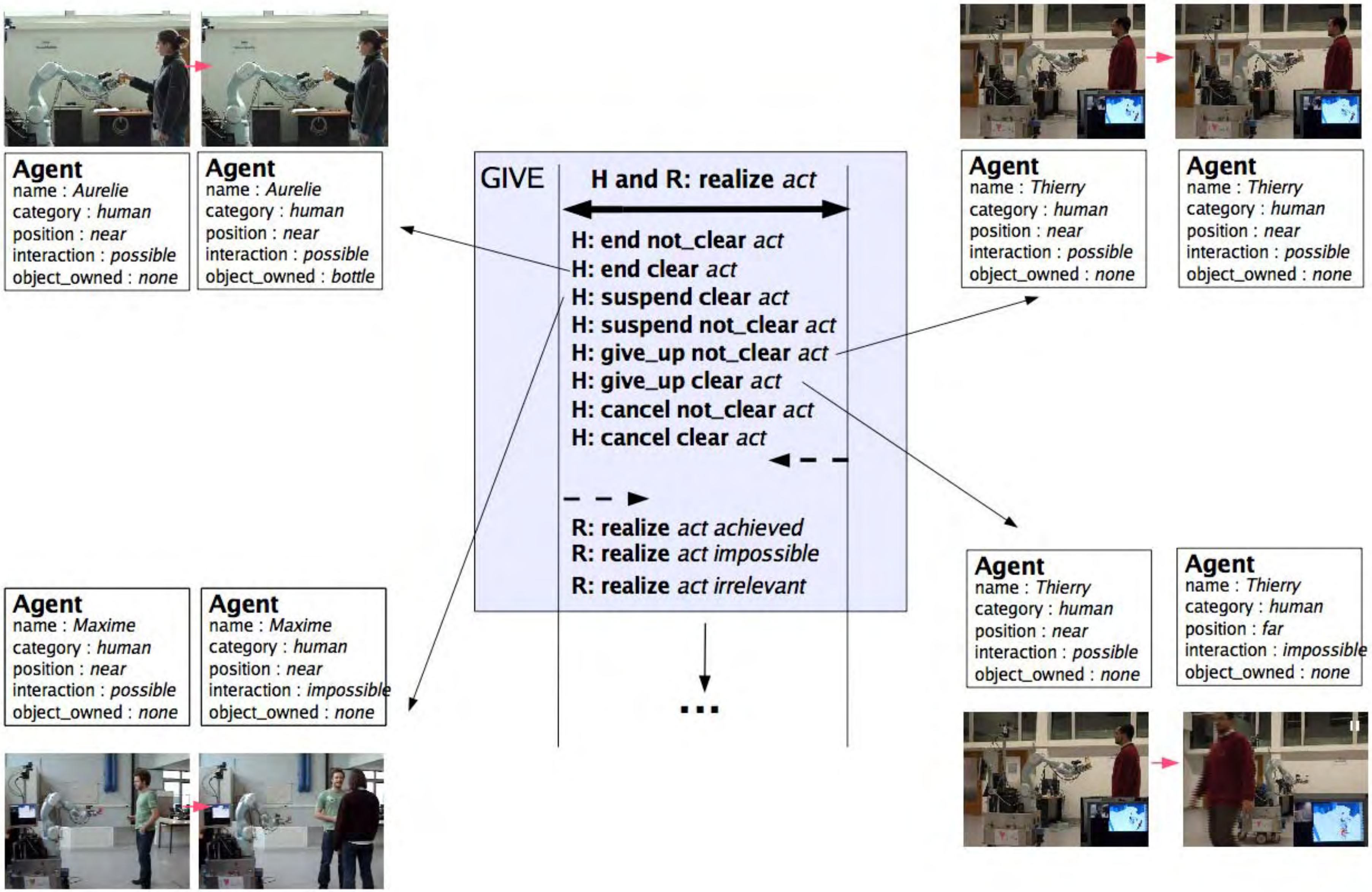


Thierry does not take the bottle

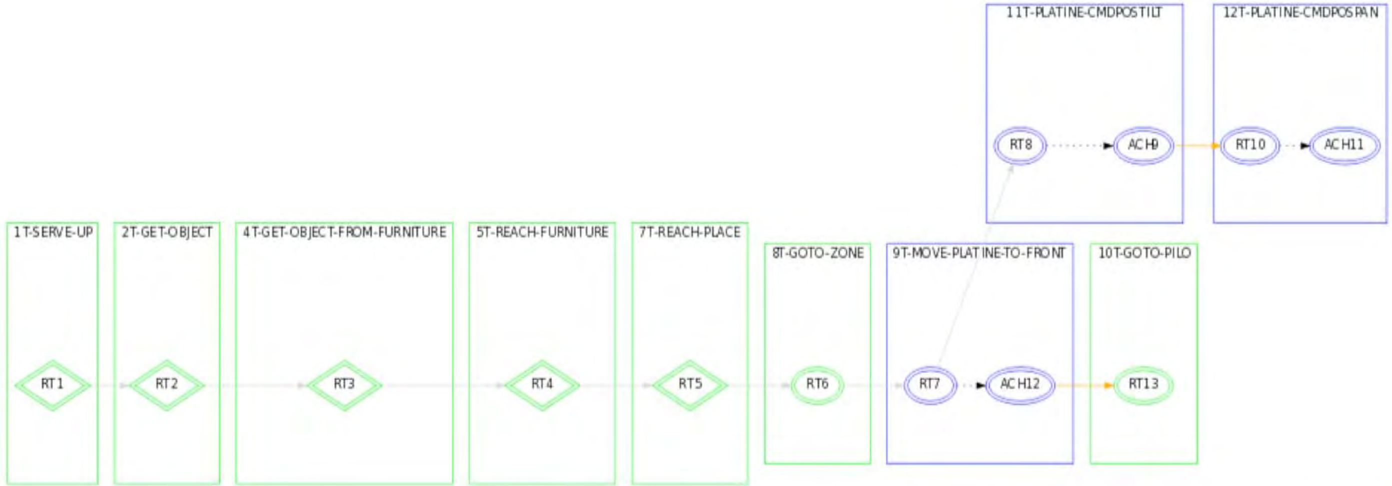
« Disturbed » attention

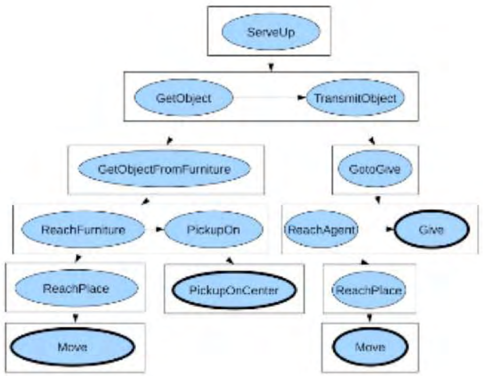
Handing a bottle to a person

Predictability, Common Ground, Responsiveness



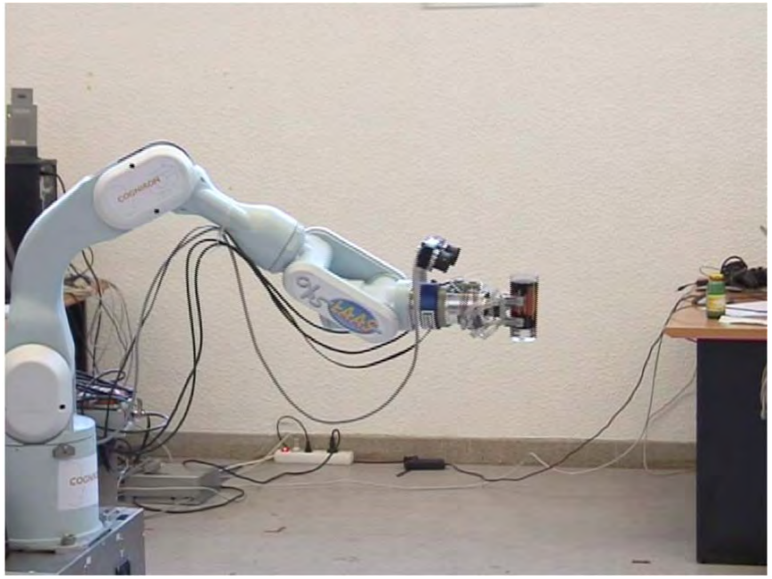
Serve a drink
High-level internal structure





Collaborative task achievement

When to release the object ?



Building a « good » plan

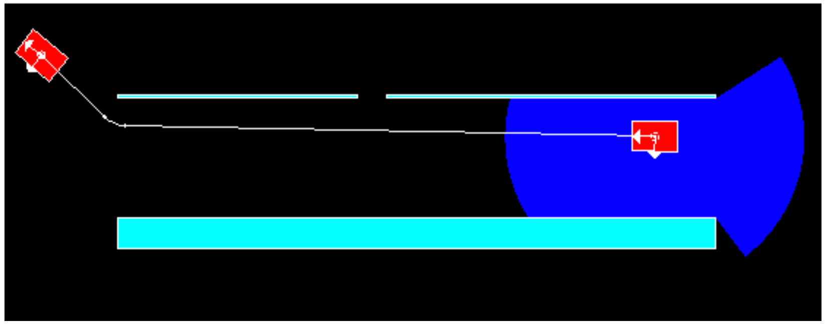
- Managing Joint task achievement
- Legibility of robot actions and intentions (intentionality)
- Acceptability of robot actions
- Compliance with "conventions"
- Coherent attitudes and behaviours

Constraints on robot plans

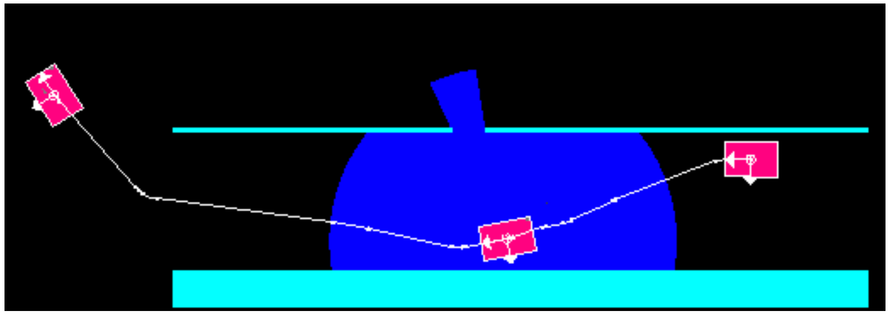
Consequences

- On robot goals management
- On planning:
  - high-level (symbolic)
  - and “geometric” level
- On task achievement
  - monitoring and adapting to human commitment
- On interplay between Dialog and Decision

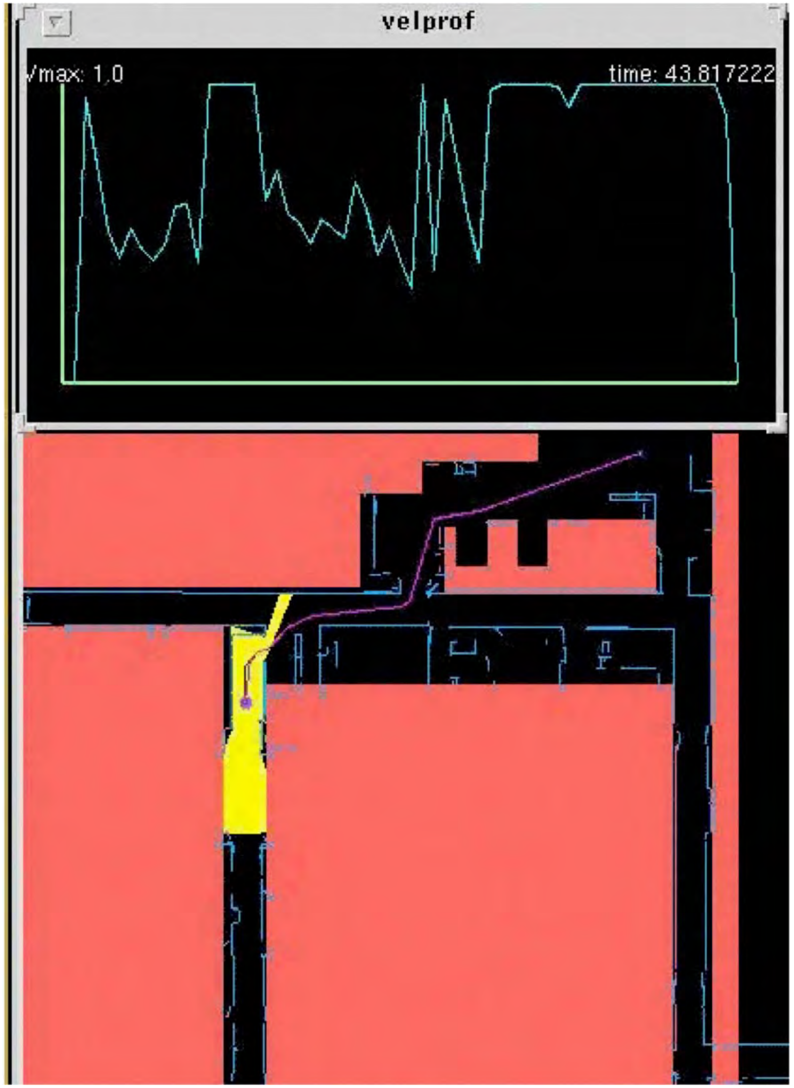
9 - A safe (but efficient) path taking into account sensor scope and robot and (unknown) mobile obstacles (humans) dynamics



A typical path computed by a motion planner



Path as obtained after minimization of trajectory time

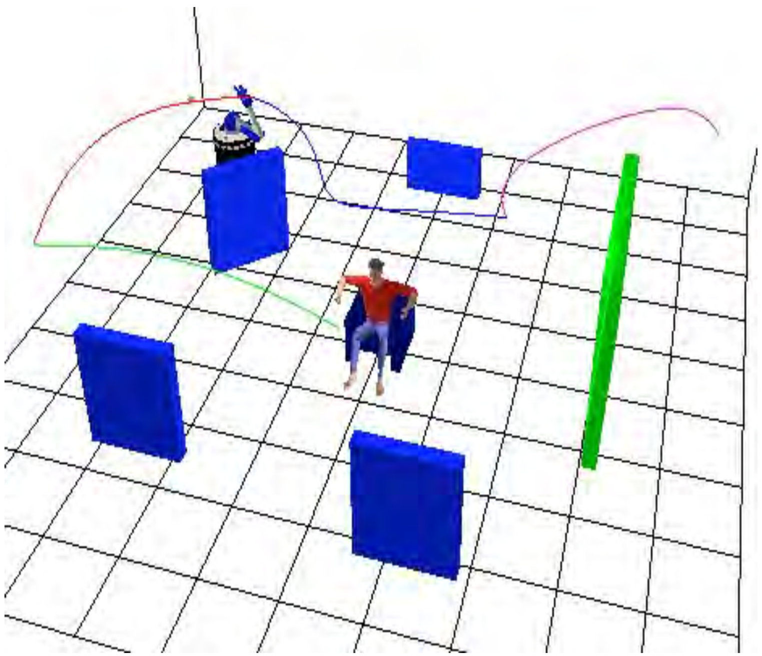


Work of M. Krishna

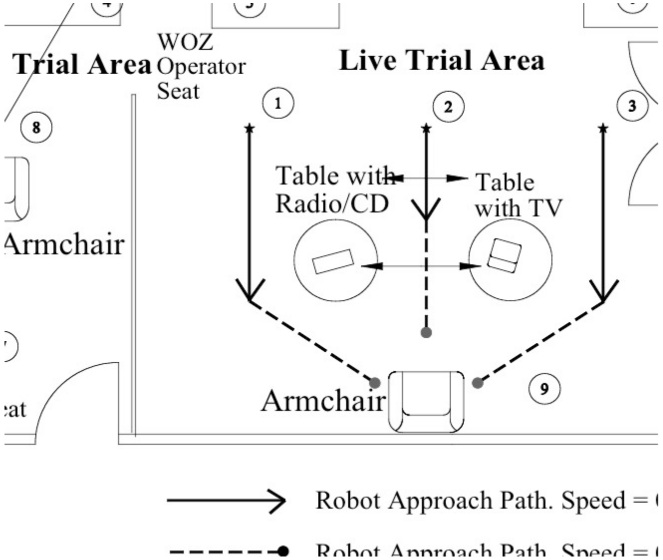
10 - Navigation in presence of humans

- Classical Motion Planning methods do not take into account specifically the presence of humans: obstacle free paths, coordination for non-collision or dead-lock avoidance

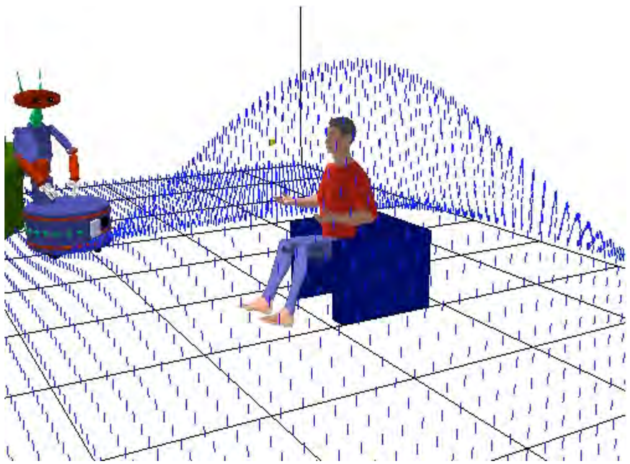
- Need to generate robot motion that is acceptable, legible and compliant with social rules

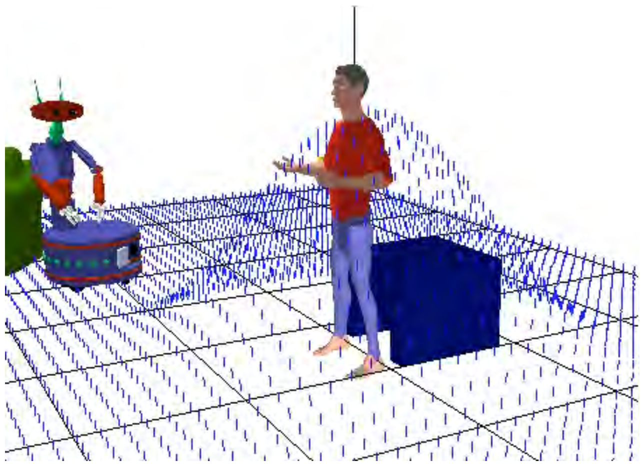


10 - Navigation in presence of humans

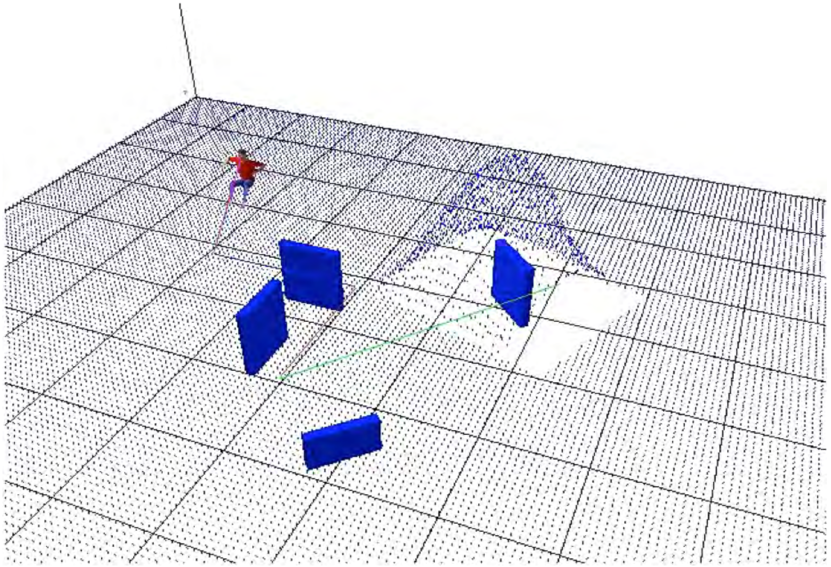


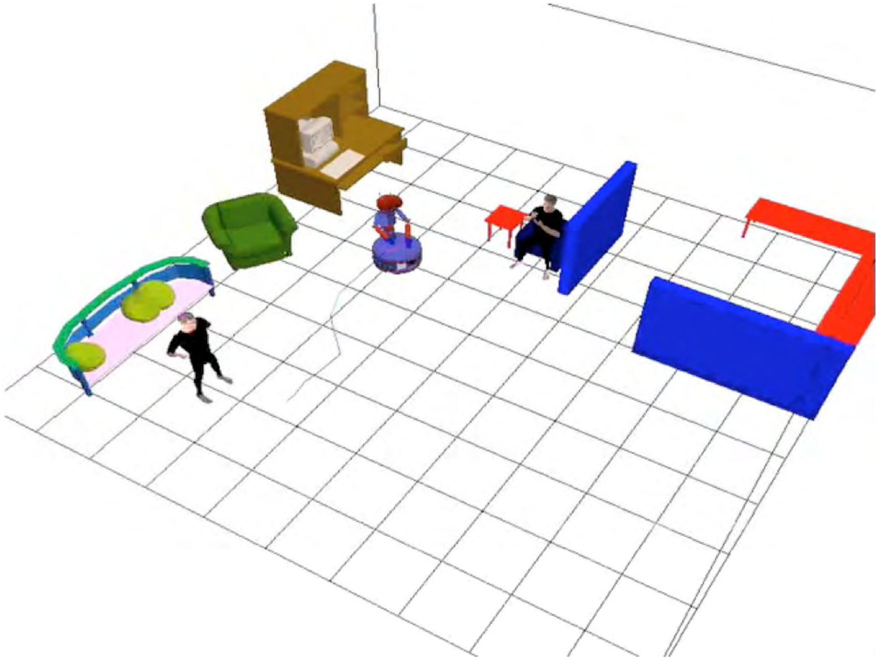
User trials performed at Univesity of Hertfordshire





Human-friendly navigation

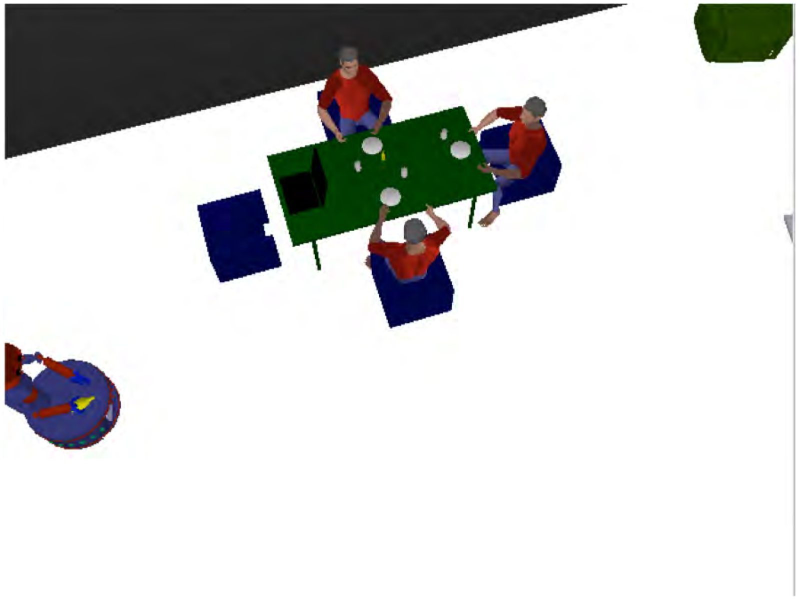




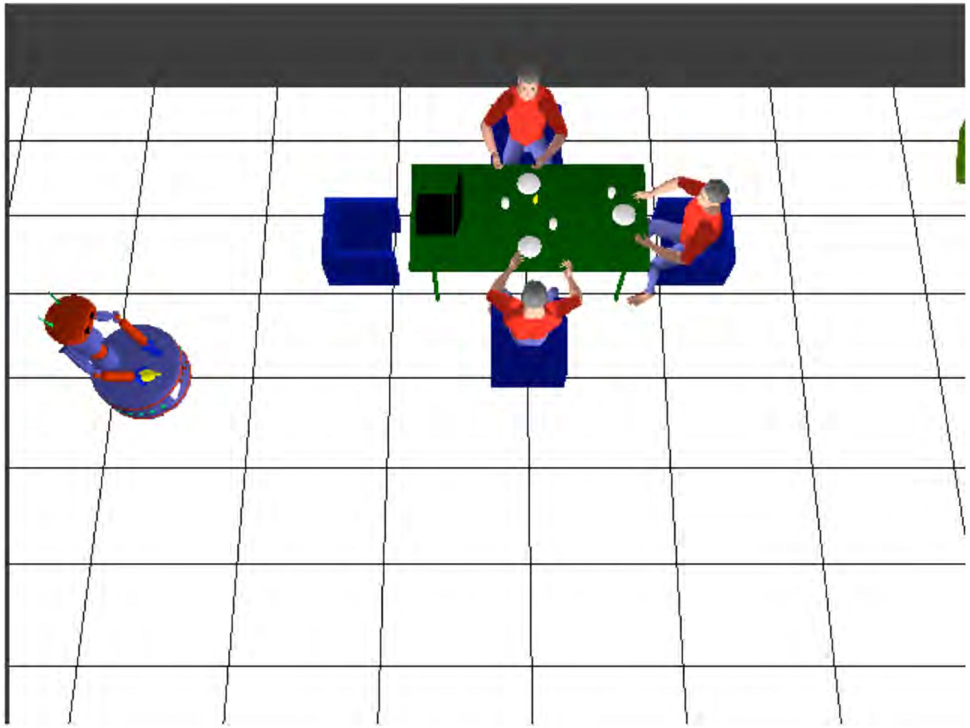
Real-time cost evaluation:
distance, posture, visibility

Incremental path adaptation

Serving Dinner



Approaching too much



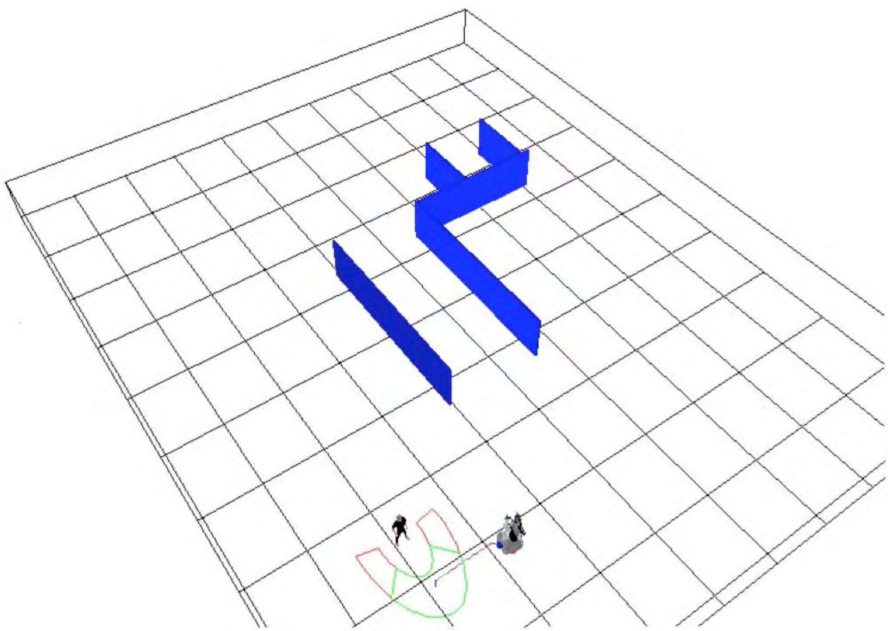
Better behavior

Crossing

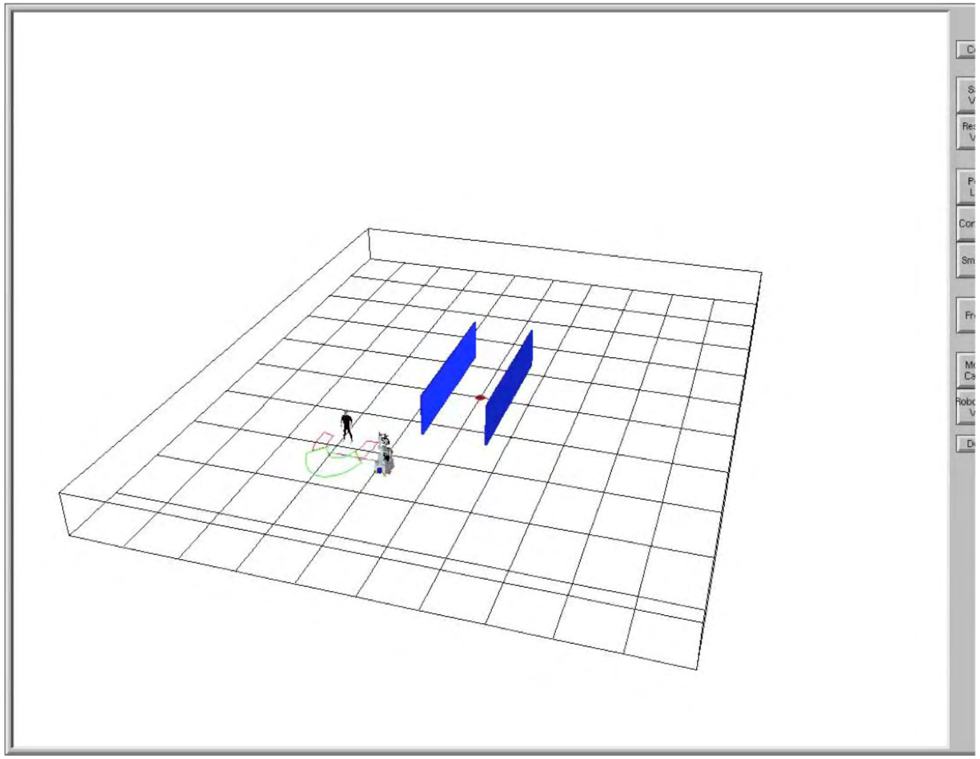
Avoiding to loom too close

Teamwork-based guiding behaviour

Human follows “freely” .. robot complies

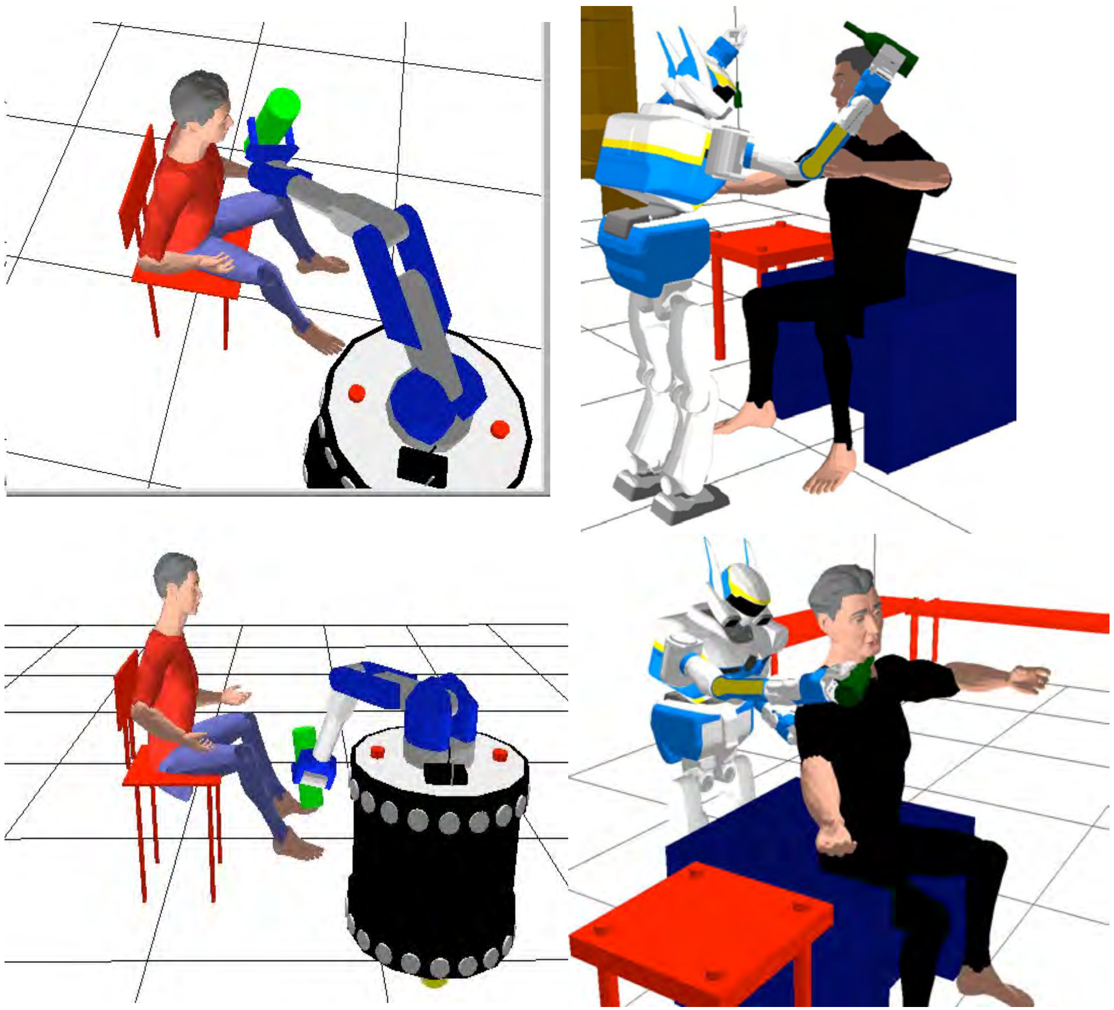


Human “breaks” the “task” from time to time

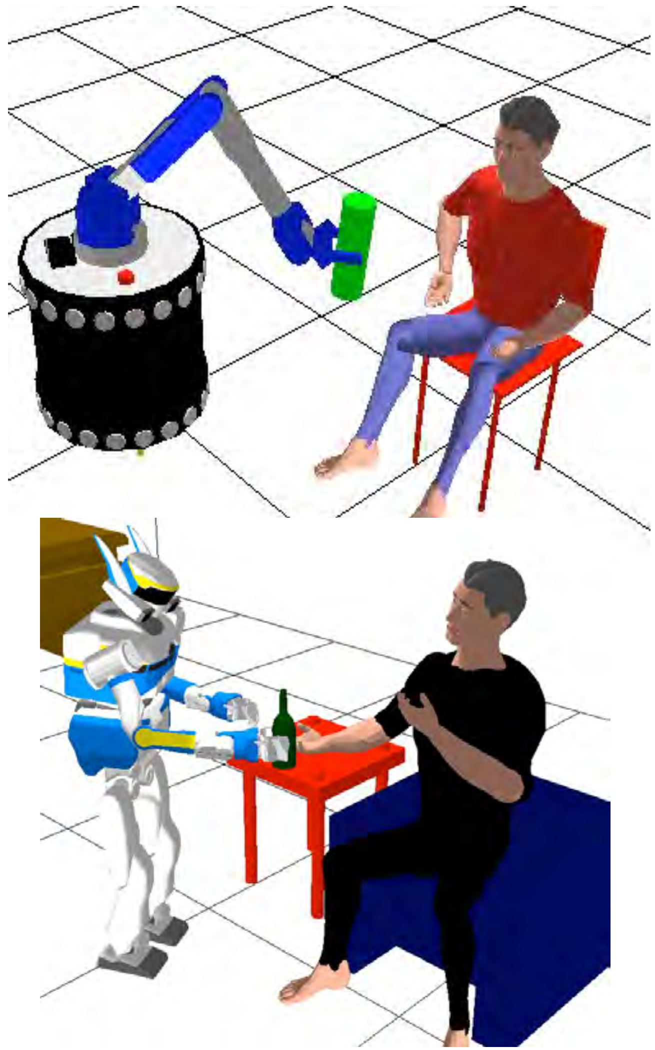


(Work of Amit Pandey)

11 - How to hand an object to a person?

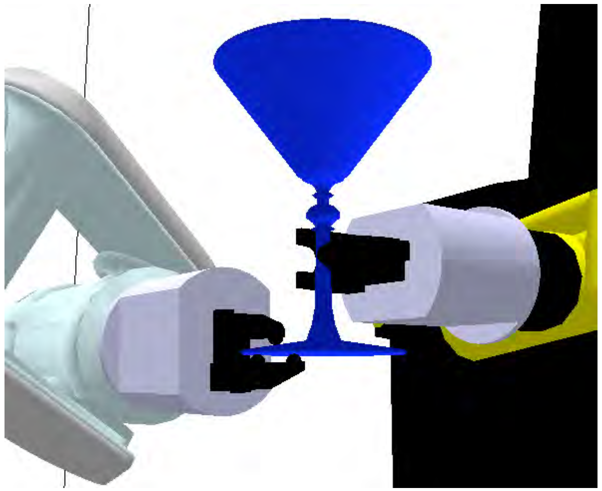


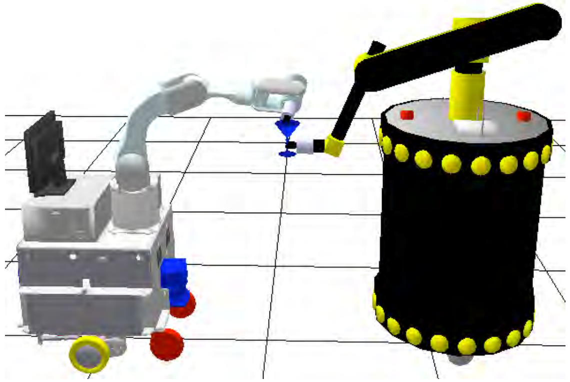
Undesirable Placements /Motions

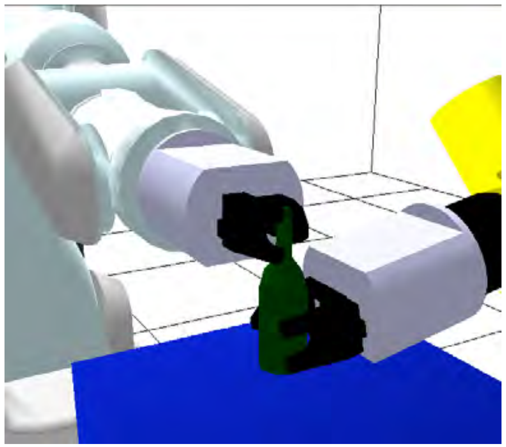


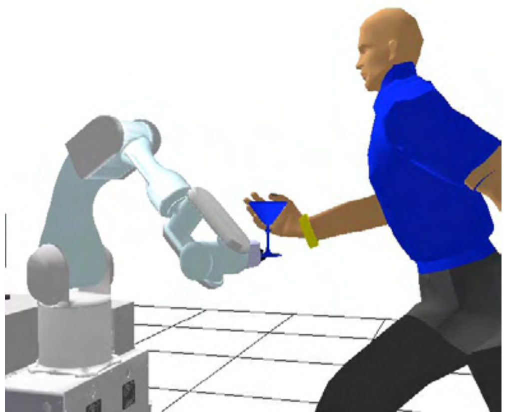
“acceptable” placements

« Double-Grasp » for handing objects



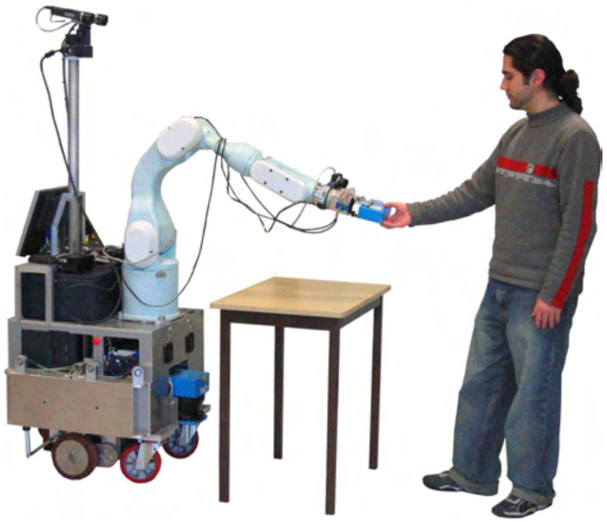


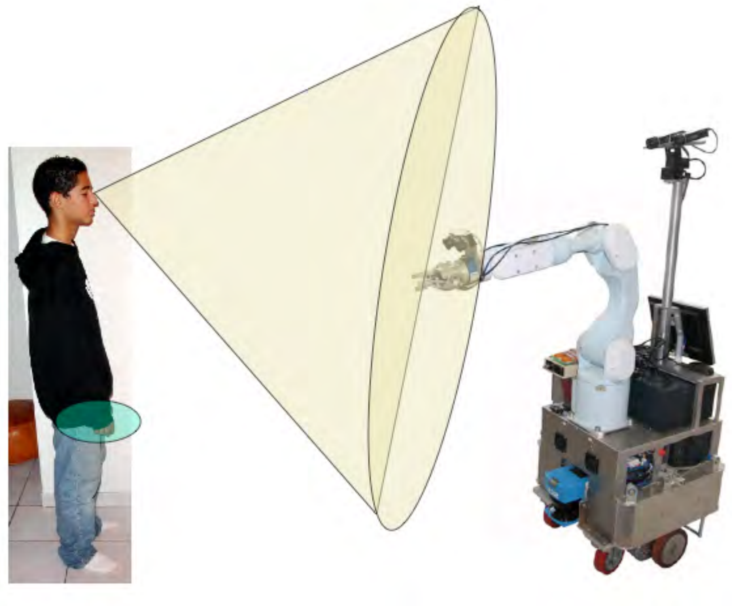




Thesis of Efrain Lopez Damian

How to hand an object to a person?

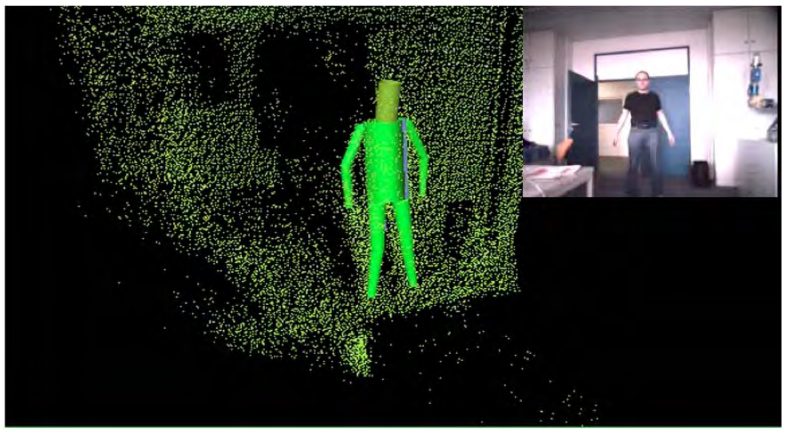


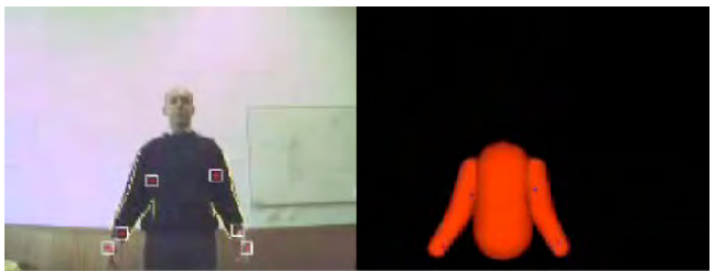


Kinematic reachability

Field of sight

Trajectory and Motion dynamics

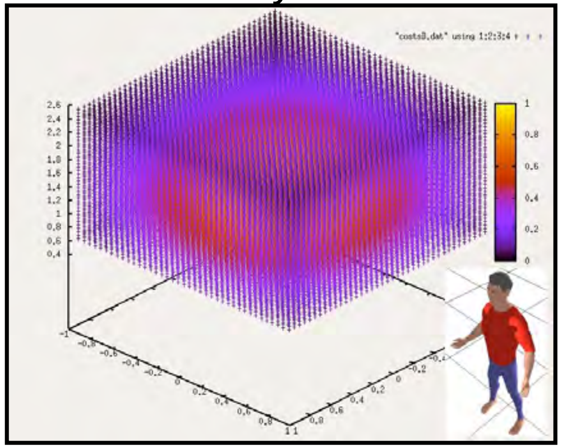




Handing an object to person

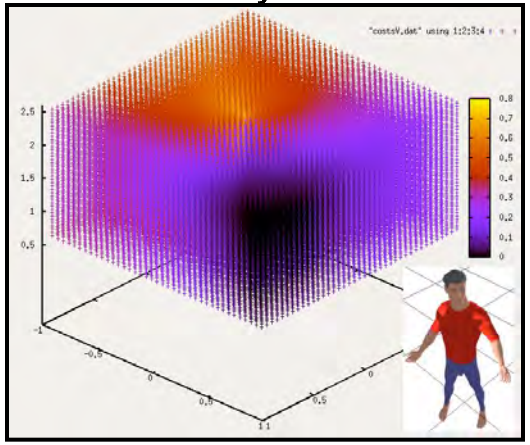
- The object should be placed in a safe and comfortable position.
- 3 different HRI properties are defined and represented as 3D cost grids around the human

Safety



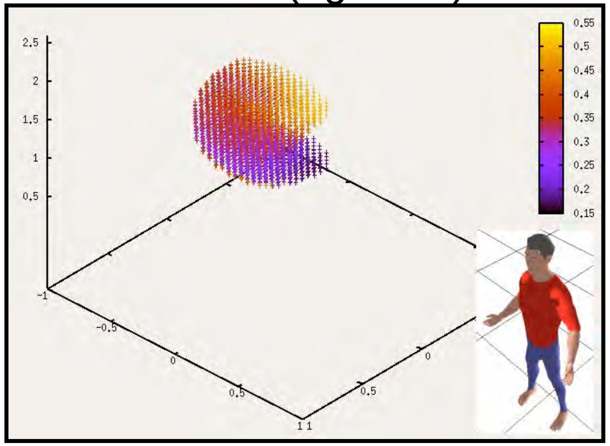
Proportional to the distance to human

Visibility



Reflects the effort to see a point

Arm Comfort(right/left)

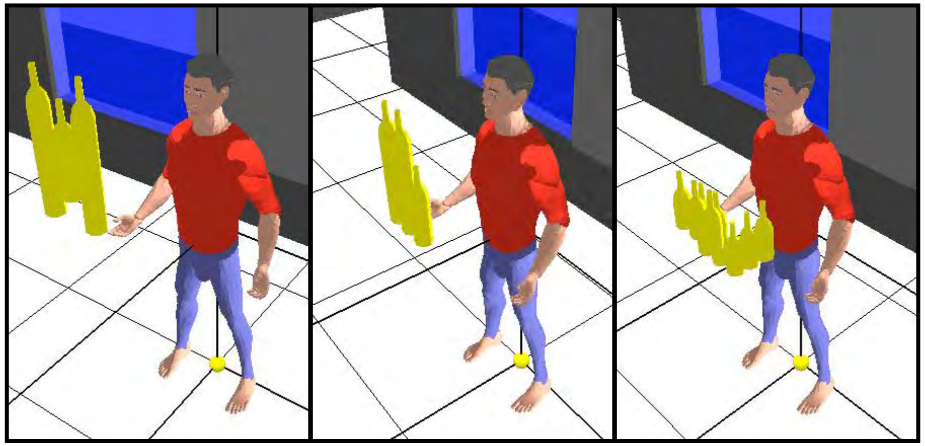


Combination of d.o.f difference and potential energy

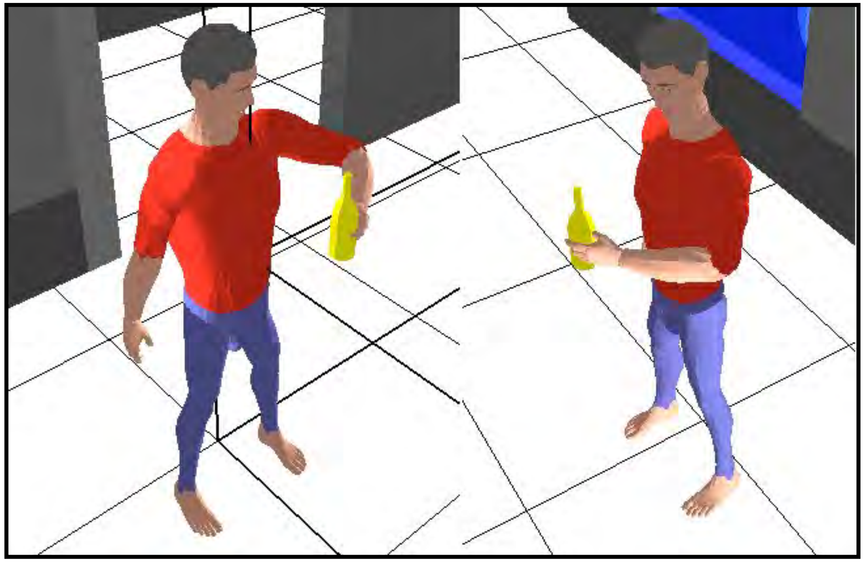
Handing an object to person

1- Calculating object position

- 3 grids are combined to form a final grid that merges all these properties.
- The cell with minimum cost is chosen to be the place where robot will place the object.

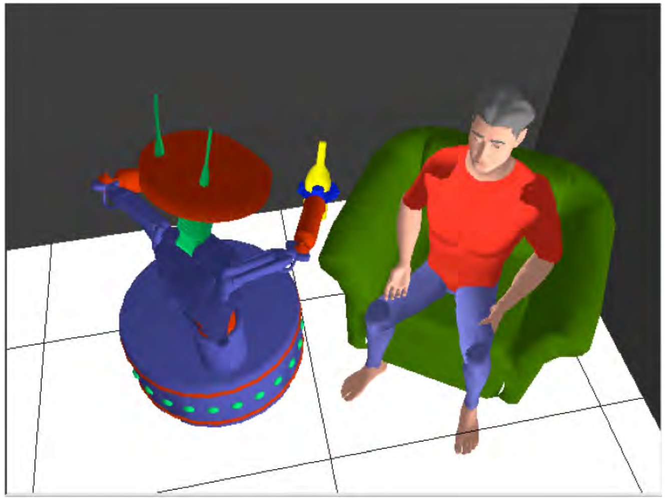


Dist > Vis >AC   Vis > Dis > AC   AC > Vis > Dis

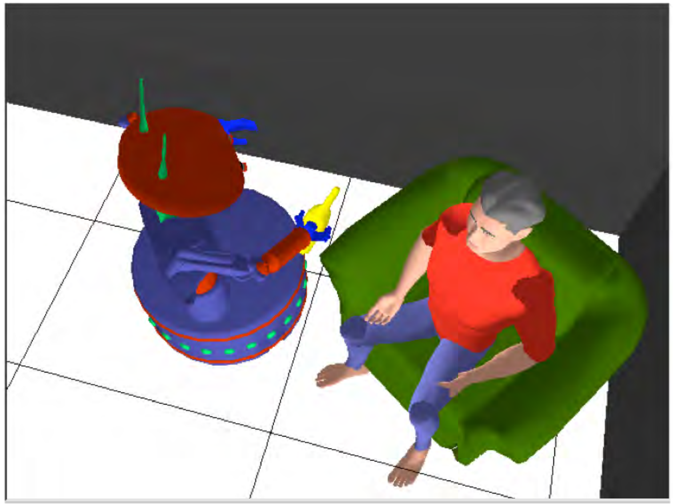


Human Aware Manipulation Planner (HAMP)

Calculating robot path



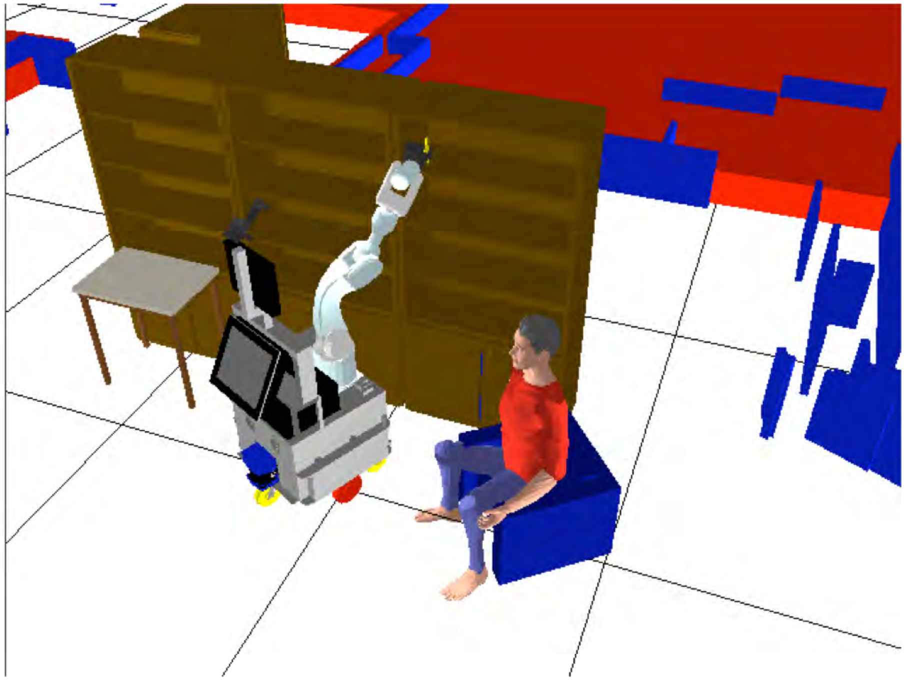
No human aware motion

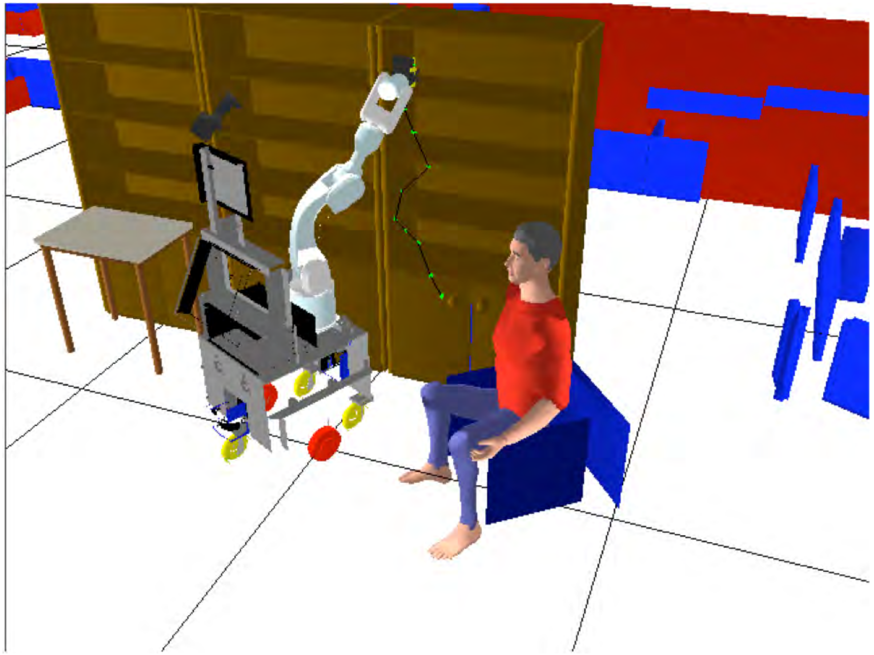


Human aware motion with 2 motion tasks:

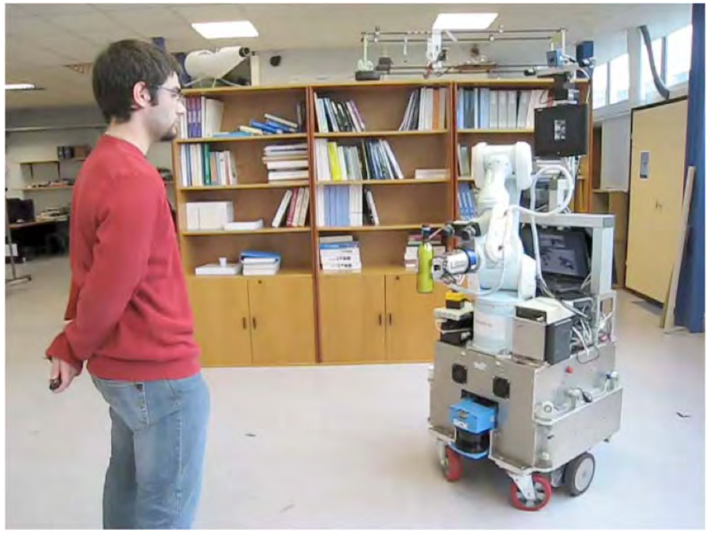
- Follow the object path
- Look to the object

Pick and Give



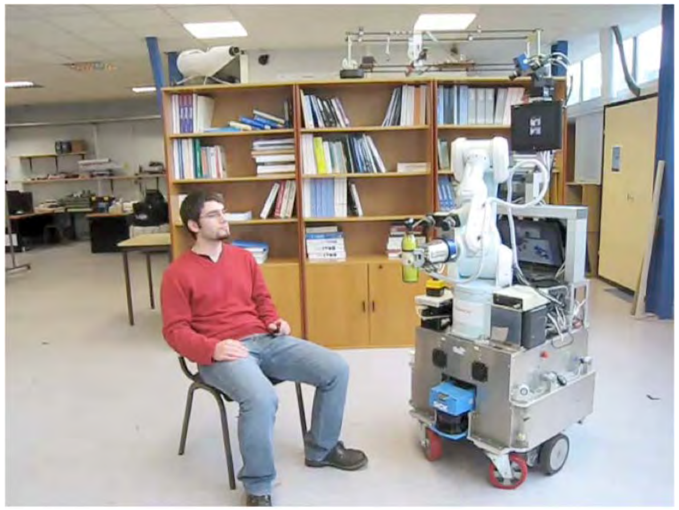


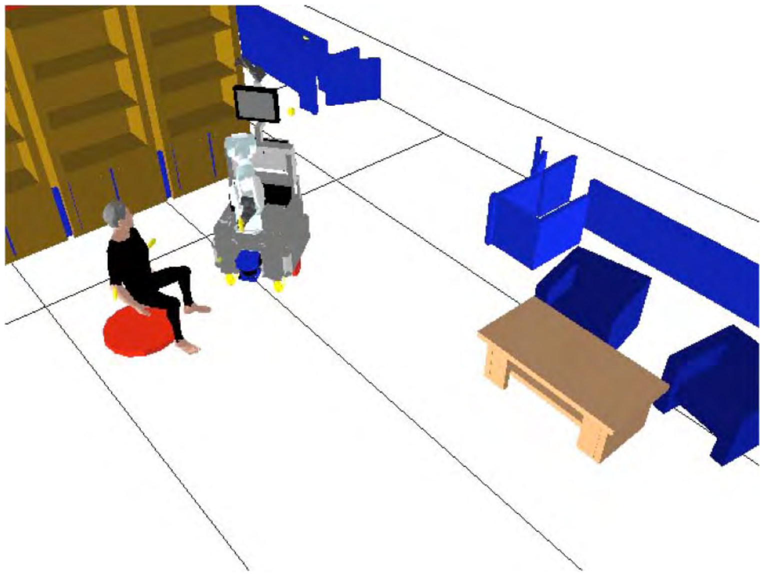
Handing an object to person (with perception)



Situation where the human does not give a « hint » (does not choose where the task has to be performed) .. The hands are even hidden

Situation where the human chooses where the task should be performed





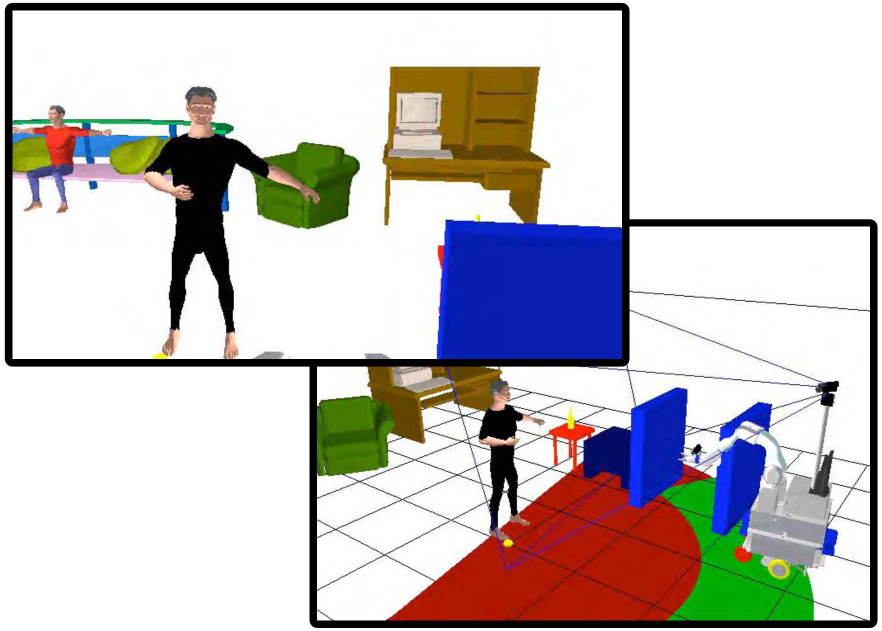
12 - One key robot capability: reasoning about placements and perspectives

- Relative Placement and Motion with respect to humans and objects in an environment
- Reasoning on the human (and the robot) perception and manipulation abilities
- In order to answer a number of questions such as:
  - Can the human see that object ? Can the human see the a given part of the robot ? (perspective)
  - Can human reach an object (grasp)
  - Where to place the robot in order to be able to see simultaneously an object, the hand and the face of a human partner (home tour, object handing)

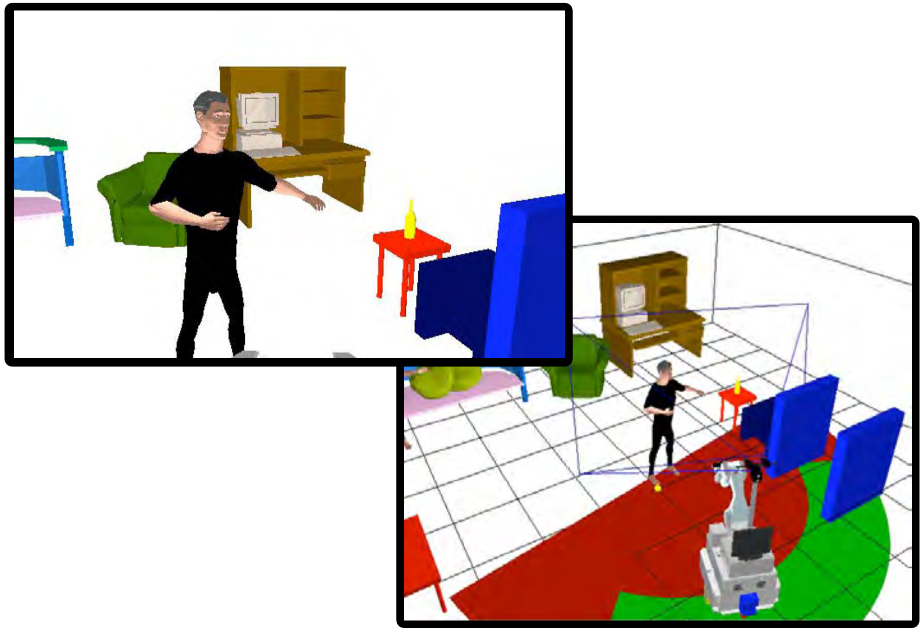
Perspective Placement

Robot (sensor) placement that satisfies:

- task feasibility,
- sensor placement for task monitoring (servoing),
- visibility by the person.



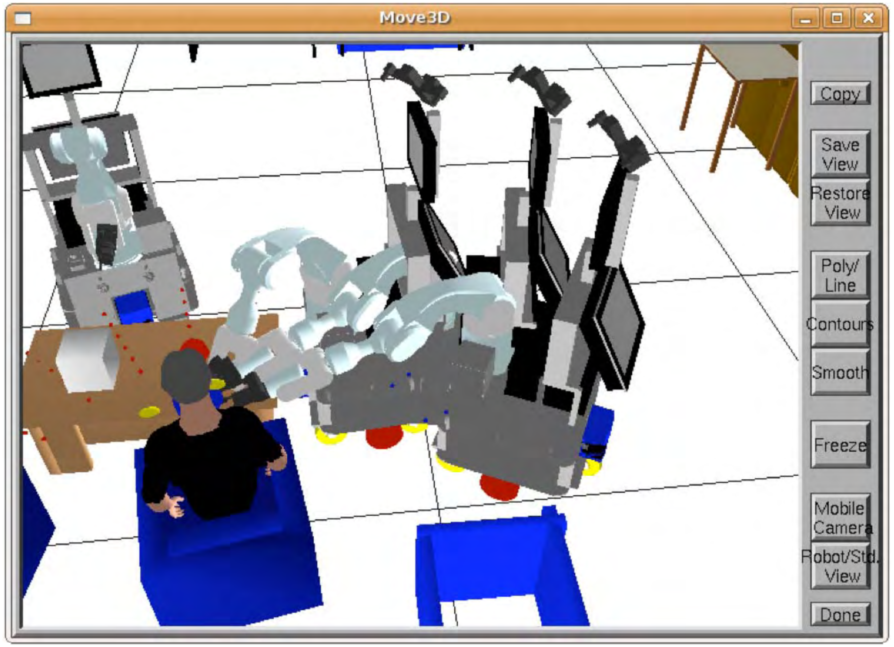
Pointed object not visible from the current
Robot configuation

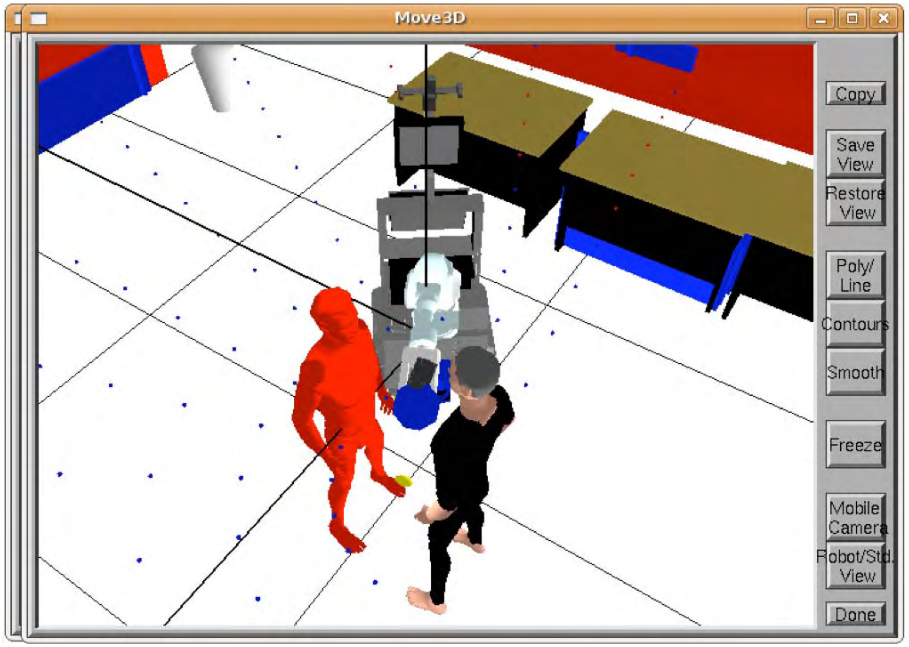


Robot moves to see the pointed object

Choosing an adequate position, posture and sensor placement

Validity, Compliance with user preferences, Reachability,



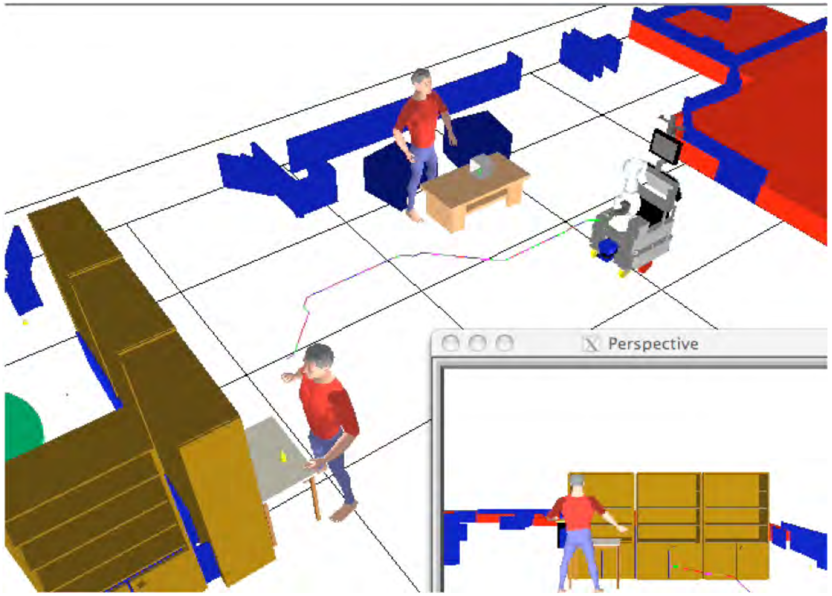


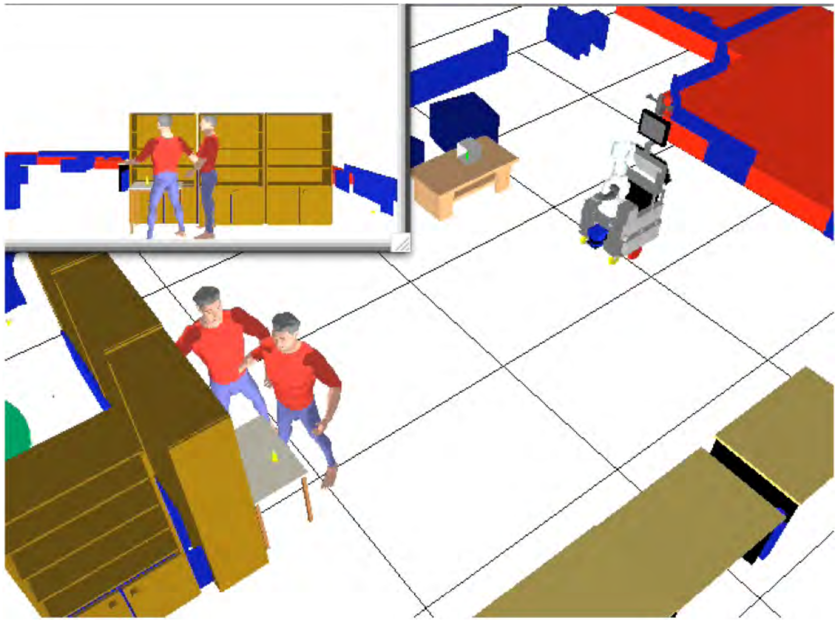
Position to speak / to hand over an object (human sitting, table is obstacle for placement not for vision or speech

Position to to hand over an object to a(person standing … avoid to « bother » the other person.

(Thesis of Luis Felipe Marin)

Go-to-look : Different contexts: obstacles





13 - Human Aware Task Planning (HATP)

- Designed to produce plans “socially acceptable” for an assistive robot.

- Link with geometric issues:
  - perspective taking
  - providing context for socially acceptable motion

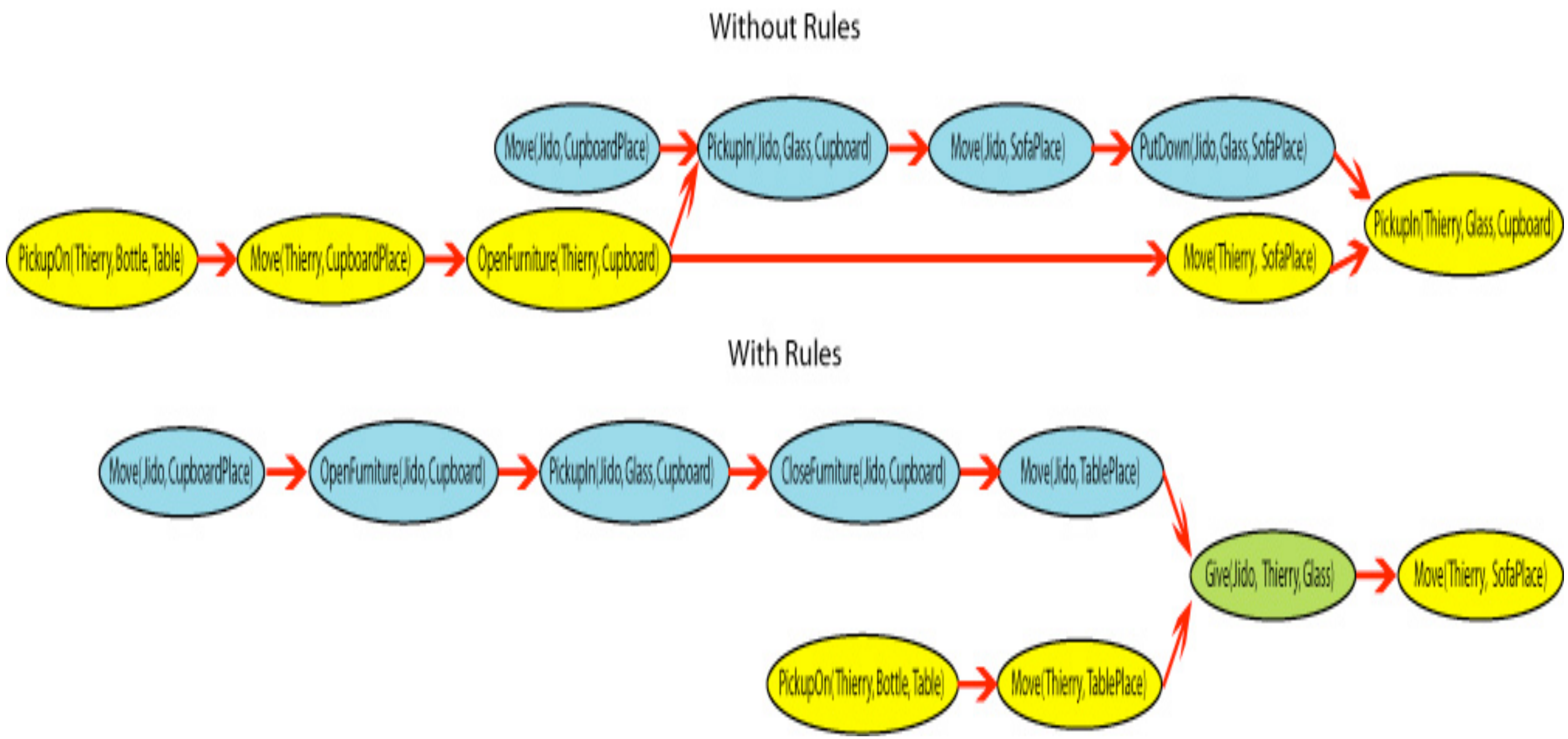
HATP key features

- the use of a **temporal planning framework** with the explicit management of two time-lines (for the human and the robot),
- a **hierarchical task structure** allowing incremental context-based refinement and fully compatible with the BDI approach adopted for the robot supervisor
- a plan elaboration and selection algorithm that searches for plans with **minimum cost** and that satisfy a set of so-called **"social rules"**.

HATP Planning process

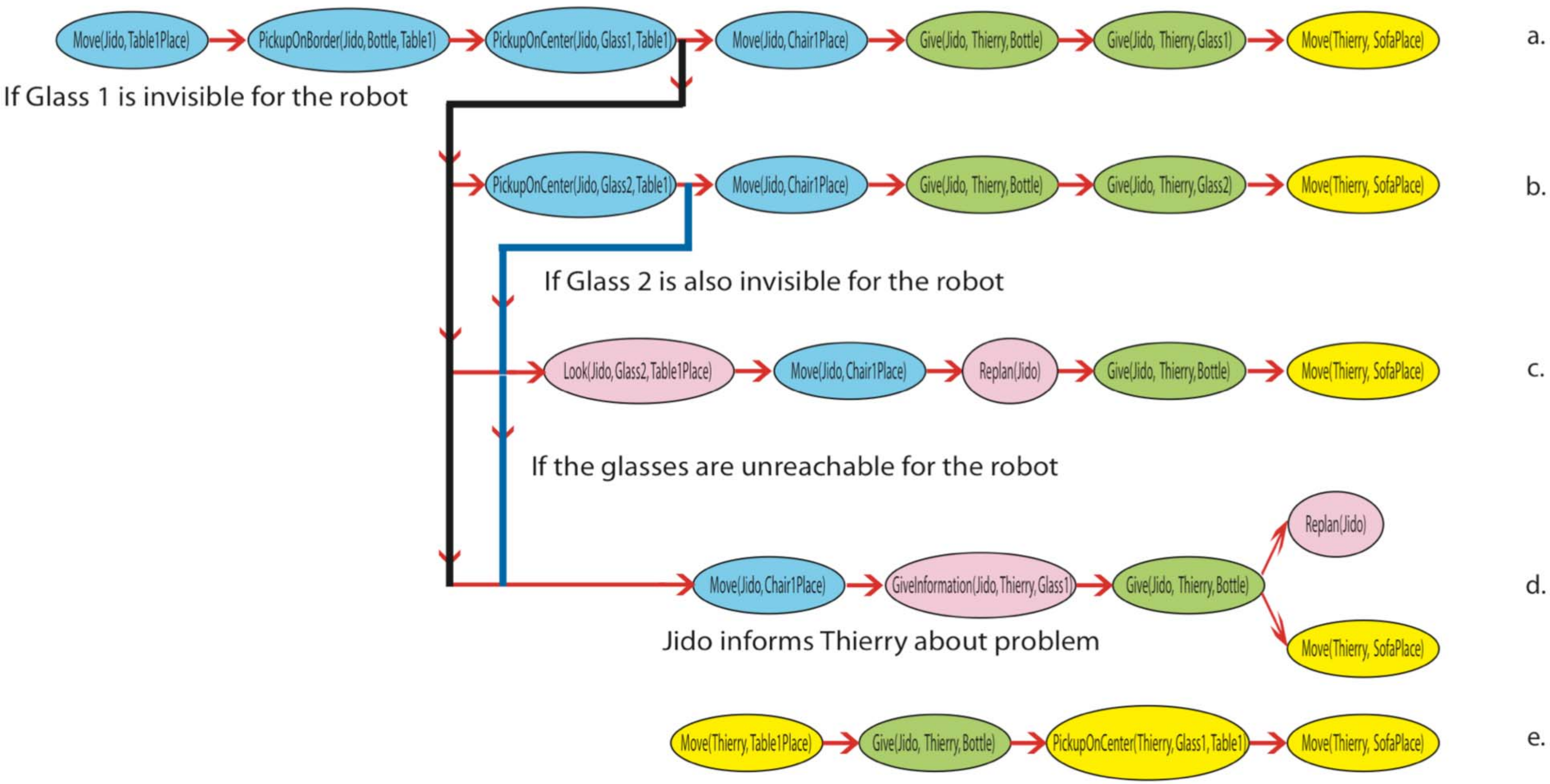
- Social rules allow a specification of social conventions:
  - Undesired states
  - Undesired sequences
  - Avoiding plans intricacy
  - Minimising human effort
- Practical planning approach in order to be able to build a planner that can effectively be used on-line (HTN planning)

HATP example (1)
promoting plans with less intricacies



Work of S. Alili

HATP example2: various reactions to contingencie



Conclusion

- Collaborative skills involve a number of issues which were not discussed
  - Sensory-motor abilities
  - Dialog
  - Learning
  - Architectural issues

Conclusion

- Toward teams of robots and humans / ambient intelligent systems

- Far more elaborate sensory-motor skills
- Finer models integrating uncertainty
- More flexible architecture
- Devising models and algorithms with larger applicability context
- Learning how to interact, how persons interact

ADREAM initiative

Ubiquitous Robotics, Ambiant Intelligence

- Devices and (micro)systems
  - Micro-systems
  - Energy
  - Communication
- Development and deployment technologies
  - Embedded systems
  - Network and protocols
  - Resilience and Privacy issues
  - Robotics and decisional systems

Thank you ...