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

Rachid.Alami@laas.fr
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

A team of cleaning robots

Several semi-autonomous wheelchairs

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

- 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
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

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

No PMO in progress

New coordination plan needed

Waiting PMO events
Deadlock treatment

Asking for critical section

Plan merging operation
Plan Merging Protocol

- No PMO in progress
  - New coordination plan needed
  - Asking for critical section
  - Plan merging operation
  - Waiting PMO events
    - Deadlock treatment

Critical section obtained
Plan Merging Protocol

- Critical section obtained
- Collect plans
- Construct global plan
- Insert plan
- No PMO in progress
- New coordination plan needed
- Asking for critical section
- Critical section obtained
- Waiting PMO events
- Deadlock treatment
Plan Merging Protocol

- Collect plans
- New coordination plan needed
- Critical section obtained
- Construct global plan
- Insert plan
- No PMO in progress
- Asking for critical section
- Critical section obtained
- Waiting PMO events Deadlock treatment
- Plan Merging Protocol
Plan Merging Protocol

- Collect plans
- Failure
- Success

New coordination plan needed

Critical section obtained

New coordination plan

No PMO in progress

Waiting PMO events
Deadlock treatment

Insert plan

Collect plans

Construct global plan

Success

Failure
Plan Merging Protocol

- No PMO in progress
- New coordination plan needed
- Asking for critical section
- Critical section obtained
- Plan merging operation
- PMO failure
- Deadlock treatment
- Wait PMO events
- PMO deferred
- Trellis
- Yes
- No
Plan-merging at a crossing

Four trajectories in Space-Time
Intricate motion coordination

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?
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

Loses the role of best candidate

Best candidate

Candidate

Eval Cost

Planning

Make an offer for a task allocation

Execution event

Idle

Tasks ready for planning

Mission

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

Dili
- Aller à P1
- Ouvrir P1
- Fermer P1
- Aller à S2
- Aller à zone-libre

H2Bis
- Aller à P1
- Ouvrir P1
- Fermer P1
- Aller à S2
- Aller à zone-libre

Emploi fusionné
- Ouvrir P1
- Fermer P1

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

The Generic Architecture

Centralized

Mission

Mission Decomposition

Planner → Supervisor

Tasks

Task Allocation

Planner → Supervisor

Allocated Task

Task Achievement

Planner → Supervisor

Problems?

Opportunism

Conflict

Redundancy

Action

An Instance...: M+

Mission

High Level Decomposition

M+NTA

M+NTA

M+CTA

M+CTA

R1

R2
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:
  \[ CP_i^{k+1} = \text{UPDATE}(e, CP_i^k) \]

- Incremental planning for Robot i:
  \[ IP_i^{k+1} = \text{PLAN}(CP_i^k, G_i^{k+1}) \]

- Collecting Coordinated Plans
  \[ GP_i^k = \bigcup_{j \neq i} CP_j^k \]

- Plan Merging Operation
  \[ CP_i^{k+1} = \text{PMO}(GP_i^k, IP_i^{k+1}) \]
Adaptative move from completely distributed to centralized decision
An example

Mission Decomposition

Task Allocation

Task achievement

Mission

Tasks

Task Allocation

Task achievement

Task

T1
T2
T3
T4
T5
Distributed Decisional activity display

Current Motion

opportunism

Redundant actions

wait

past present future
La simulation
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

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
Plan:
- “transit” and “transfer” motions
- Individual (synchronized) or cooperative motion
- Choose grasps 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, in the best possible way
    - 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
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

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
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 University 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 configuration

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 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"."

Thesis of V. Montreuil
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 contingency

If Glass 1 is invisible for the robot

If Glass 2 is also invisible for the robot

If the glasses are unreachable for the robot

Jido informs Thierry about problem
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 ...