Model-Based Development and Validation of Multirobot Cooperative System

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Doctoral course 'Advanced topics in Embedded Systems'. Lyngby'08

Goals of the course

- To give “work in progress” style introduction in the field of collaborative robotics.
- To attract interest to some fast evolving and rich problem domains inspired by nature,e.g.
  - “swarm intelligence”
  - “human adaptive robotics”.
- Real life examples on how to apply FMs to handle problems of collaborative robotics.

Structure

- **Modules**:
  - introduction
  - theoretical background,
  - applications
  - hands-on exercises

Syllabus

- **Monday morning: (9:00 – 12.30)**
  - 9:00 – 9:45 Introduction
  - 10:00 – 11:30 Hands-on exercises I: Uppaal model construction
  - 11:45 – 12:30 Theoretical background I: XTA semantics, model learning
- **Lunch** 12.30 – 13.30
- **Monday afternoon: (13:30 – 16:30)**
  - 13.30 – 14:15 Applications I: Human Addaptive Scrub Nurse Robot
  - 14.30 – 15.15 Theoretical background II: model checking
  - 15.30 – 16:15 Hands-on exercises II: model checking
- **Tuesday morning: (9:00 – 12.30)**
  - 9:00 – 9:45 Theoretical background III: Model based testing
  - 10:00 – 10:45 Applications II: reactive planning tester
  - 11:00 – 12:30 Hands-on exercises III (model refinement)

Lecture #L1 : Introduction
Lecture Plan

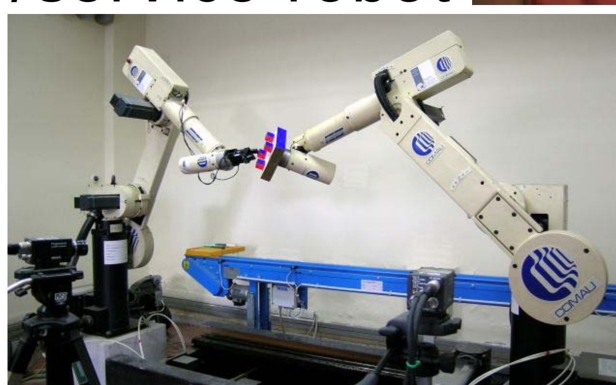
- From single robot to multi-robot systems (MRS)
  - Single-robot systems
    - Examples
    - Advantages/Disadvantages
  - Multi-robot systems and swarms
    - Lessons from nature
    - What makes the MRS special?
    - How can a swarm function: 3-tier architecture
  - Formal Methods for Multi-robot Cooperative System
    - Why formal methods?
    - Problems and methods

From single-robot to multi-robot systems

- Single super-robots:
  - Autonomous space explorers:
    - NASA's Mars Exploration Rover

  - Humanoids:
    - Asimo (Honda),
    - Tara

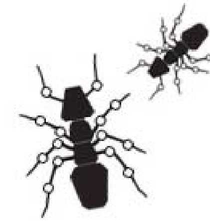
  - Manufacturing/service robot complexes

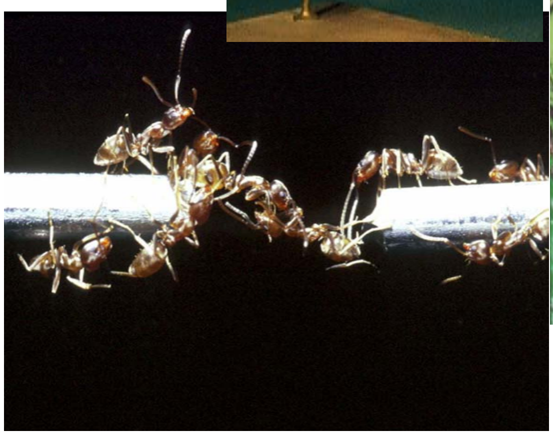


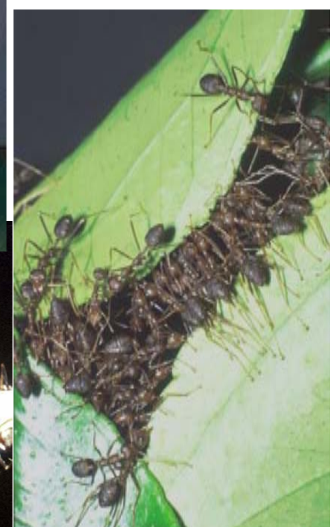
Traditional single-robot systems

- Advantages:
  - Able to mimic human/pets' behaviour, e.g., home assitant Tara, cyberdog Aibo
  - Capable of operating autonomously for long time (Mars Rover)
  - High performance in well-defined tasks,.e.g car composing
- Disadvantages:
  - Advanced robots are expensive
  - Inefficient in teamwork and spatially distributed activities
    - A group of super-robots is not neccessarily a supergroup
  - Sensibility to HW/SW failures – whole mission can fail if the robot fails

Multi-robot systems: swarms Learning from nature







Simple organisms like ants and termites are able to conduct amazingly complex cooperative tasks: carring loads, building bridges, nests etc.

Swarm intelligence (SI)

- SI systems are typically made up of a population of simple agents
  - Agents interact
    - locally with one another and
    - through their environment (stigmery).
  - the agents follow very simple rules,
  - there is no centralized control structure dictating how individual agents should behave,
  - local interactions between agents lead to the emergence of complex global behavior.

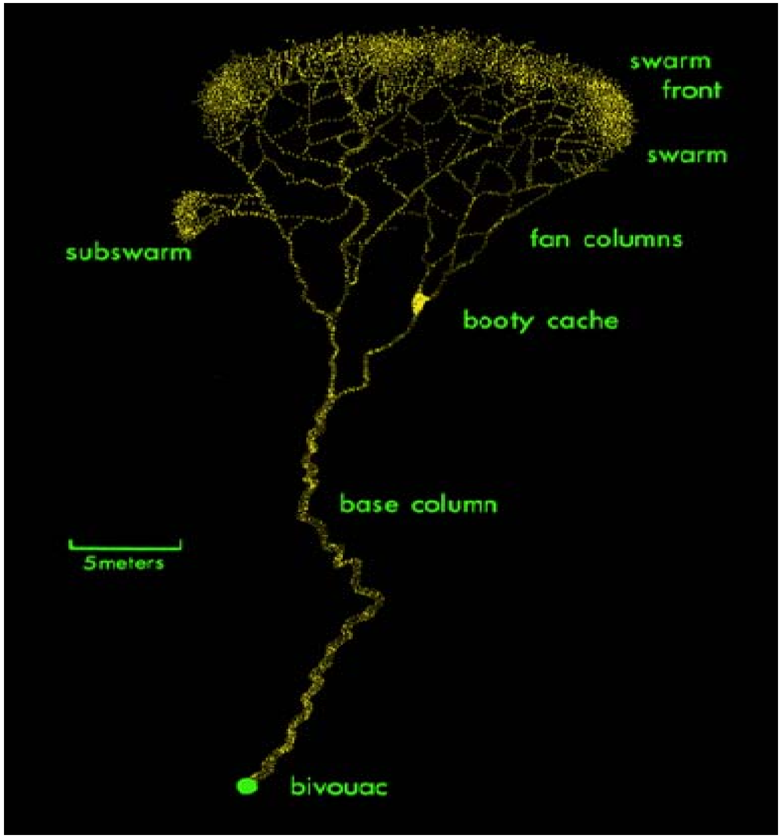
Examples of swarm intelligence

- ant colonies,
- bird flocking,
- animal herding,
- bacterial growth,
- fish schooling
- etc

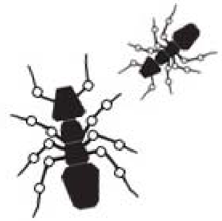
Examples of swarm intelligence: Collective Hunting Strategies

Benefits of Collective Hunting

- Maximizing prey localization
- Minimizing prey catching effort



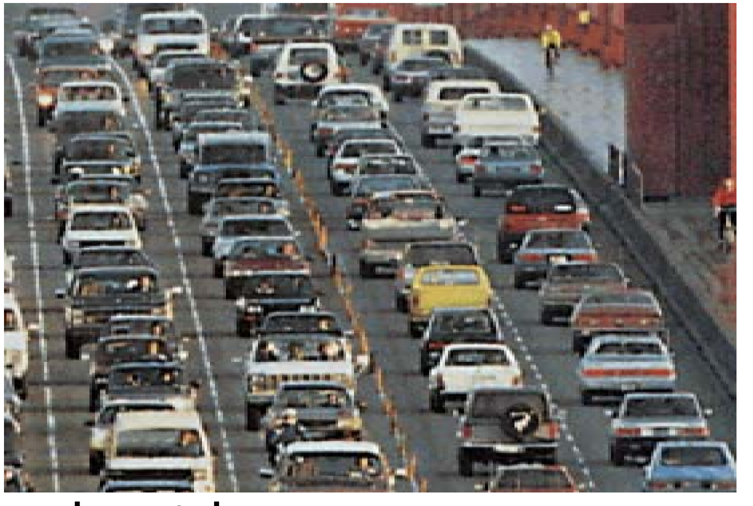
What makes a swarm/collective intelligent?



- Coordination
  - distributed control
  - individual autonomy
  - self-organization
- Communication
  - direct (peer-to-peer) local communication
  - indirect communication through signs in the environment (stigmergy)
- Robustness
  - redundancy
  - balance exploitation/exploration
  - individual simplicity

How does it work?

- Collective intelligence appears in
  - *consensus–based* decision making,
  - i.e., respecting a set of *uniform* behavioral rules
    - e.g., traffic rules.

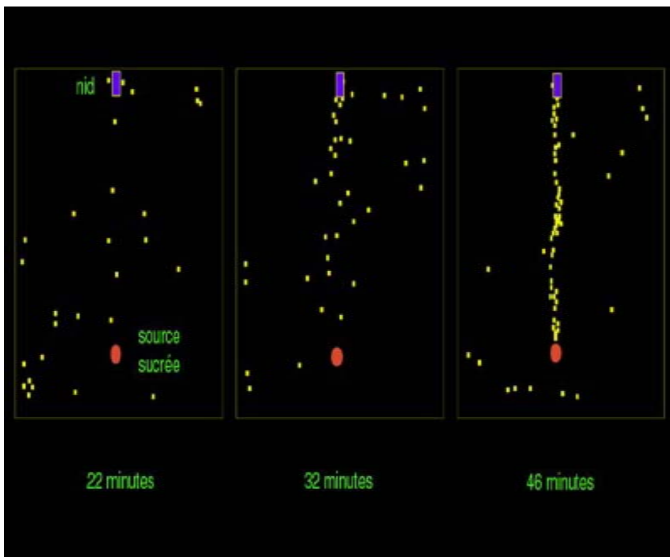


+Meta-rules – the rules about how
- the new rules are created
- and obsolete ones discarded

Why does it work?
Stigmeric Communication

Since the rules are dynamic and/or location specific a feasible way keeping and communicating the rules is **environment**

Example: Routing problem



Ants world:
Formation of the ants' trail

Robots world: Virtual
Pheromones on smart dust

Cooperative intelligence: summary

- **Stochastic individual behavior**

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- **repetitive, context sensitive amplification of (local)information**

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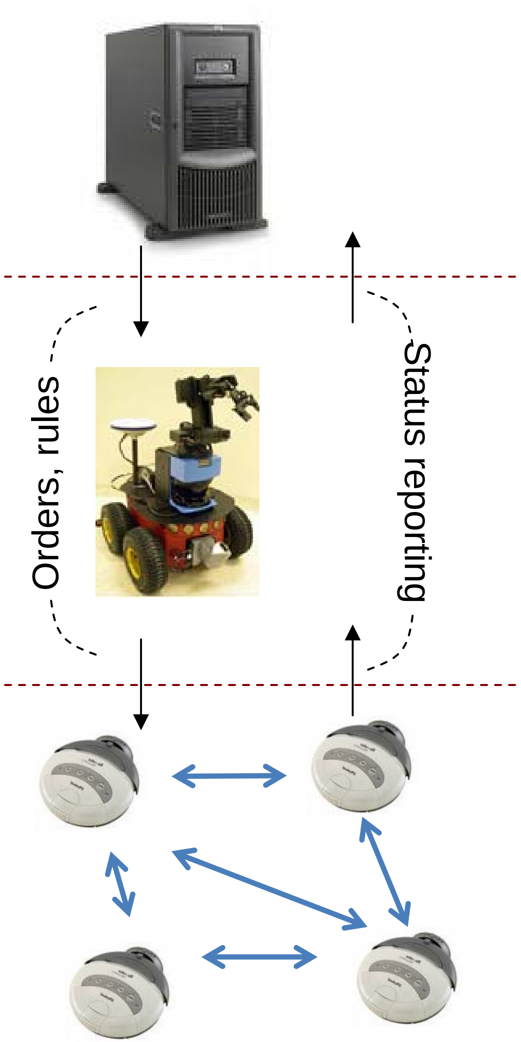
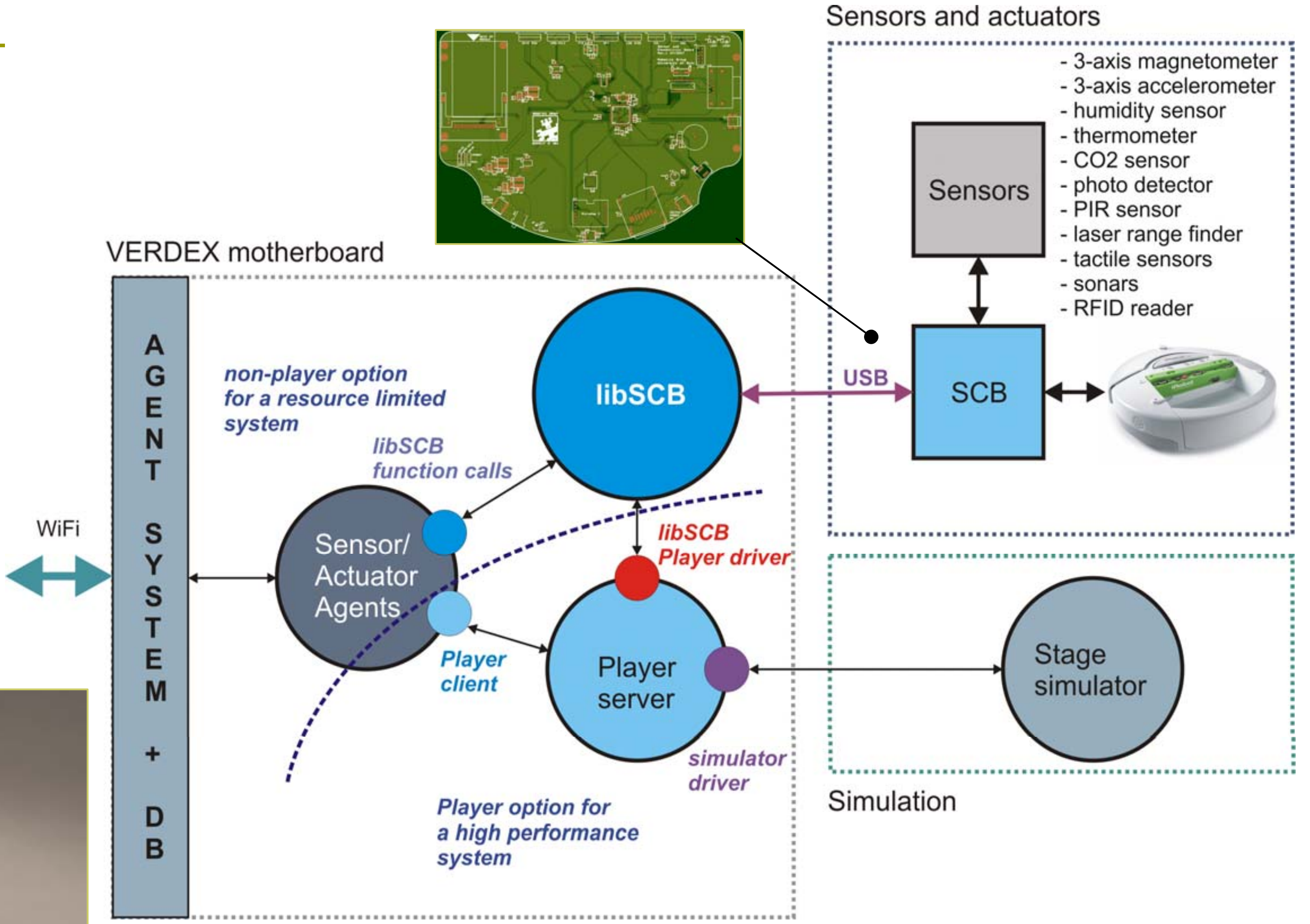
Efficient Collective Decisions

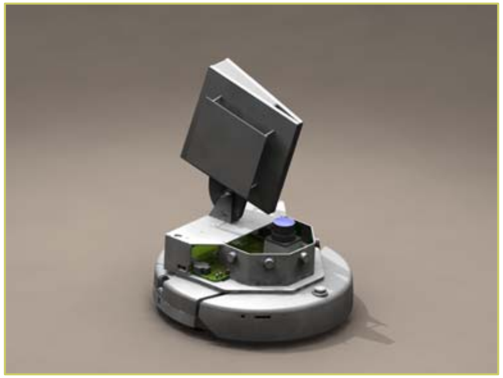
ROBOSWARM 3-tier swarm control architecture



- “Big Brother” – strategic planning and preparation of the swarm mission:
  - analyzes the goals given by human(s)
  - generates ext./int. service requests
  - synthesizes behavioural constraints and rules
  - communicates the rules to T2 and T3 robots
- “Scouts” – mission preparation and maintanance on the spot
  - area exploration, semantic mapping
  - deploying RFID tags (create mission infrastructure)
  - write the mission context on tags (create *context awareness*)
- “Swarm of Workers” - mission performers
  - accomplish main workoperations
  - coordinate tasks locally (e.g., using auxion)
  - propagate mission relevant knowledge

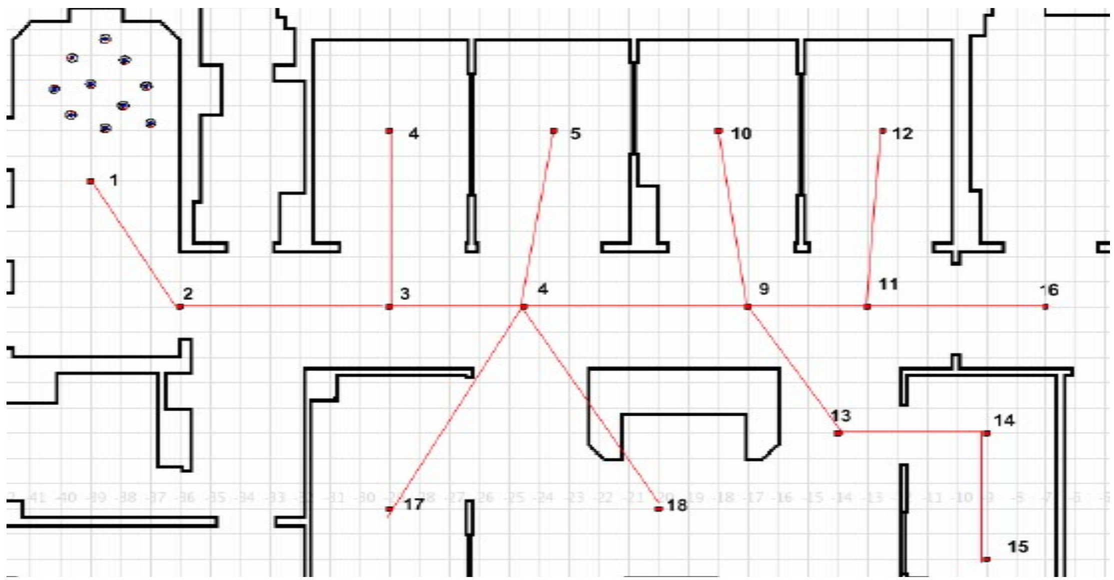
ROBOSWARM Worker: iRobot Create (extended)





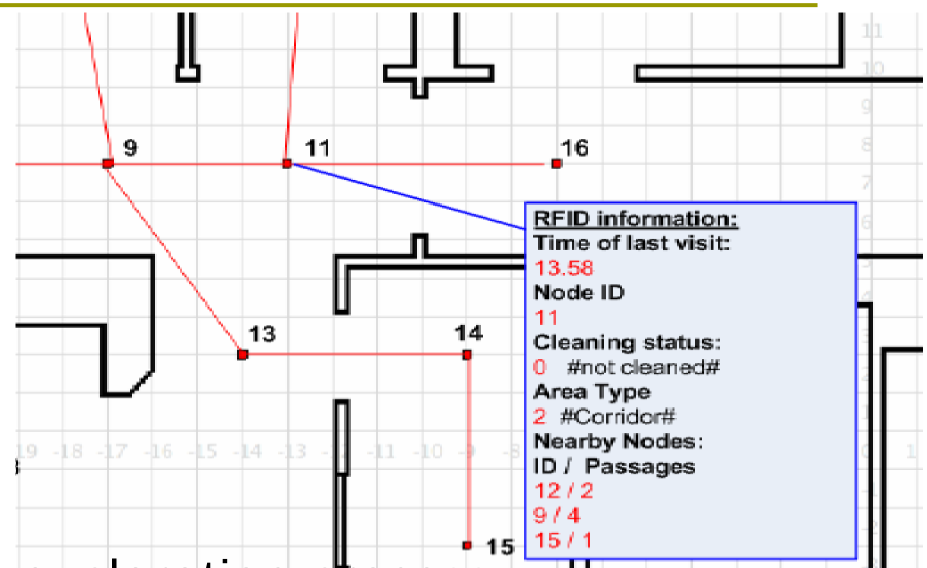
ROBOSWARM: RFID-based smart environment for exploration and cleaning

- The tags deployed in the environment by Scouts form a graph



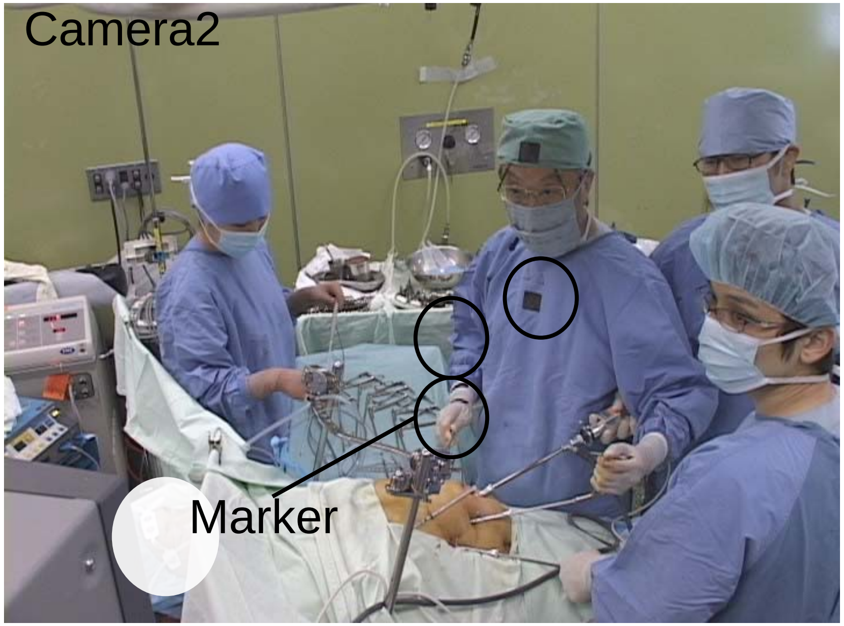
• - hotspot

“Smart” environment on RFID tags



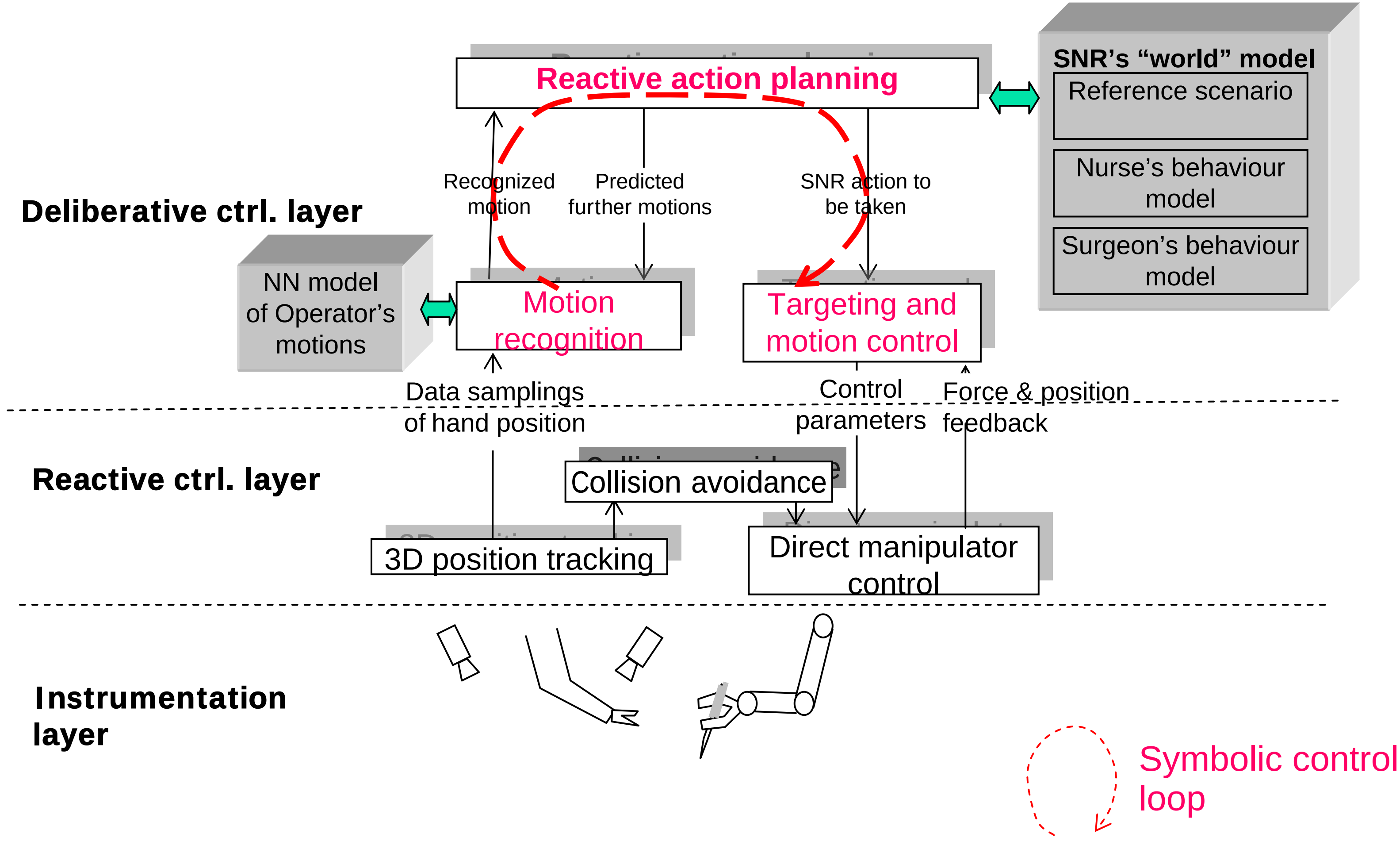
- Navigation Information
  - Nearby Nodes
    - Relative nodes positions
  - Information about current exploration process
    - Best node to visit in order to continue exploration process
  - Environment information
- Information about the cleaning process
  - Time of last cleaning operation
  - Best algorithm to clean the area (Corridor, Room, Corner etc.)

Multirobot Cooperative Systems (2):
Human addaptive robots: Scrub Nurse Robot (SNR)



Photos from COE on HAM, Tokyo Denki University

SNR Control Architecture



Conclusions (1)

- Present state-of-the-art in cooperative robotics:
  - Resesarch still largely in conceptualization phase
  - No “strong” theory of swarms or cooperative robotics yet
  - But, large part of research on multi-agent systems is reusable

Conclusions (2)

- Critical tasks in MRS are *model-based control* and *planning*, including:
  - automated model learning and abstraction
  - efficient model-based decision algorithms for planning and coordination
  - combining semi-formal heuristic planning/optimization methods with FM-s

Aspects covered in the course

- Timed automata model learning
- Techniques of efficient model checking
- On-line reactive planning tester synthesis (to handle dynamicity/non-stationarity of the MRS)

Questions?