Robotic Agents for Disaster Response Robotics

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Basic Terminology

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Rescue robots serve as extensions of responders into a disaster, providing video and other sensory data about the situation

Search and Rescue Robotics *Handbook of Robotics*

- RESCUE is indeed SEARCH and RESCUE (SAR)
- RESCUE ROBOTs are SEARCH ROBOTS
- Hence: **DISASTER RESPONSE ROBOTICS**

- URBAN SAR (USAR) specific to building collapse

Disasters

Natural

- Earthquakes
- Volcanos

- Mud slides
- Floodings

- Tornados
- Hurricanes

- Forest Fires (?)

Man made

- Nuclear/ Chemical
- Bacteriological
- Mines
- Oil wells

- Tunnel
- Subway
- Building collapses (due to many causes)

L’Aquila earthquake (April 09)

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Rescue Robotics Tasks

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SAR

- *Search*
- *Exploration*
- *Reconnaissance*
- *Mapping*

Logistics

- *Network connectivity*
- *Transportation support*

USAR specific

- *Rubble removal / escavation*
- *Structural inspection*

Medical assistance

- *In situ medical assessment and intervention*
- *Medically sensitive extrication and evacuation of casualties*

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Ground Rescue Robots

- Snakes
- Legged
- Climbing

- Other concepts

- Tracked
- Wheeled


The New York Times June 25, 2007

Jessica Kourkounis for The New York Times

Satoshi Tadokoro operates the Active Scope Camera, an optic robot that inches along like a snake.

Water Rescue Robots

Surface

Underwater

Aerial Rescue Robots

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Wheeled Robots

Tracked robots

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Bomb disposal robots are quite "popular"

In (some US regions) every county has 1 ore more robots

In use up to 3 times a week

- Hard to use in teleoperation
- Heavy
- Limited mobility
- Slow
- Not very effective for SAR

Tracked Robots: Kenaf

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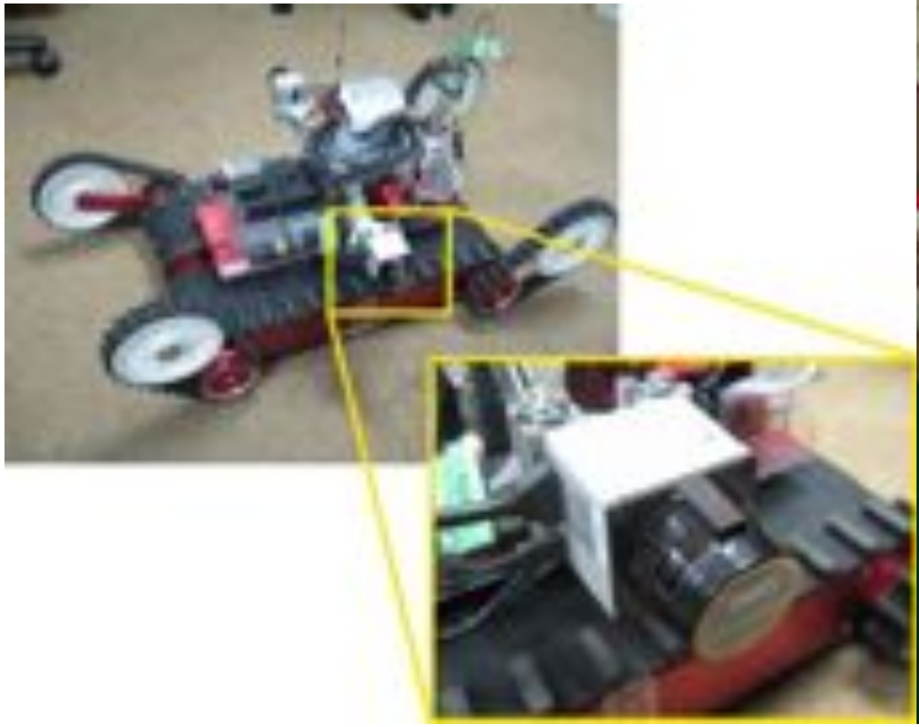
- 3D odometry
- Navigation support
- Automatic flipper control
- 3D Mapping LRF



Tracked Robots: Lurker

- Cheap mobile base (Tarantula)
- Pose tracking
- Complex autonomous behaviours
- Real time elevation map

Equipment for Rescue Robots

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Sensors

- Vision/Omni/Stereo
- Distance (Laser)
- LIDAR Swiss LRF
- Inertial
- GPS
- Thermal sensors
- CO2/gas/bio/X
- Audio

Communication

- Cable
- Wireless Standard/Ad hoc
- Dedicated image transmission
- Ad hoc networking
- Stigmergic (through RFIDs)

Interaction devices

- PC
- Hand-held devices
- Googles
- Wii-mote
- Audio/Speech

What's needed?

Although prevention is much more effective than cure …

a lot is needed, in different fields, but for AAMAS and ICAPS **Autonomous Behaviour** is the key issue:

- Communication failures
- Not under operator's view
- Better performance
- Deployment of several robots

Tasks for rescue robots

SAR

- *Search*
- *Exploration*
- *Reconnaissance*
- *Mapping*

Robot Capabilities

- Navigation
- Localization and mapping
- Object/target/victim detection
- Coordination and cooperation

All started because of RoboCup

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Padova 2003, SPQR @ RoboCup Rescue

SIED Lab

Sistemi Intelligenti per l'Emergenza e la Difesa Civile

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Mission: development of intelligent systems for emergency and civil defense

Research Issues: autonomous systems for Urban Search and Rescue

- Agent coordination in simulated emergency scenarios
- Search (& Rescue) Robots

Istituto Superiore Antincendi

National Fire Department

Disaster Response Robots

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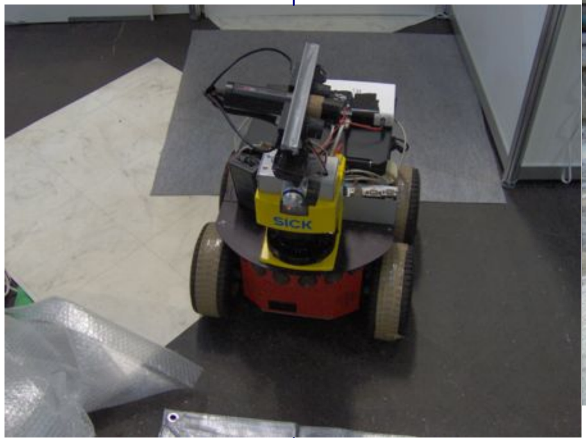
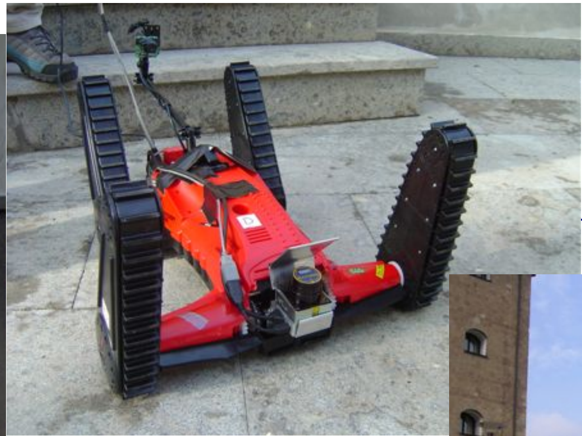
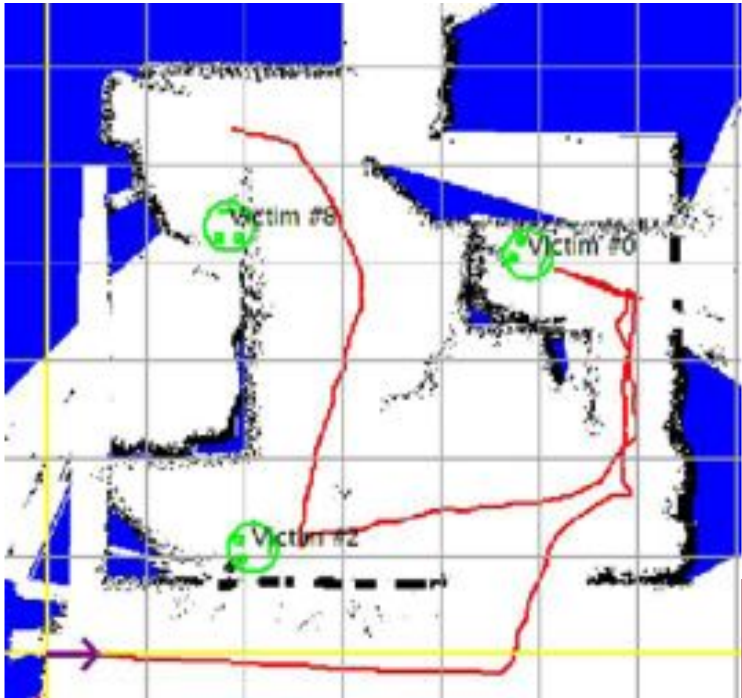




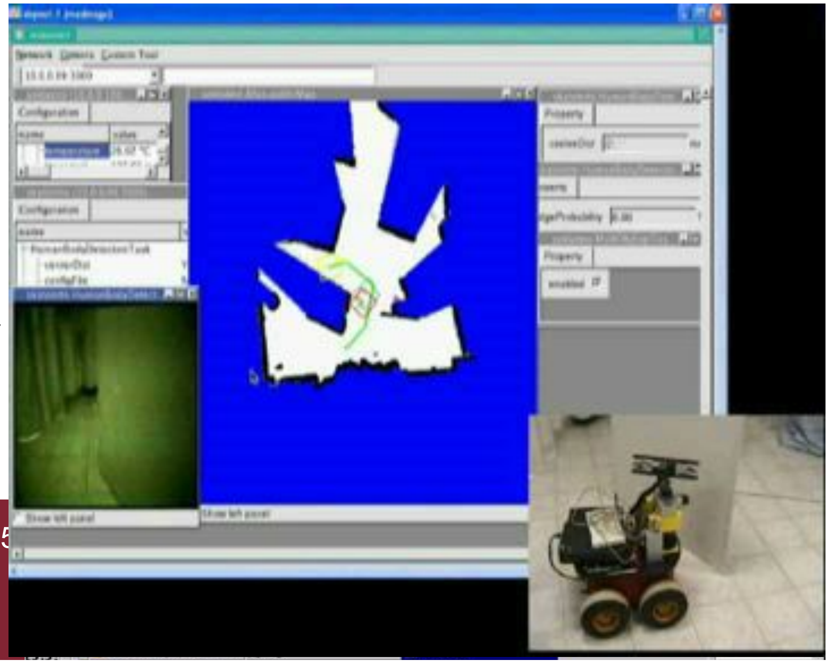
WLAN

Robot
team



Mission

Operator
Interface



Simulation of emergency scenarios

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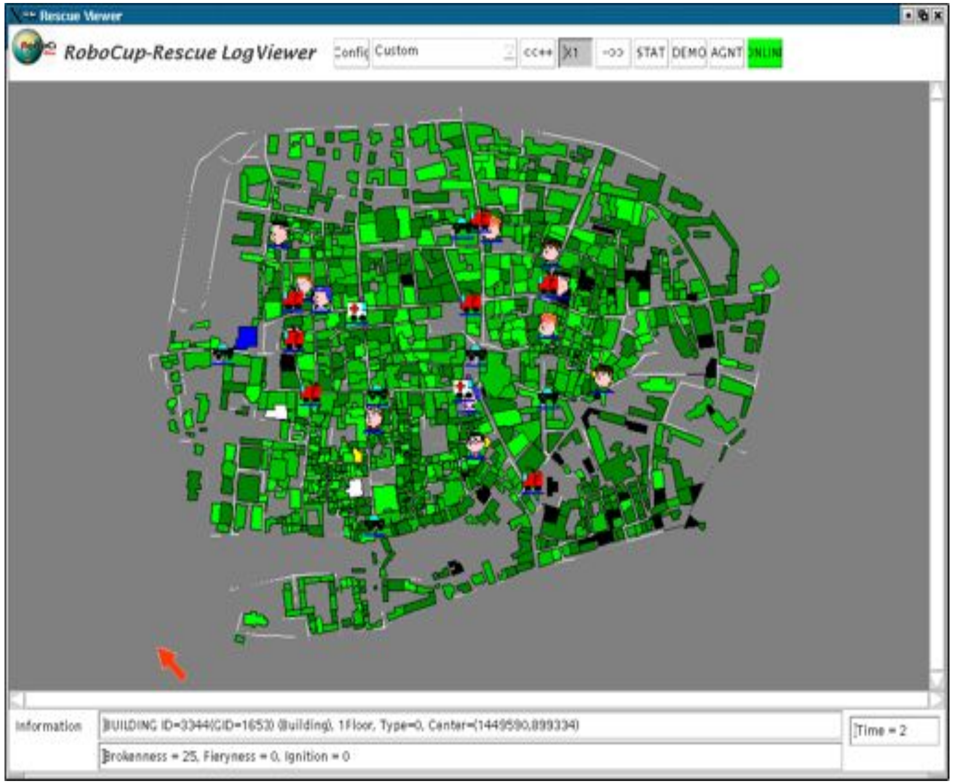
- Simulation of operation procedures



- Multi Robot Modeling
- System test& development

(Egocentric) Research survey

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- Plan representation
- Contextual kr&r
- Teams of robots
  - Situation Awareness
  - Human Robot Interaction
- Benchmarking

Robot actions

- Representation matters!
  - Sensing
  - Actions Duration
  - Concurrency
  - Interrupts
  - Coordination

- Monitoring execution matters!
  - Reactiveness
  - Goal driven

Petri Net Plans (PNP)

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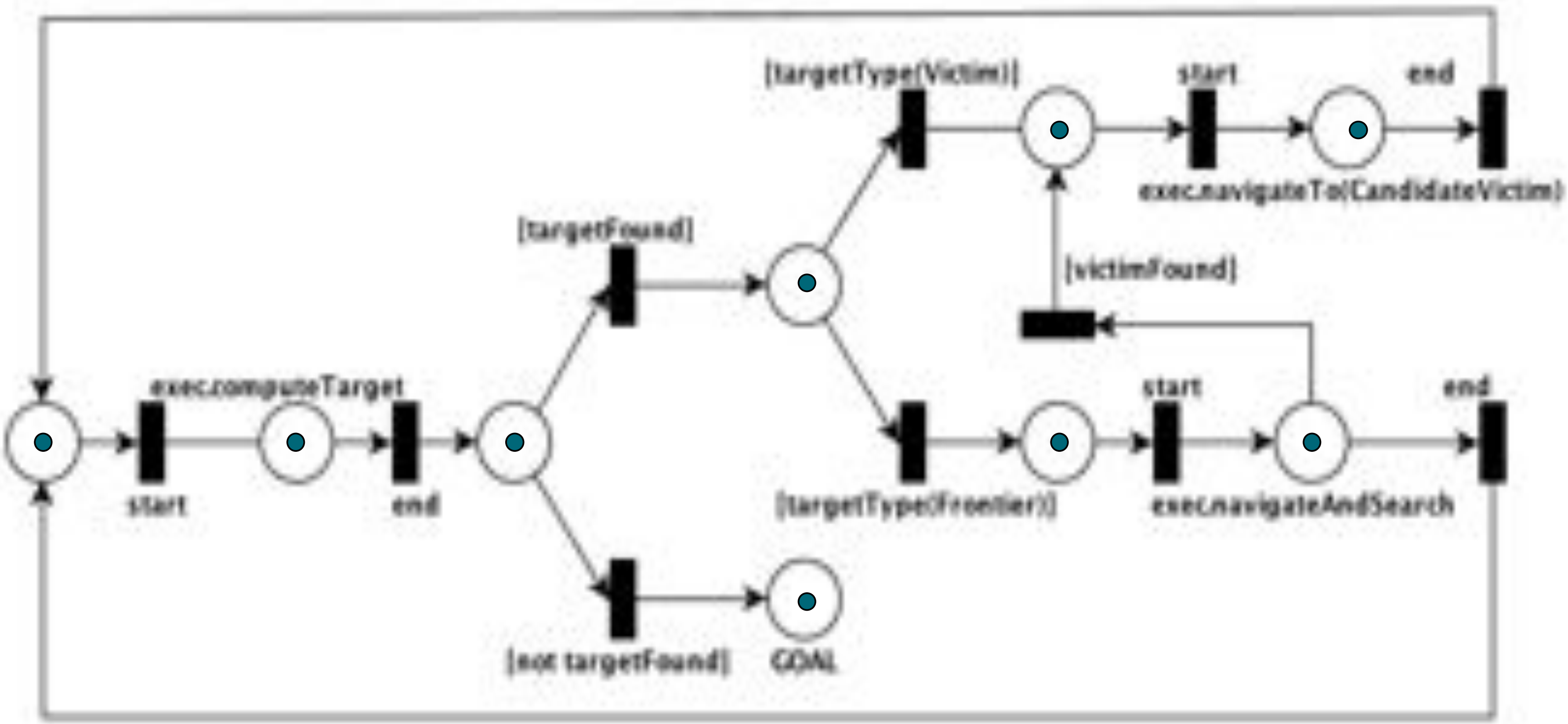

Multi-Robot PNP

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- Centralized Design
  - Action Synchronization
  - Joint Actions (Joint Intentions Theory)

- Automated Decomposition & Distributed Execution

- PN-based analysis for Single/Multi-Robot PNP

Joint Intentions in PNPs

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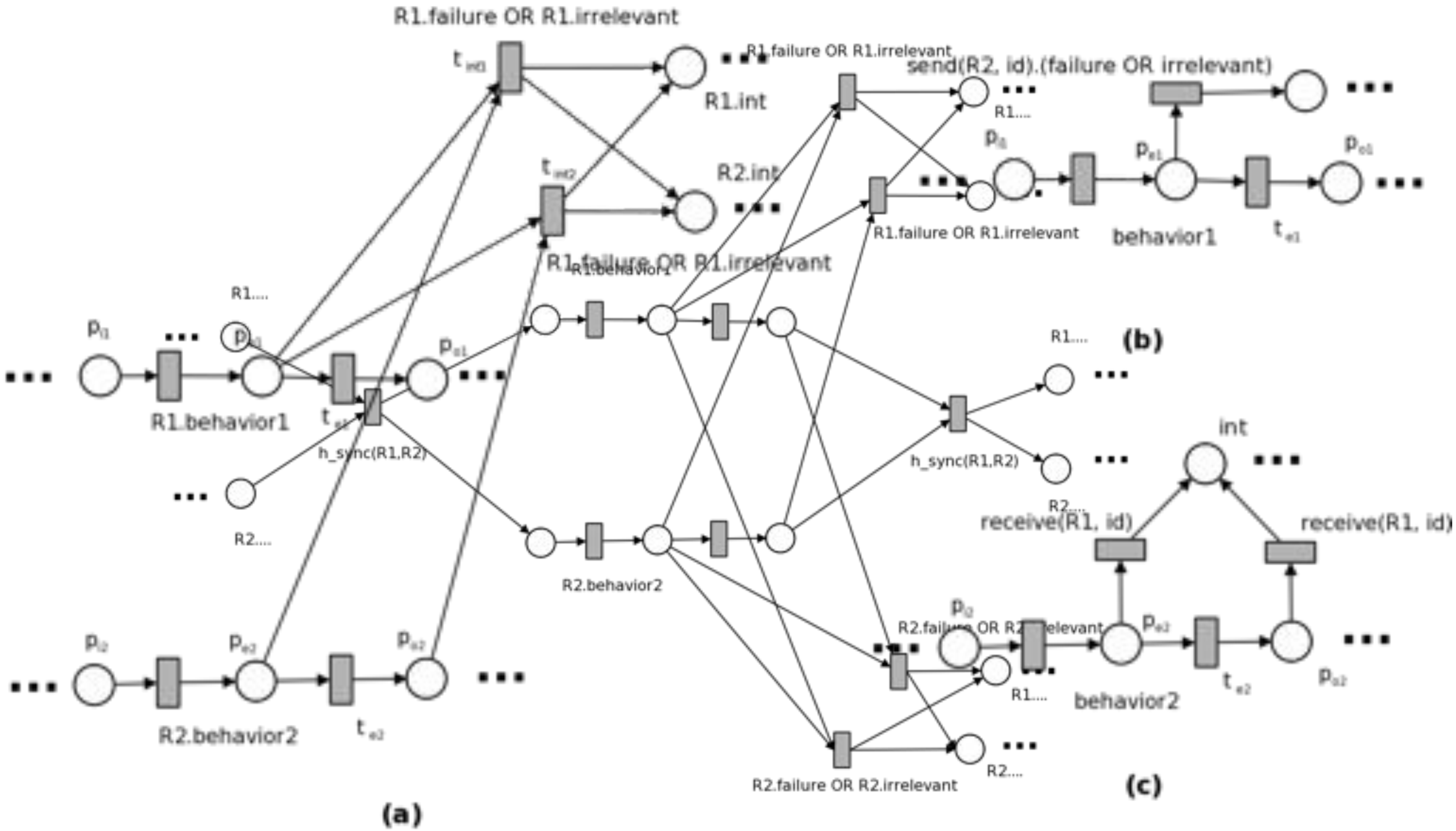

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Execution Monitoring

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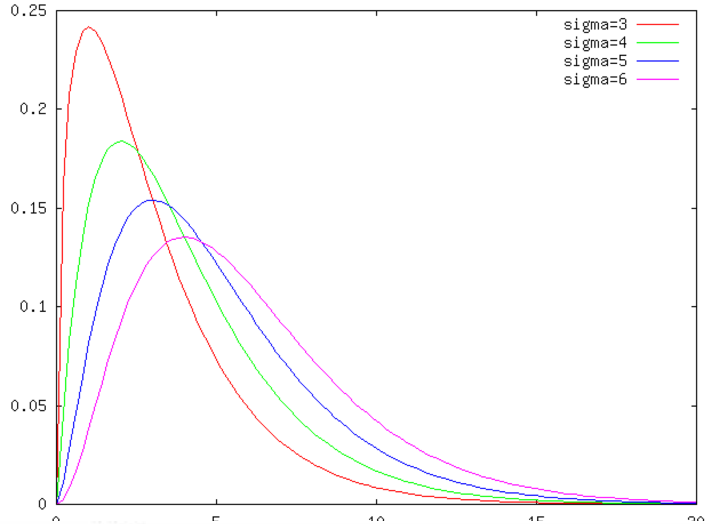
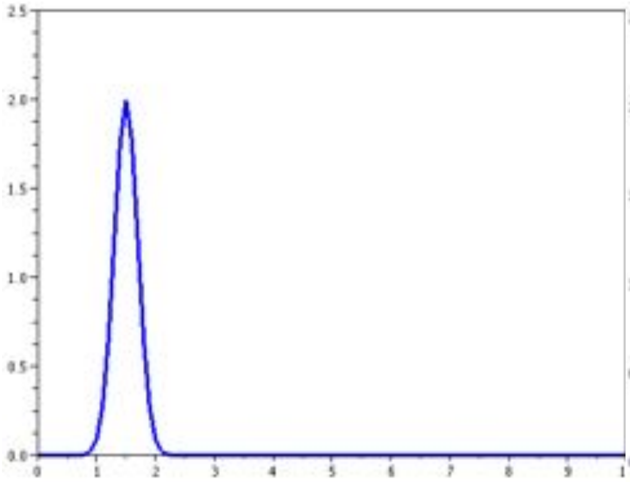
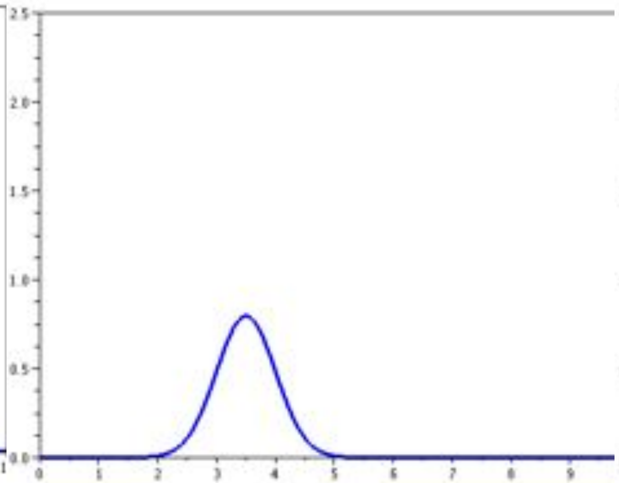
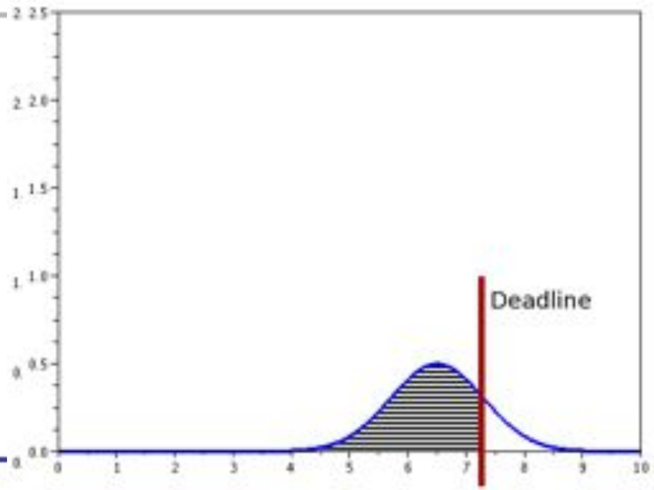
- Time is critical!
- Uncertainty in duration of actions
  - => Probabilistic representation
- Reasoning of overall probability of success
- On-line Plan Selection









Semantic Knowledge and Symbol Grounding

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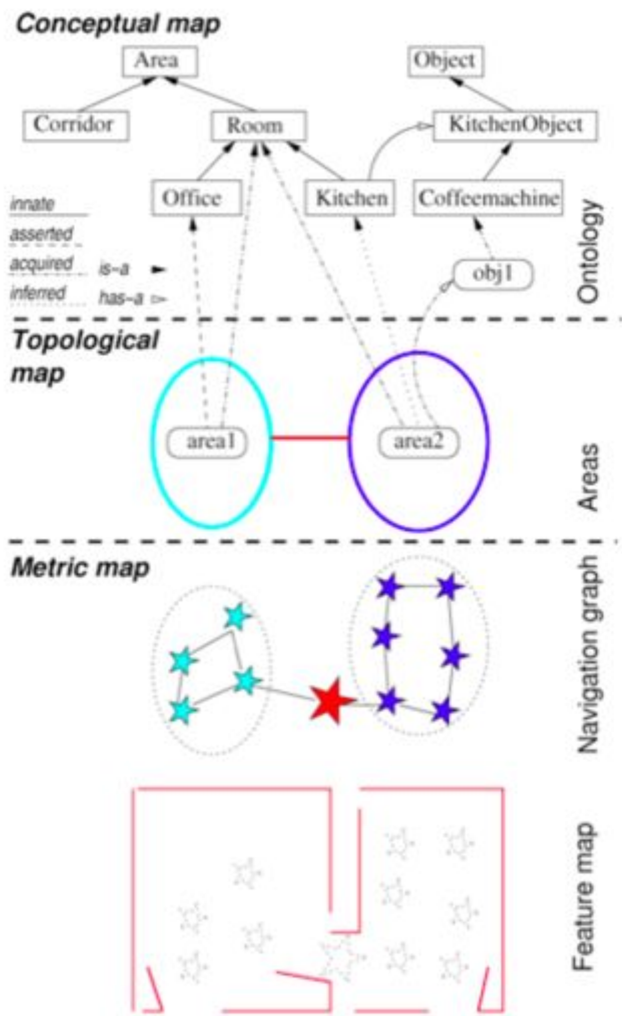
Symbolic representations:
- more comfortable for humans
- improve human-robot awareness
- enhance human-robot interaction

Semantic knowledge requires:
- explicit representations (ontology)
- **grounding** the symbols used with real objects the environment



Context

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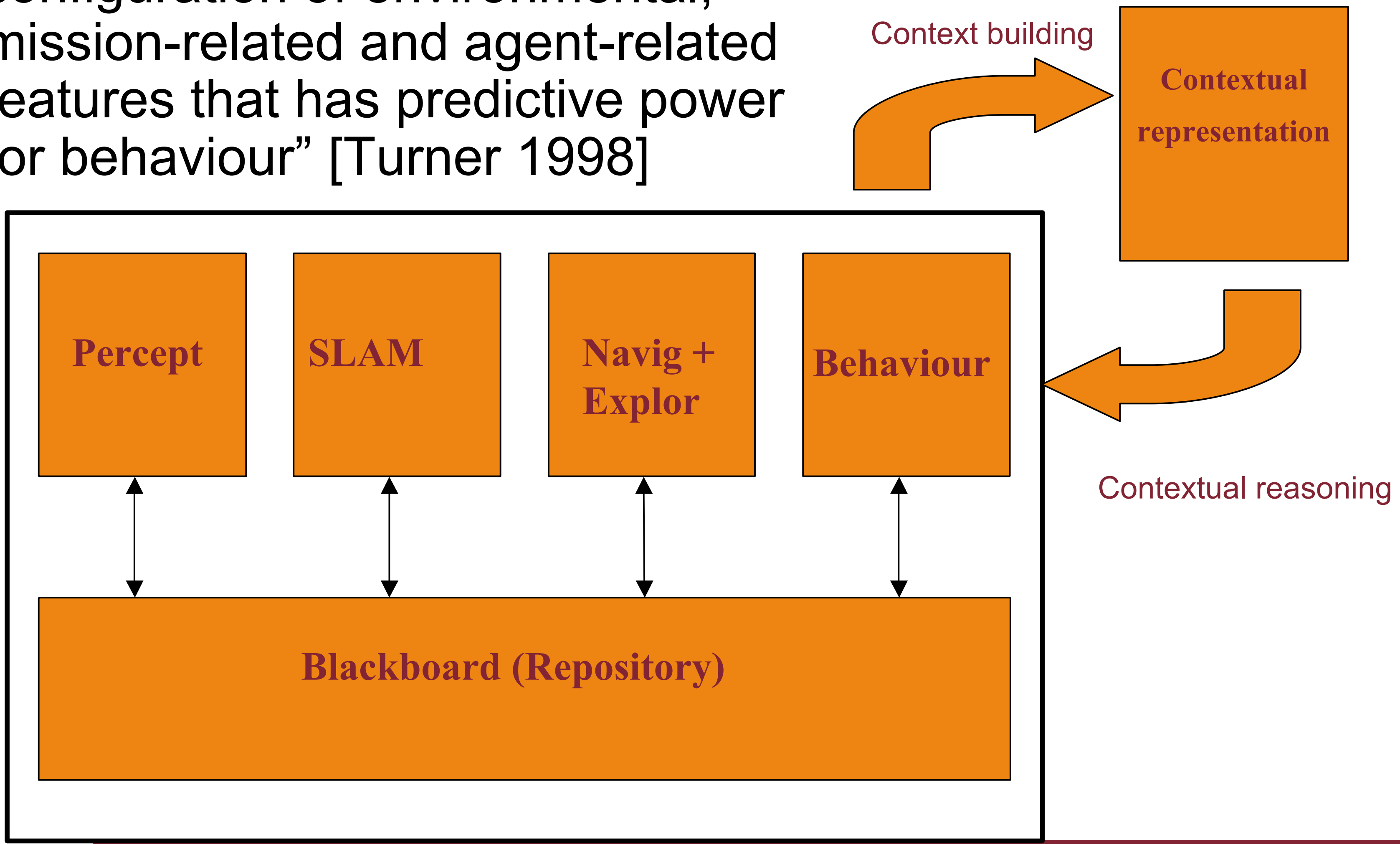
"A context is any identifiable configuration of environmental, mission-related and agent-related features that has predictive power for behaviour" [Turner 1998]



Mapping: Scan Matching & RFIDs

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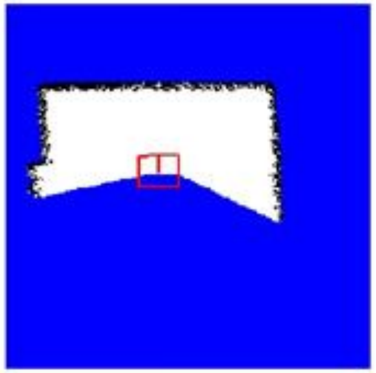
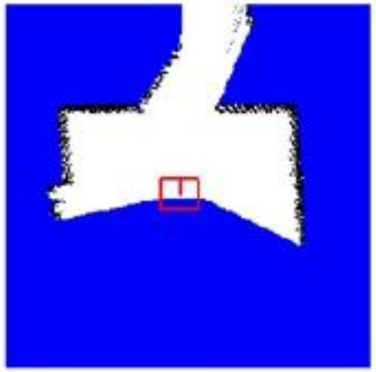
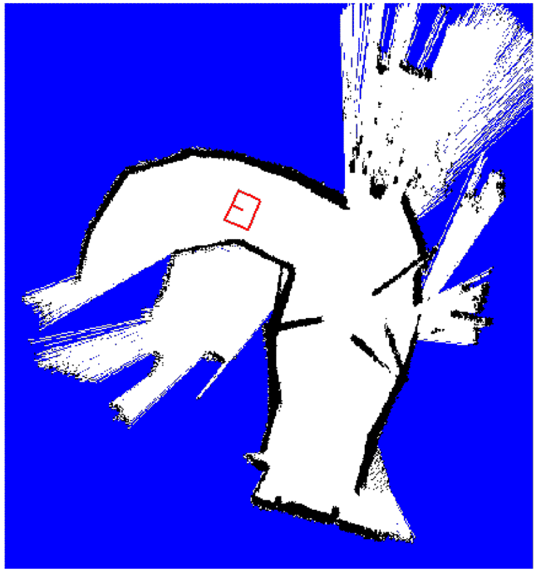
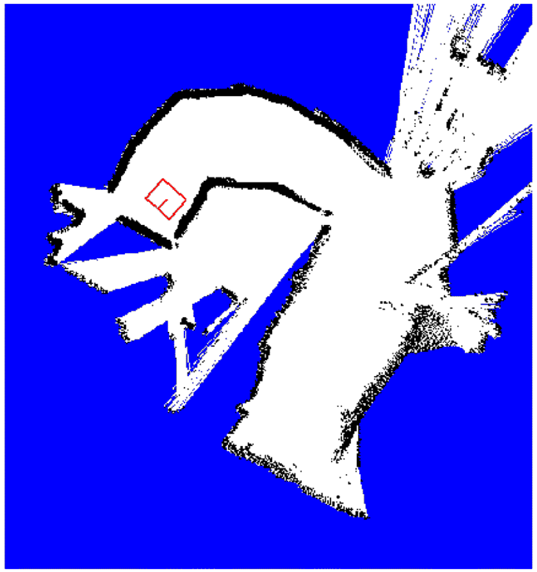
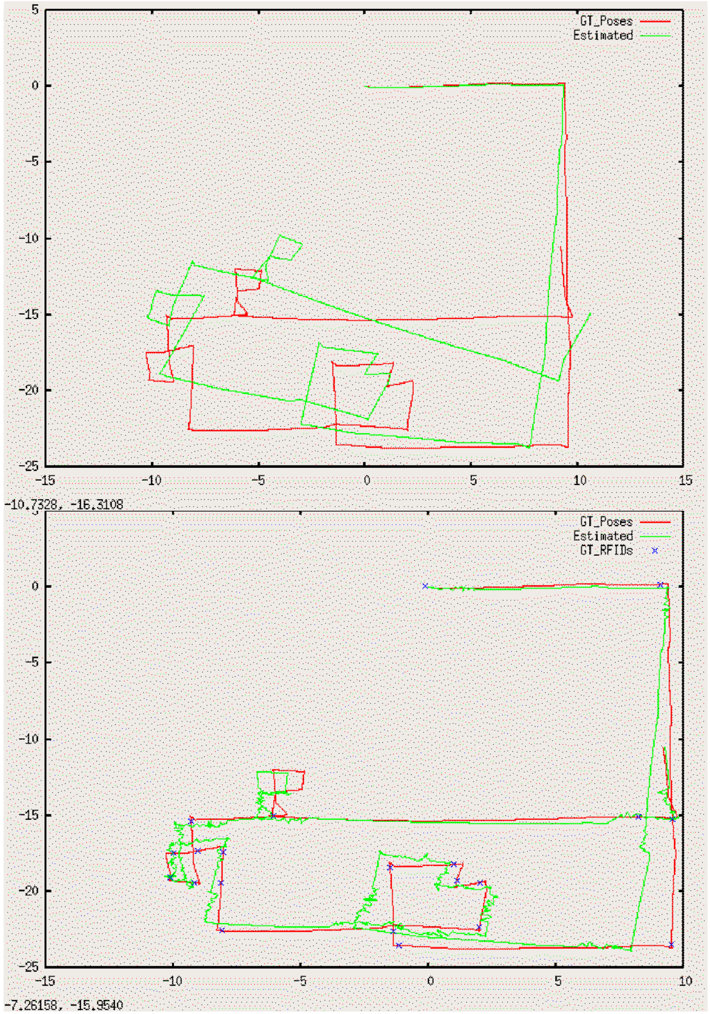

Mapping, Navigation and Exploration

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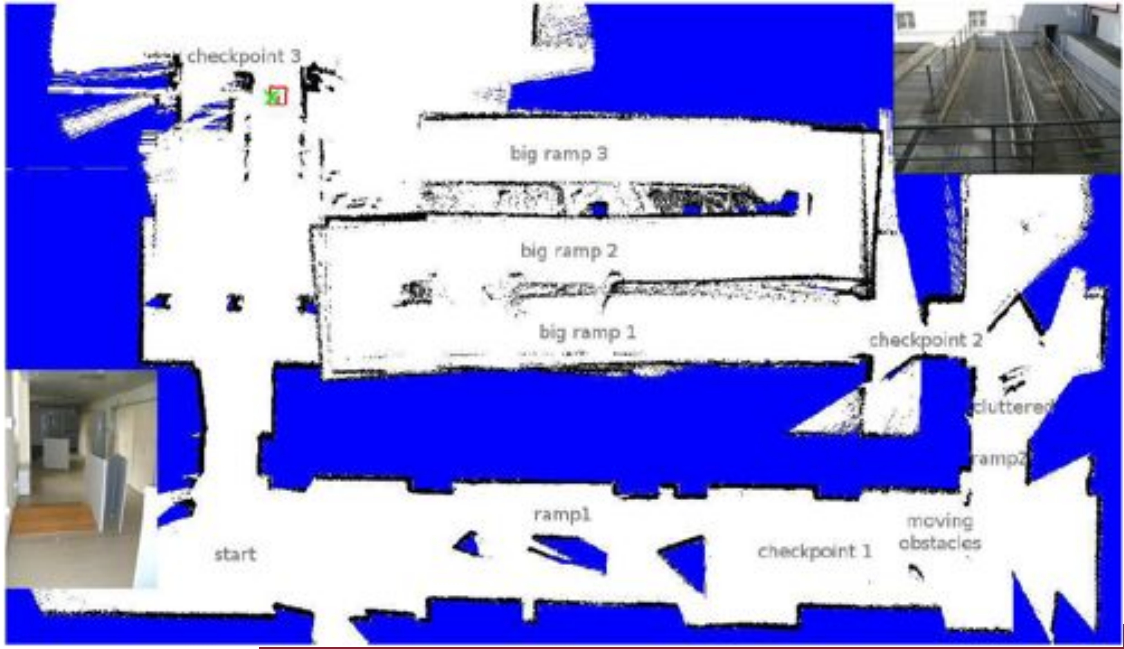
Module	Parameter	Values
Navigation	MAX_SPEED MOTION_PLANNER	low, medium, high RKT, DWA
Mapping	MAPPING_MODE SCAN_MATCH	static, dynamic, off on, off

Contextual Variable	Meaning
cluttered	robot is in a cluttered area
rough	robot is in a rough terrain
big_ramp	robot is approaching or on a big ramp
ramp	robot is approaching or on a small ramp
dynamic	robot is in an area with dynamic obstacles
rotating	robot is rotating
DWA_stalled	robot is stalled with DWA motion planner
RKT_stalled	robot is stalled with RKT motion planner



Contextual Rules
IF *cluttered* OR *ramp* OR *rough* THEN MAX_SPEED = low
IF *big_ramp* THEN MAX_SPEED = medium
IF *dynamic* THEN MAX_SPEED = medium
IF *dynamic* THEN MAPPING_MODE = dynamic
IF *cluttered* THEN MOTION_PLANNER = RKT
IF *cluttered* THEN SCAN_MATCH = off
IF *big_ramp* AND *rotating* THEN SCAN_MATCH = on
IF *ramp* THEN MAPPING_MODE = off
IF *ramp* OR *big_ramp* THEN SCAN_MATCH = off
IF *DWA_stalled* THEN MOTION_PLANNER = RKT
IF *RKT_stalled* THEN MOTION_PLANNER = DWA
IF *true* THEN SCAN_MATCH = on
IF *true* THEN MAPPING_MODE = static
IF *true* THEN MOTION_PLANNER = DWA
IF *true* THEN MAX_SPEED = high

Multi-robot Teams for disaster response robotics

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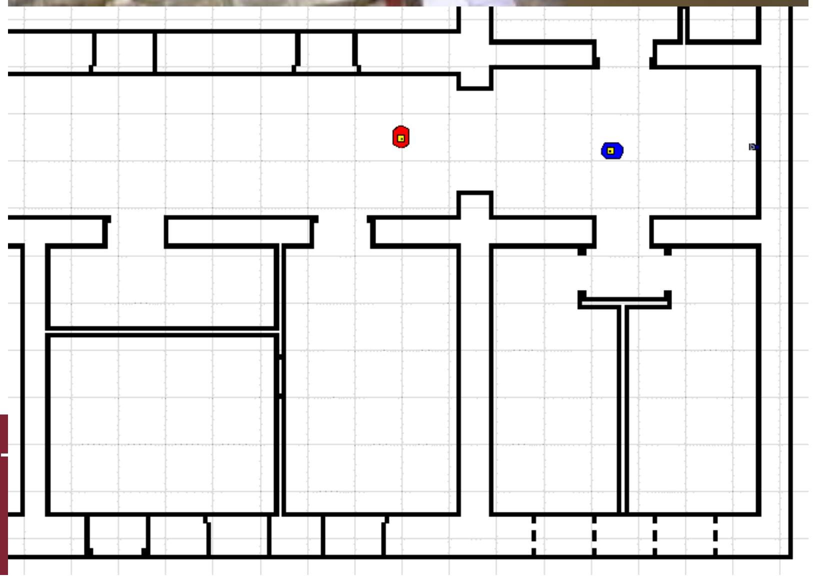
- Multiple robots:
  better performance and robustness
  - Cooperative Situation Awareness
  - Cooperative Search and Exploration
- Multi-Robot ≠ Multi-Agent
  - Partial knowledge
  - Perception noise
  - Communication constraints

… coordination

… operators/robots ratio



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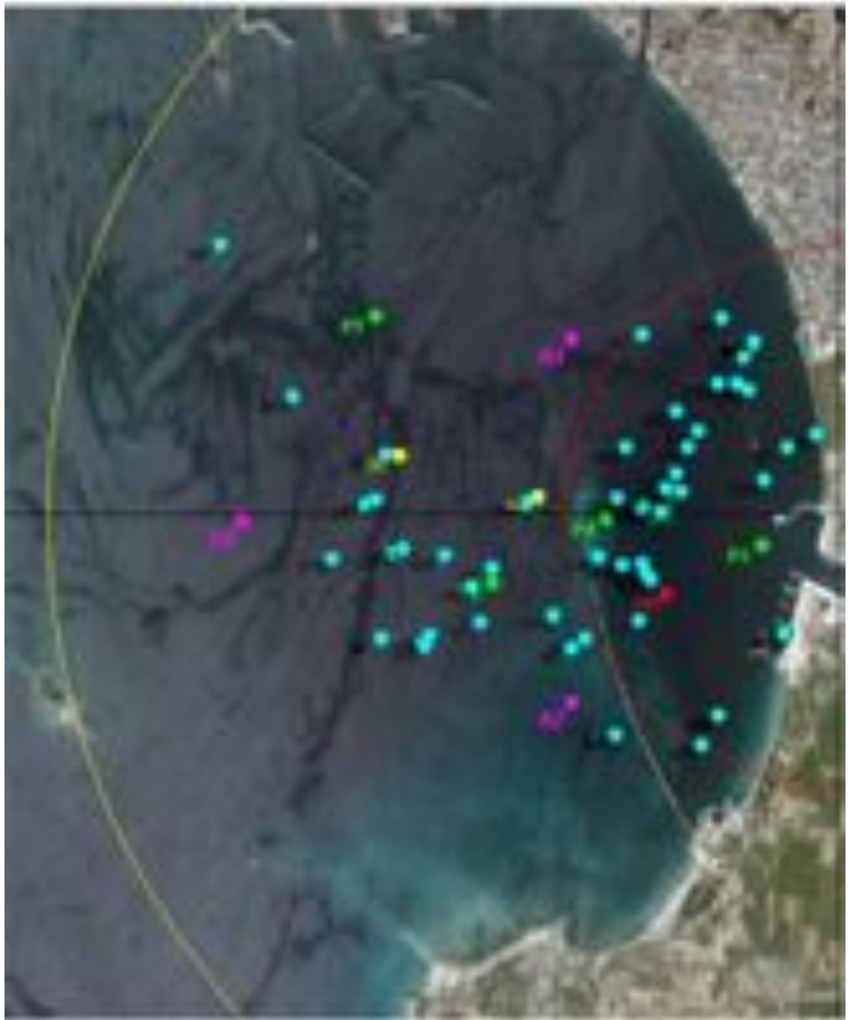
Cooperative Perception

- Perception is a bottleneck
- Dynamic Environment
- Many agents
- Situation awareness



NOT only ROBOTS

Problem modeling & solution

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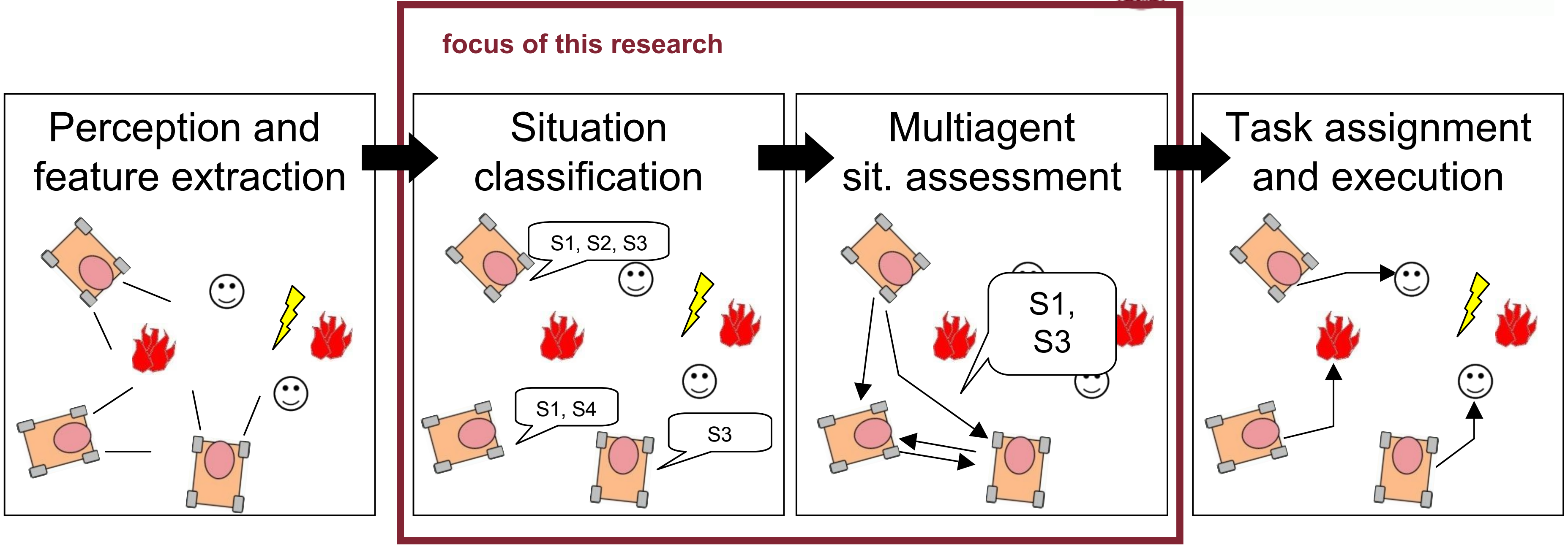

1. Single-agent Situation Assessment using ontology classification
2. Distributed Situation Assessment with simple events
3. Distributed Situation Assessment with justifications

HRI for Multi Robot

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Single Operator / Multi Robot

Design as result of experiments

Adjustable Autonomy

Egocentric and allocentric views

Video Feedback

Remote Control

Task oriented benchmarking

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(Steps) towards:

Benchmarking individual tasks

- Navigation/Mapping/HRI

Benchmarking missions:

- Simulation
- Competitions
- Rescue robotics exercises

Benchmarking not provided by product developers!

Benchmarking navigation

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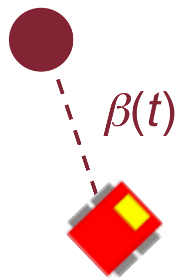
MoVeME is a framework to evaluate motion systems in terms of obstacle avoidance, path-planning, motion planning (but also mapping and localization)

Benchmarks *and* performance metrics specific to important features for end-users

Examples (rescue missions)
- Success (task metric)
- Accuracy (task metric)
- Time (task metric)
- Curvature Change (trajectory metric)
- Risk (trajectory metric)

$$Risk = \int_0^{t_F} \frac{1}{\beta(t)} dt$$



$$\kappa(t) = \left| \frac{\omega(t)}{v(t)} \right| \quad CC = \int_0^{t_F} |\kappa'(t)| dt$$

Benchmarking interfaces

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Mobile interfaces for mobile operators

Tradeoff mobility /quality of display

Cooperation among remote and in situ operator

SoA benchmarking and Performance Evaluation

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- Fancy mobile platform
- Powerful sensors
- Best SLAM
- Super Navigation
- Optimal Exploration
- Faboulous Object Detection
- Wonderful HRI

But, … **rescue robots get stuck !!!**

USARSim

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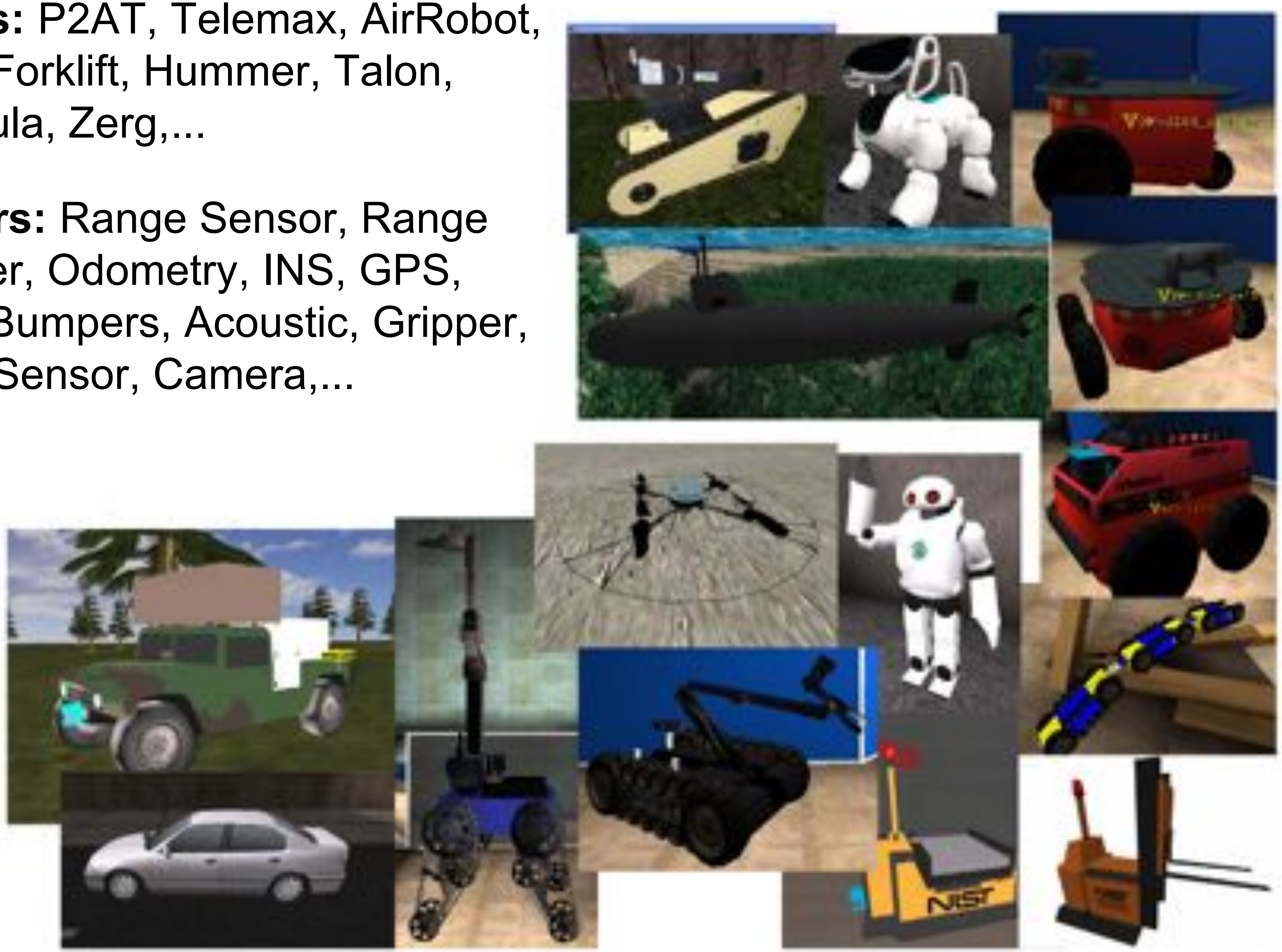
Unified System for Automation and Robot Simulation

3D rendering with UT3 game engine

USARSim Robots and Sensors

Robots: P2AT, Telemax, AirRobot, AIBO, Forklift, Hummer, Talon, Tarantula, Zerg,...

Sensors: Range Sensor, Range Scanner, Odometry, INS, GPS, RFID, Bumpers, Acoustic, Gripper, Victim Sensor, Camera,...



Images are courtesy of NIST

NIST-RoboCup Rescue Arenas

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RoboCup Competitions

Goal: find victims in a disaster scenario

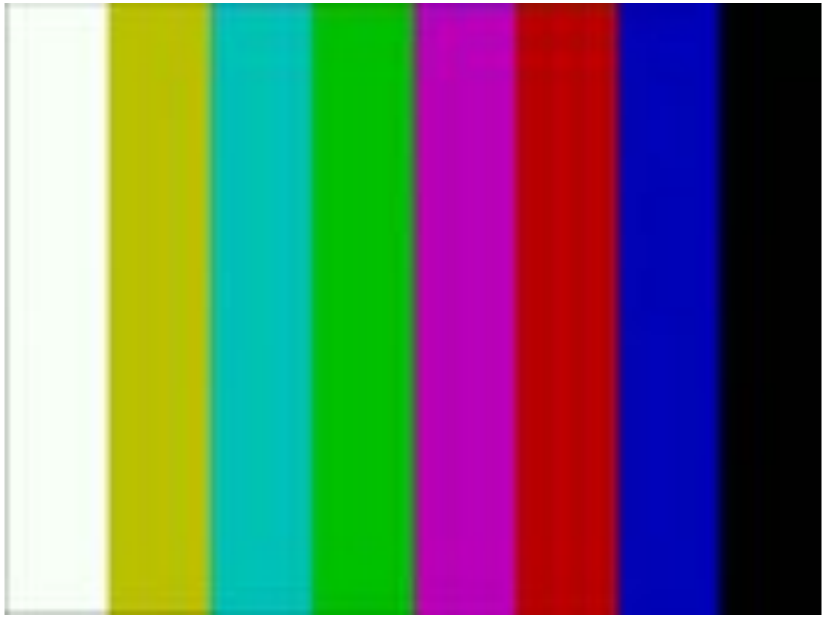
- Rescue arenas from NIST

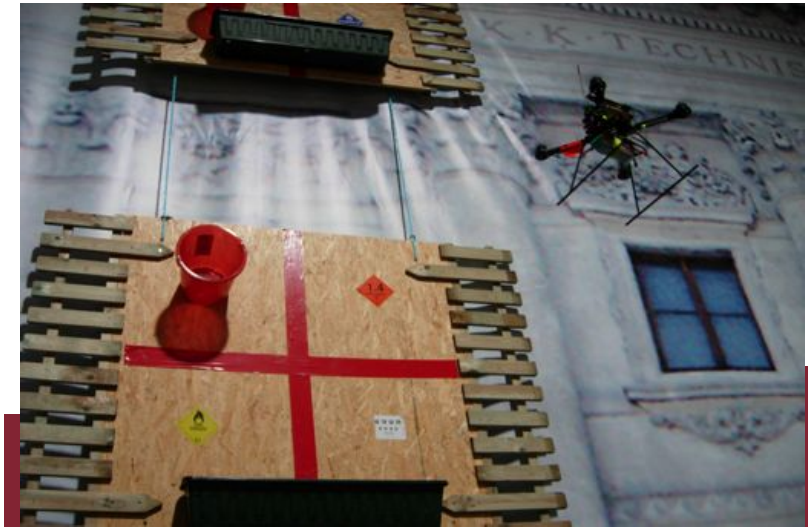
Two categories in competition

- Autonomy
- Tele-operated

Soon

- flying robots





Disaster Response Exercises

- **NIST Response Robot Evaluation Exercise #6 (Disaster City, TX, US), March 8-11, 2010**

- **C-ELROB (2011)**

EU trial for Robotics in security domains, fire brigades,civil protection, and disaster control

The development cycle

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Camps
- Test new devices and solutions
- Develop performance evaluation

Competitions
- Integrated prototype systems
- Test performance methods

Disaster Response Exercises
- Field evaluation of best in class
- Challenge industrial solutions

RESEARCH

Market

Future

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Disaster response robotics

- μ-aerial
- Fleets of μ-aerials
- Human Robot Interfaces

AI Research

- AI on robots
- Prove that knowlegde can "pay off" in Robotics
- Methodologies for evaluation (benchmarking)

Lisbon ECAI 2010 19th European Conference on Artificial Intelligence PORTUGAL

Workshop

Benchmarking Intelligent (Multi-)Robot Systems

Acknowledgements

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