Cooperative Multi-robot Systems

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MINESWEEPERS
TOWARDS A LANDMINE-FREE WORLD

Outline

- Introduction to Multi-robot Systems (MRS)
- MRS Taxonomy
- Benchmark Problems of MRS
- Cooperative Multi-robot Systems
- Multiple Minesweepers

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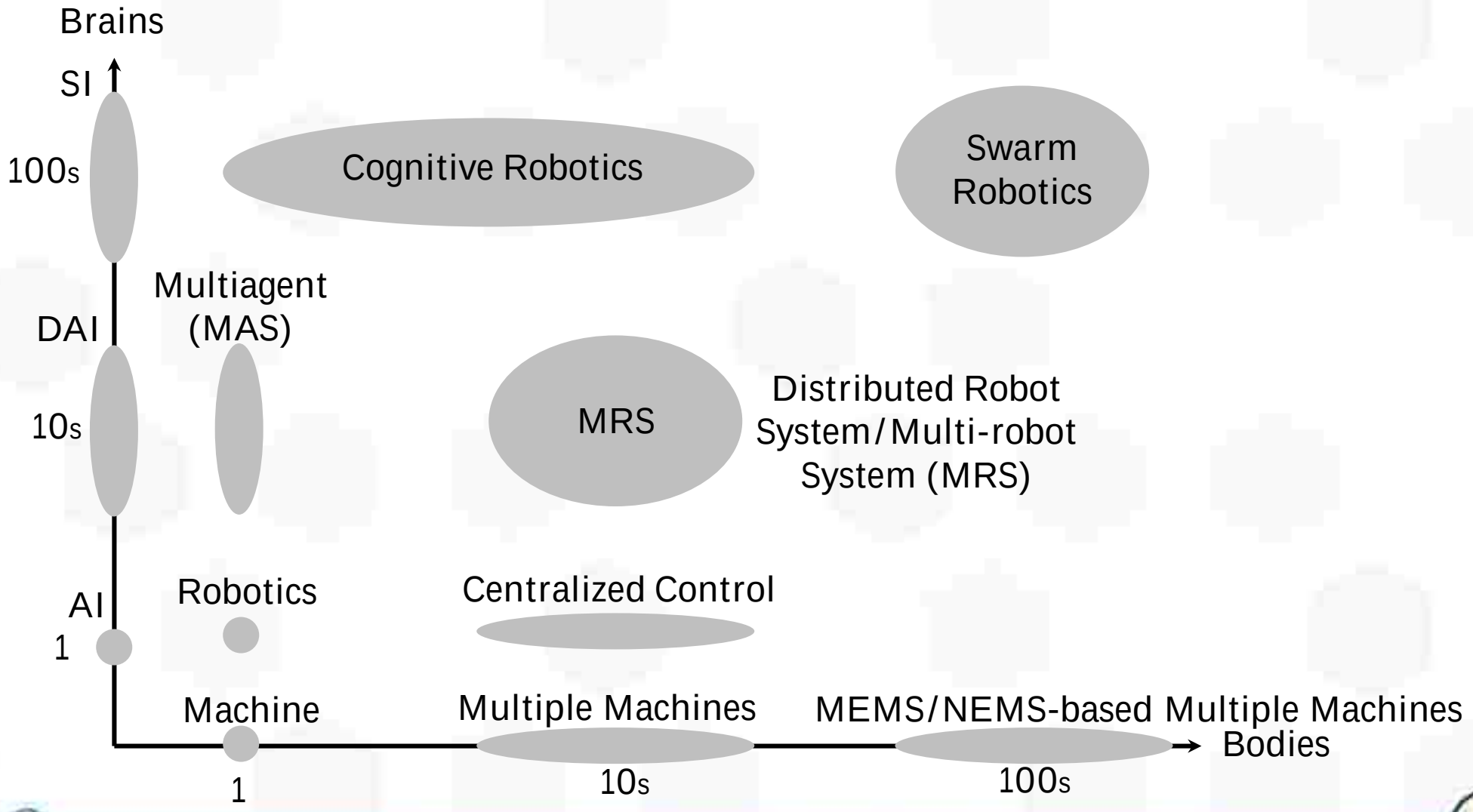
• Introduction to Multi-robot Systems: Body/Brain Evolution



• Introduction to Multi-robot Systems

Multirobot systems (MRS) are a group of robots that are designed aiming to perform some collective behavior.

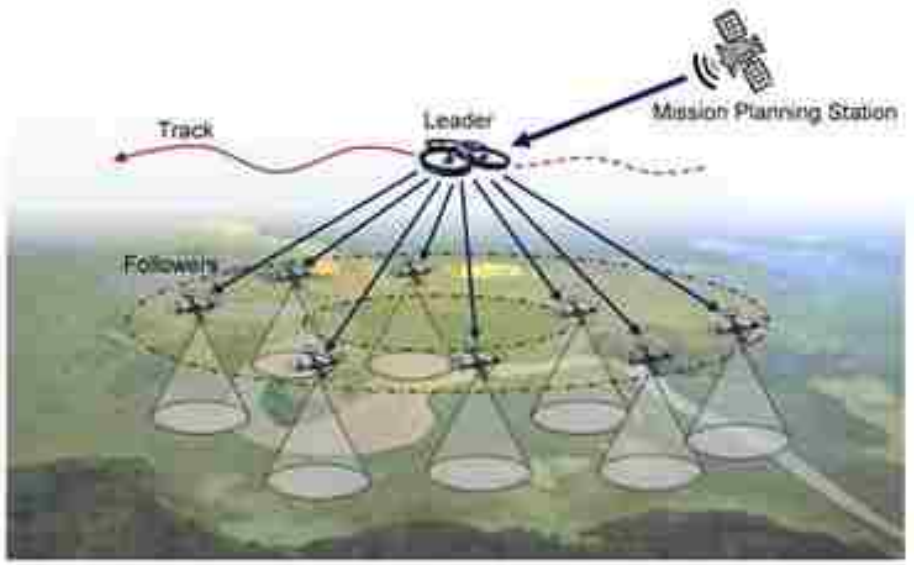
The MRS is gaining great interest because of the following reasons:

◊ Resolving task complexity

◊ Increasing performance

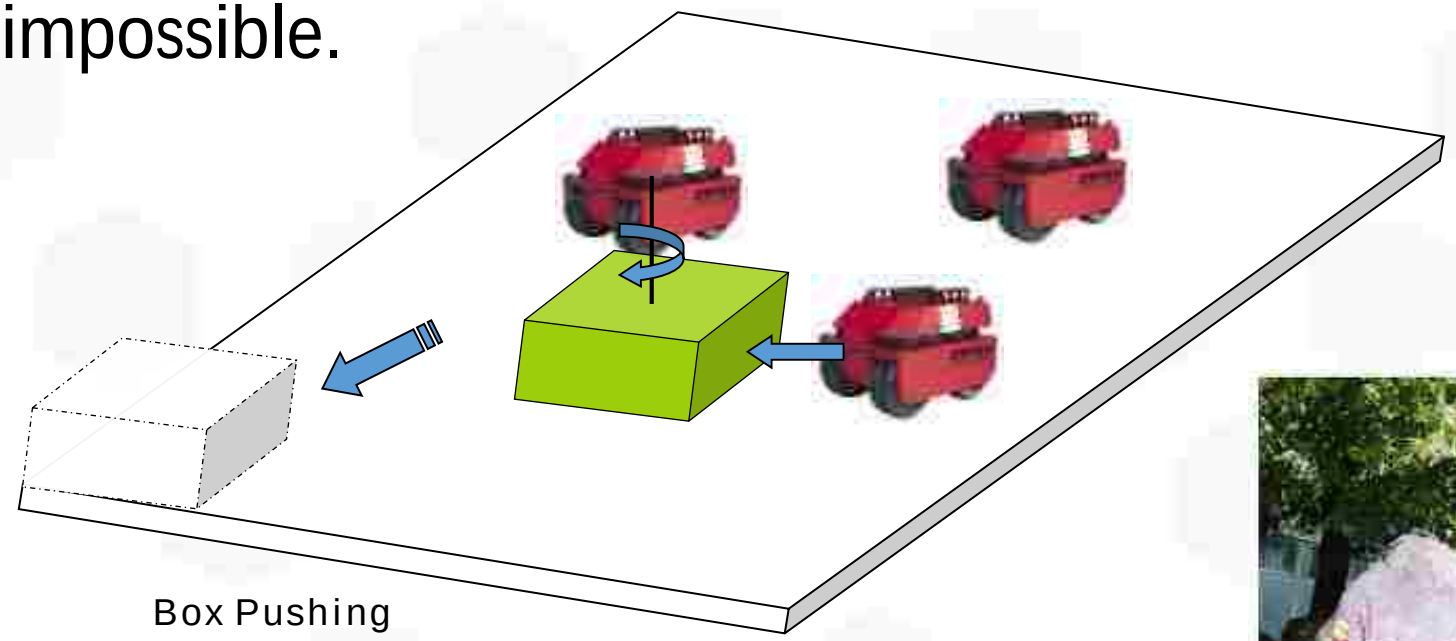
◊ Reliability

◊ Simplicity in design



• Why Multi-robot Systems?: Resolving task complexity

Some tasks may be quite complex for a single robot to do or even it might be impossible.



Box Pushing

Crossing a gap

• Why Multi-robot Systems?: Resolving task complexity

Some tasks are inherently distributed.

Heterogeneous team of an air and two ground vehicles that can perform cooperative reconnaissance and surveillance

• Why Multi-robot Systems?: Resolving task complexity

Some tasks are diverse and required different capabilities.

A robot in every home

“As I look at the trends that are now starting to converge, I can envision a future in which robotic devices will become a nearly ubiquitous part of our day-to-day lives.

The challenges facing the robotics industry are similar to those we tackled in computing three decades ago.”

Bill Gates, 2007
Scientific American

• Why Multi-robot Systems?: Increasing performance

Multiple robots can solve problems faster using parallelism.

Minimize:

- Task completion time

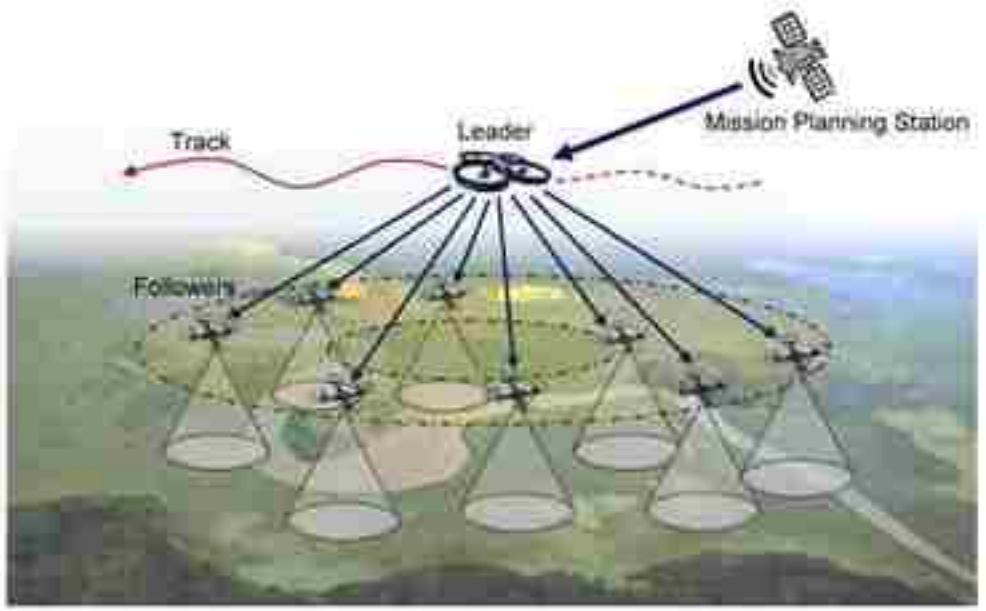
Maximize:

- Area Coverage
- Object Coverage
- Radio Coverage

• Why Multi-robot Systems?: Increasing performance

Multiple robots can solve problems faster using parallelism.

Forces fire real-time monitoring



Multiple Spectral Bands Aerial Imaging

• Why Multi-robot Systems?: Reliability

The introduction of multiple robots increases robustness through redundancy.

Increasing the system reliability because having only one robot may work as a bottleneck for the whole system especially in critical times.

But when having multiple robots doing a task and one fails, others could still do the job.

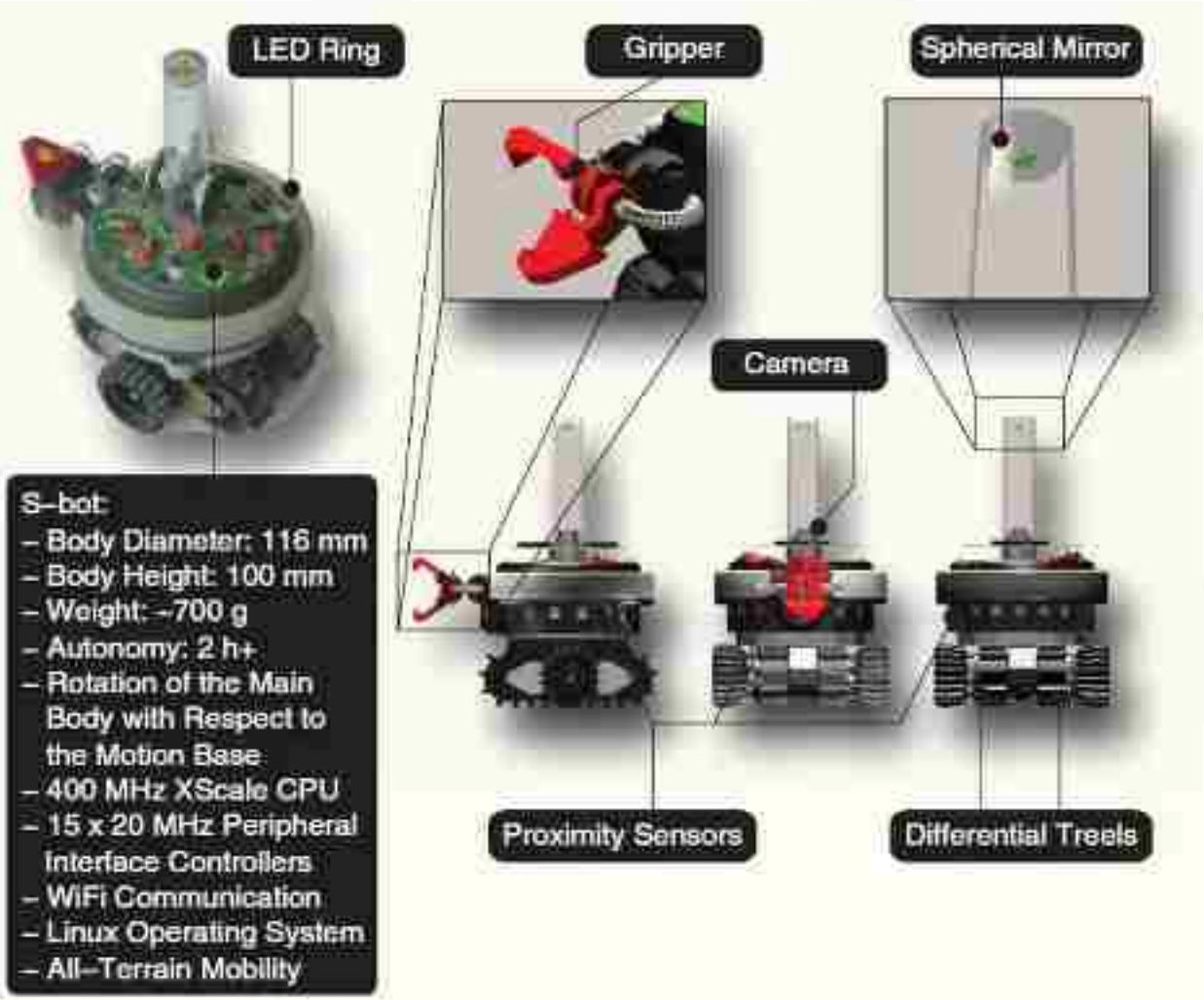
• Why Multi-robot Systems?: Simplicity in design

Building several resource-bounded robots is much easier than having a single powerful robot

Powerful single robot

Several resource-bounded simple robots

• Why Multi-robot Systems?: Simplicity in design

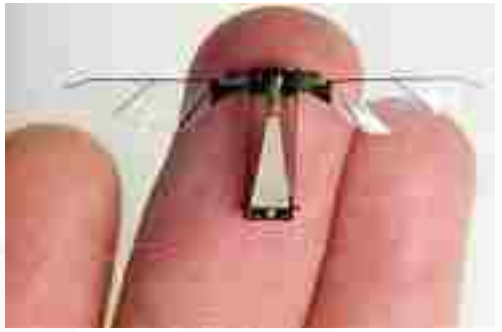


S-bot: an autonomous, mobile robot capable of self-assembly

ANDERS LYHNE CHRISTENSEN, REHAN O'GRADY, AND MARCO DORIGO, "Morphology Control in a Multirobot System: Distributed Growth of Specific Structures Using Directional Self-Assembly", IEEE Robotics & Automation Magazine, December 2007.

- # MRS Applications: Intelligence, Surveillance and Reconnaissance

PD-100 PRS



Black Hornet Nano

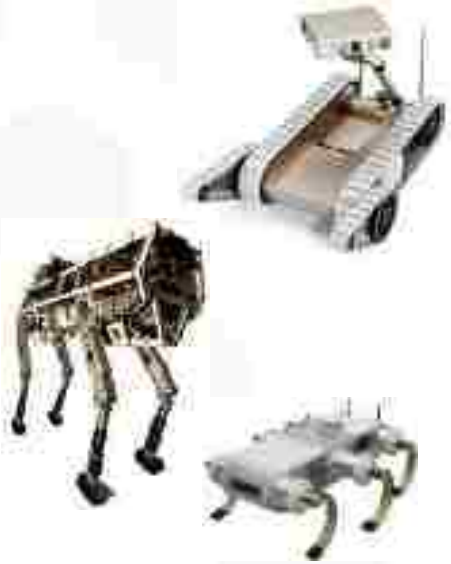
• MRS Applications: Search and Rescue

Companion slides for the book Bio-Inspired Artificial Intelligence: Theories, Methods, and Technologies by Dario Floreano and Claudio Mattiussi, MIT Press

• MRS Applications: UXVs

Unmanned Vehicles (UXVs)

Unmanned Ground Vehicles (UGV)



Unmanned Aerial Vehicles (UAV) & Micro Aerial Vehicles (MAV)

Unmanned Surface Vehicles (USV)

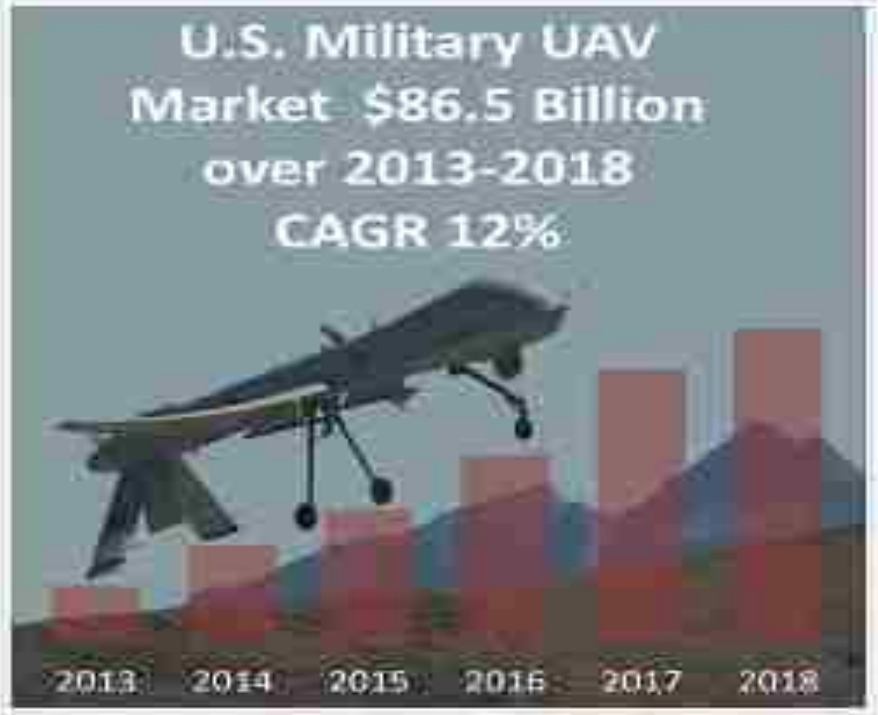
Unmanned Underwater Vehicles (UUV)

MRS Applications: UXVs

- Congress has mandated that by 2015, 1/3rd of all US military missions should be unmanned.
- There are 17,300 drones in the US army inventory.
- These drones can carry up to 1360 kg of weapons.
- Fabricated by Boeing

A forward looking infrared (FLIR) camera onUAV

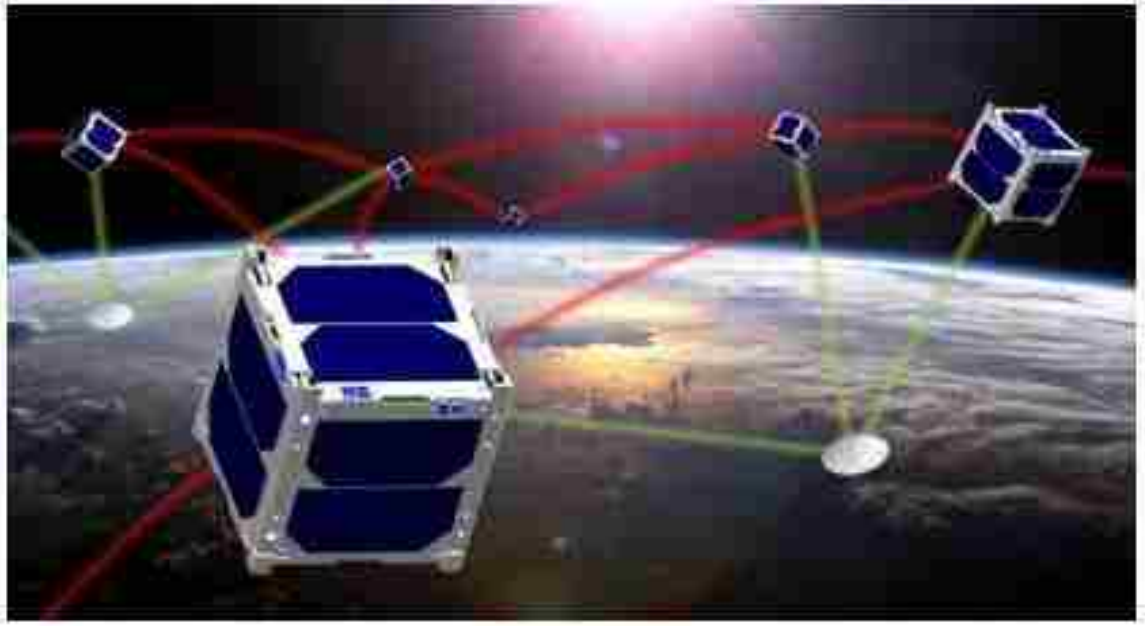
UAV carrying Viper Strike Weapon System



Source: http://www.marketresearchmedia.com/?p=509

• MRS Applications: Small and Pico Satellites

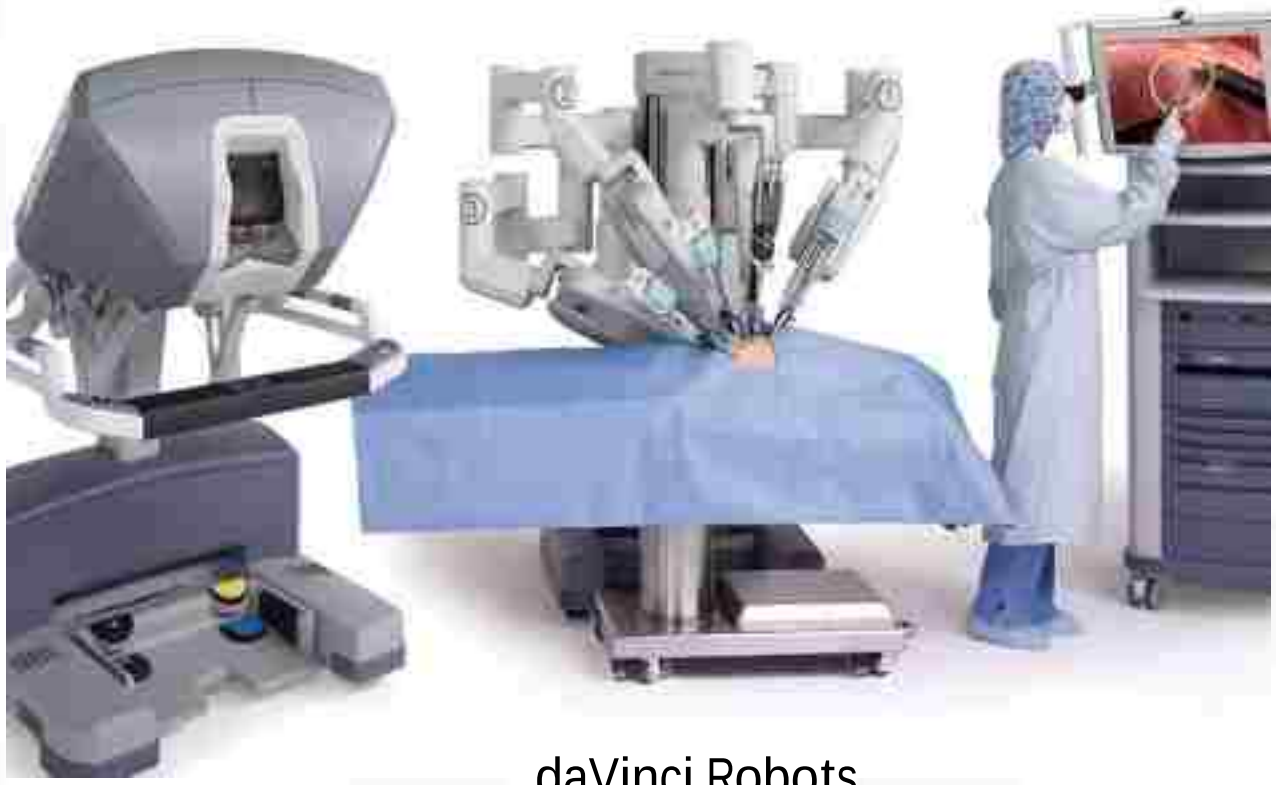
Giant Solar-powered Satellite



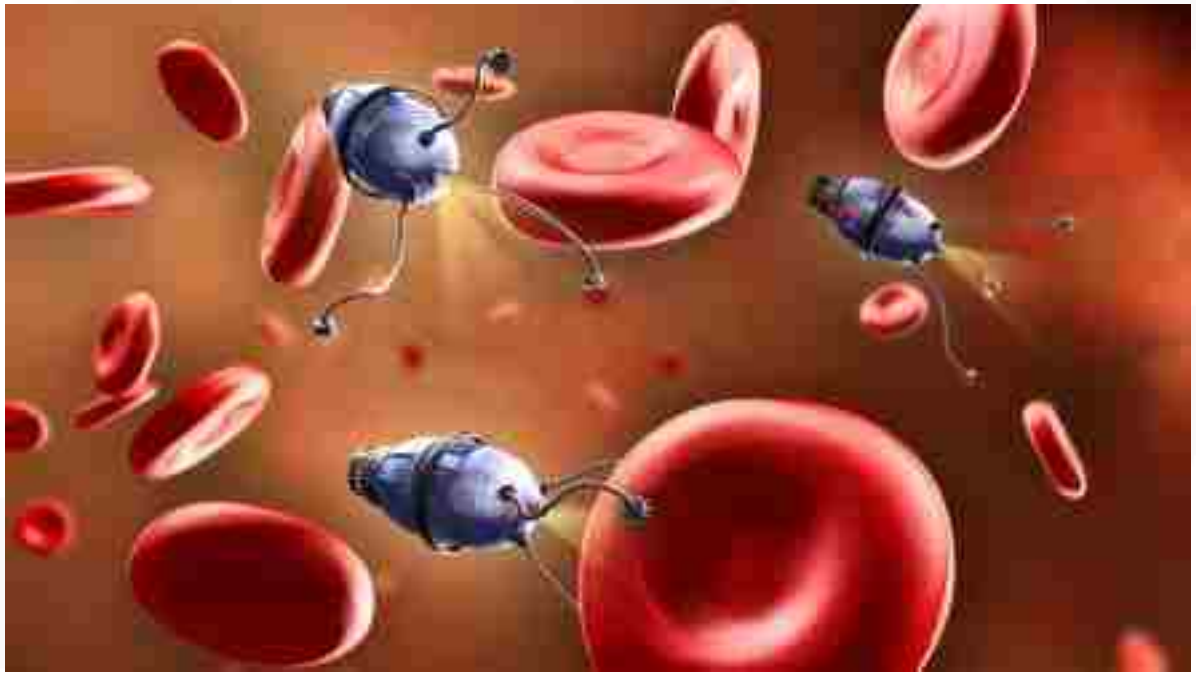
Network of CubeSat

More info: Klaus Schilling, IEEE Distinguished Lecture Available at: http://ras-egypt.org/activities.html

• MRS Applications: Medicine

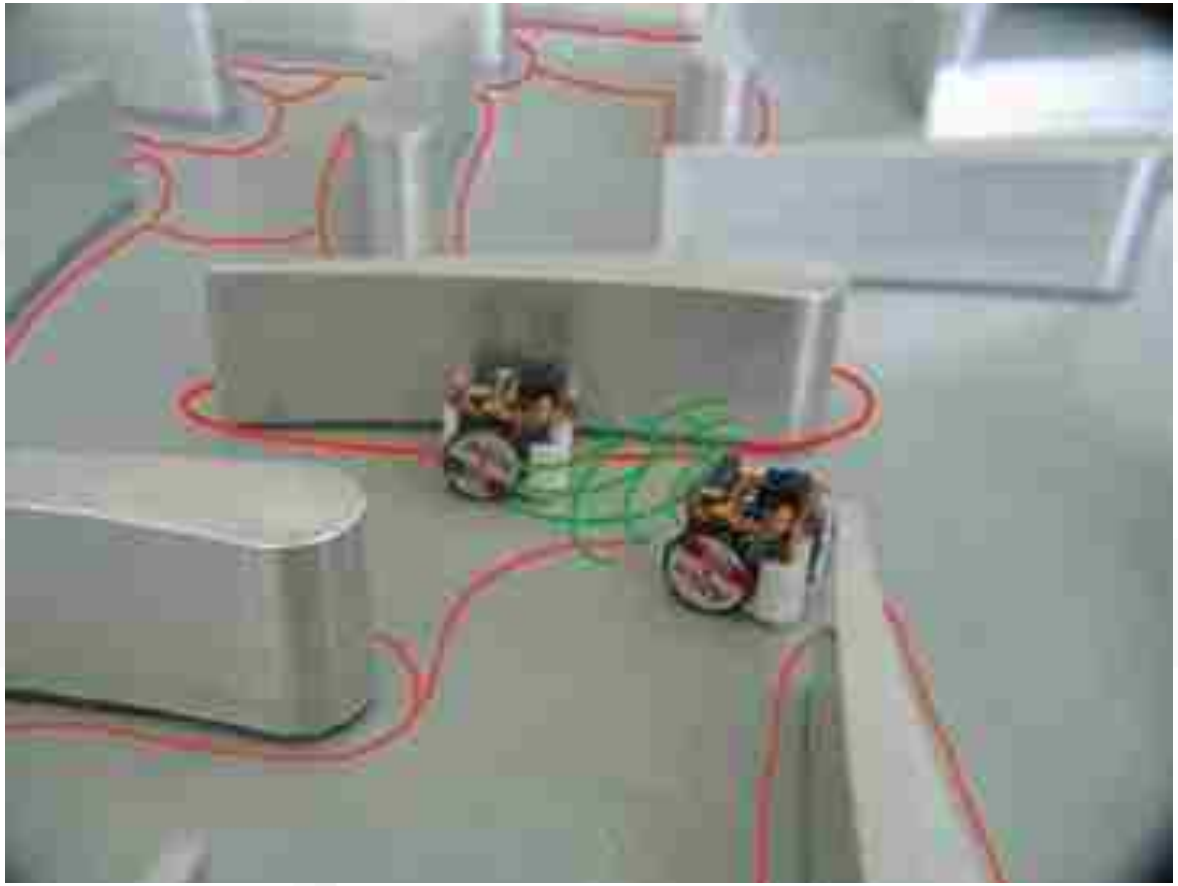


daVinci Robots



Smart drug delivery

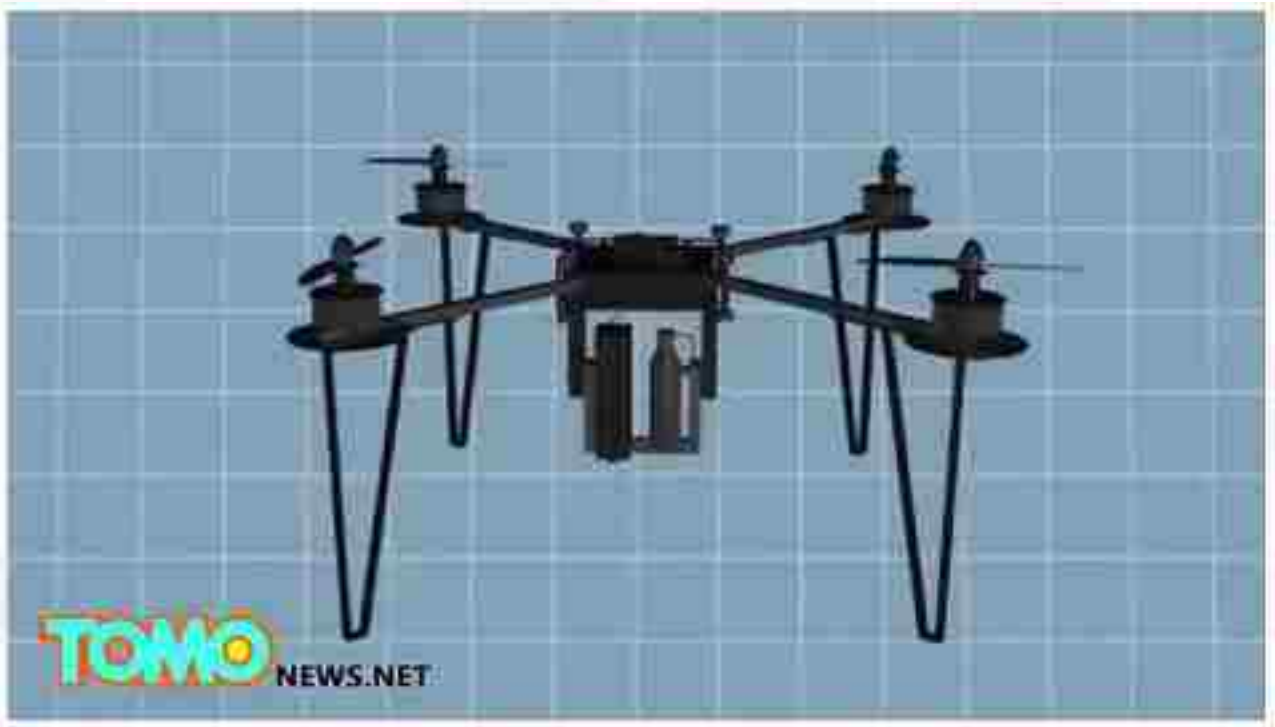
- MRS Applications: Maintenance



Examining turbine blades

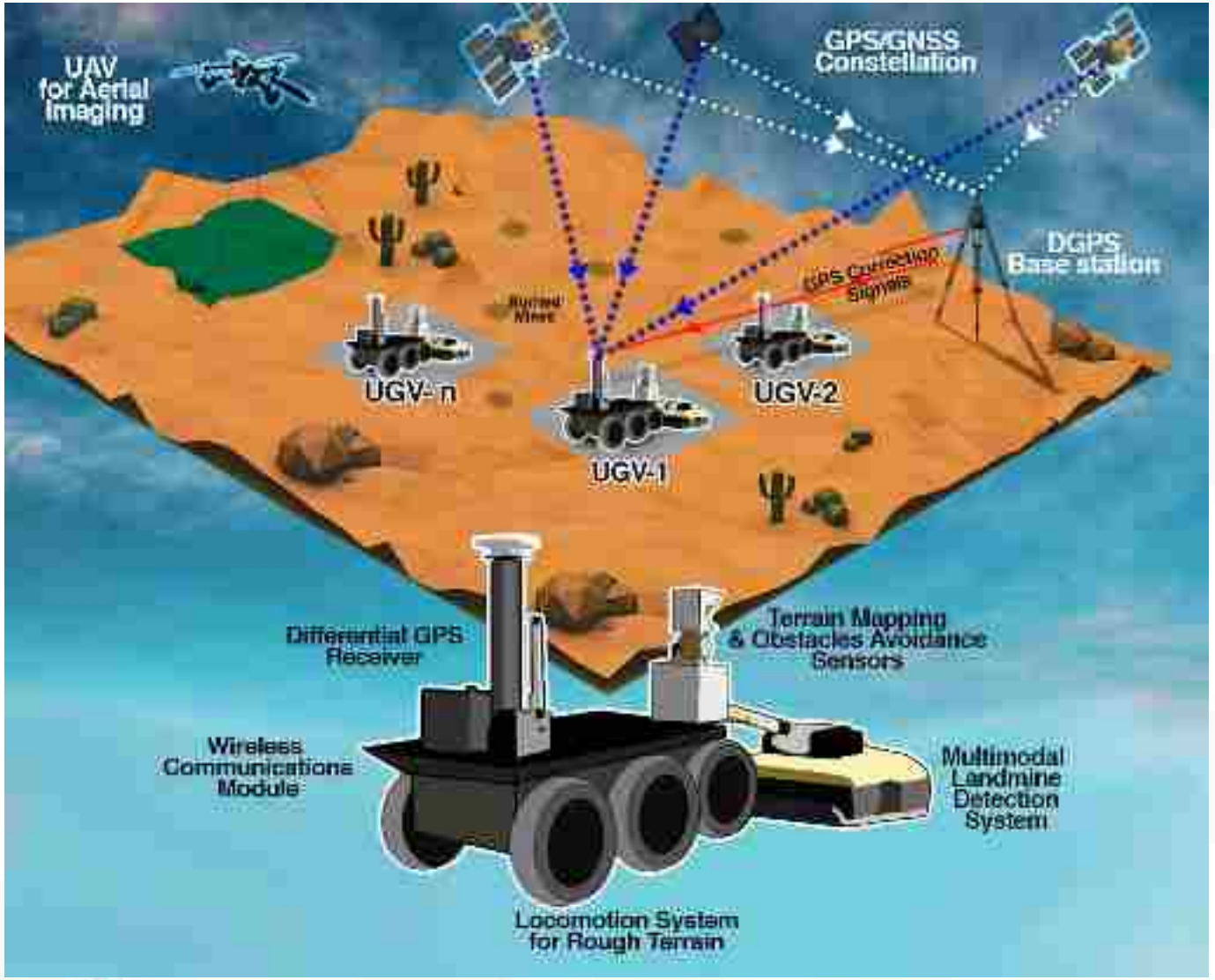
• MRS Applications: Agriculture

The drones will fire pods containing pre-germinated seeds at the ground



YouTube: https://www.youtube.com/watch?v=Ld8omo8xRgQ

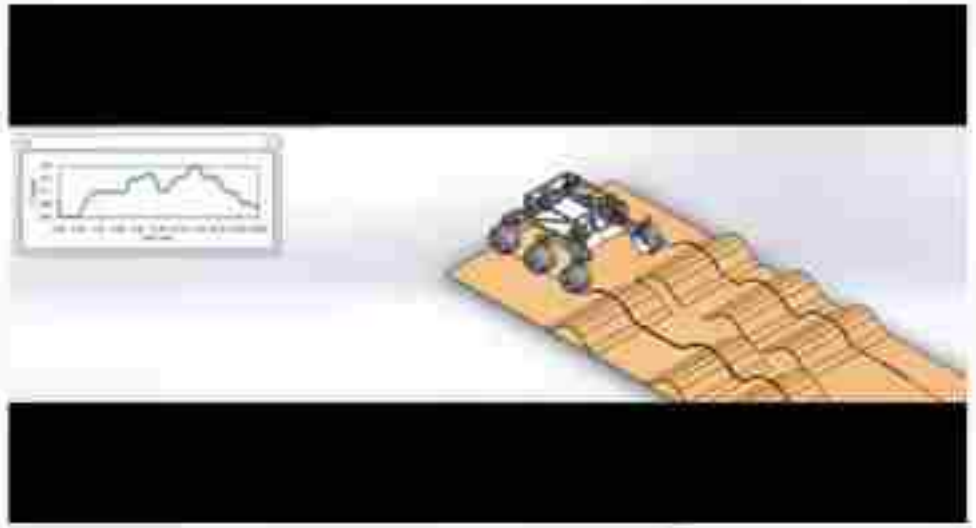
• MRS Applications: Humanitarian Demining



MineProbe: A Distributed Mobile Sensor System for Minefield Reconnaissance and Mapping in Egypt

http://www.mineprobe.org/

PI: Dr. Alaa Khamis



YouTube: MineProbe Channel

• MRS Applications: Self-assembling

http://www.swarm-bots.org/

The SWARM-BOT project aims to study a novel swarm robotics system.

- ◊ It is directly inspired by the collective behavior of social insects and other animal societies.
- ◊ It focuses on self-organization and self-assembling of autonomous agents.
- ◊ Its main scientific challenge lays in the development of a novel hardware and of innovative control solutions.

Swarm-bots, Marco Dorigo, 2005

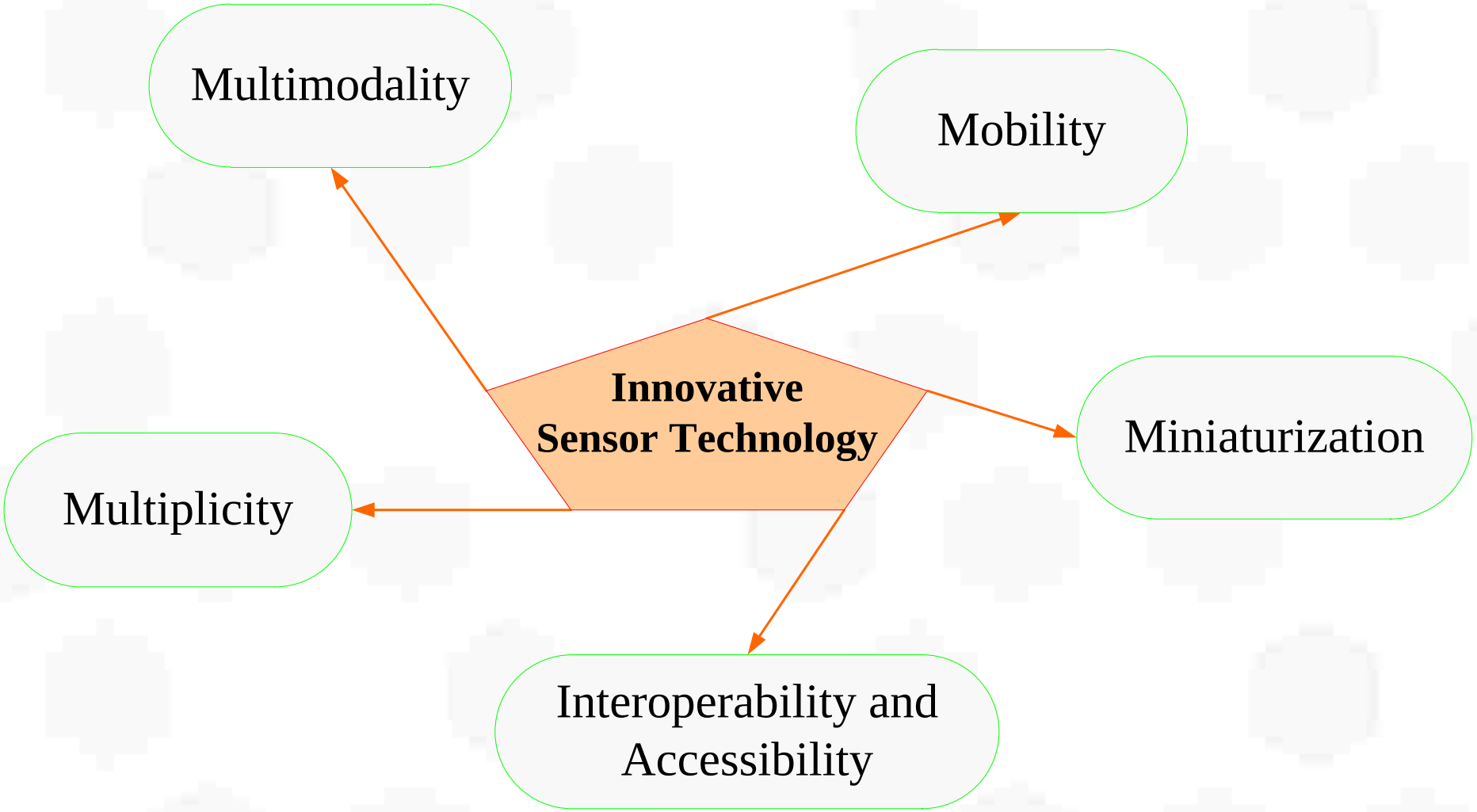
• MRS Applications: Cooperative Mapping

The Centibots project

- The Centibots are a team of 100 autonomous robots (97 ActivMedia Amigobot and 6 ActivMedia Pioneer 2 AT).
- The goal of the project is to demonstrate 100 robots mapping, tracking, guarding in a coherent fashion during a period of 24 hours.

http://www.ai.sri.com/centibots/index.html

• MRS Applications: Smart Sensors



Alaa Khamis: Innovative Sensor Technologies, State Estimation and Multisensor Data Fusion

- **MRS Applications: Smart Sensors**

lower manufacturing cost (mass-production, less materials)

wider exploitation of IC technology (integration)

wider applicability to sensor arrays and lower weight (greater portability)

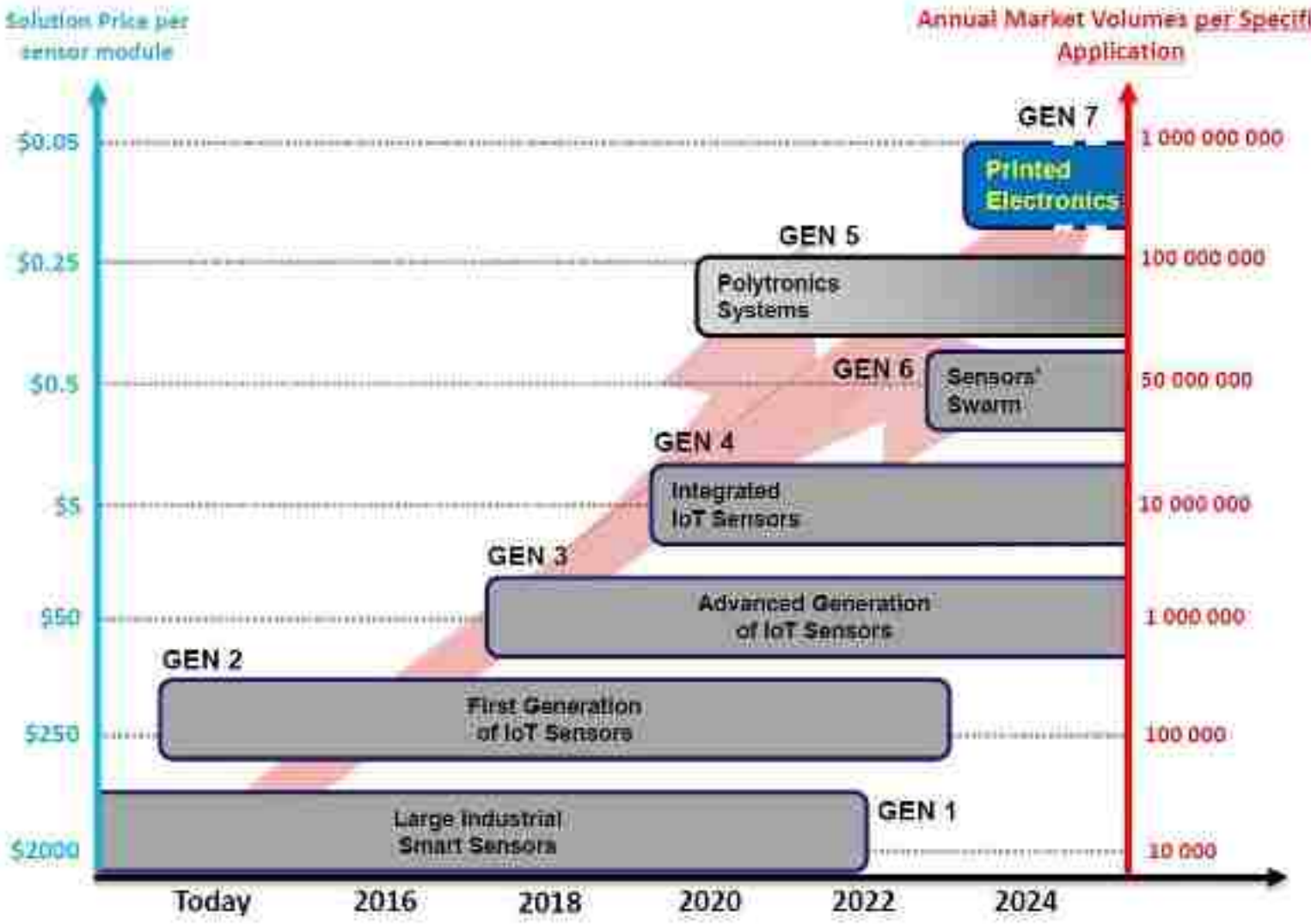
Google contact lens with embedded circuitry to monitor blood glucose levels

Smart patch: a wearable health monitor sensors. Besides the thermal sensor and accelerometer, the device carries a signal amplifier, batteries and radio

Sensirion's highly sensitive thermal flow sensor microchips to measure non-invasively through the wall of a flow channel inside a microfluidic substrate

Printed sensors: Unique sensing labels – based on printed electronics- bring new functionality and crystal clear reads to temperature controlled supply chains.

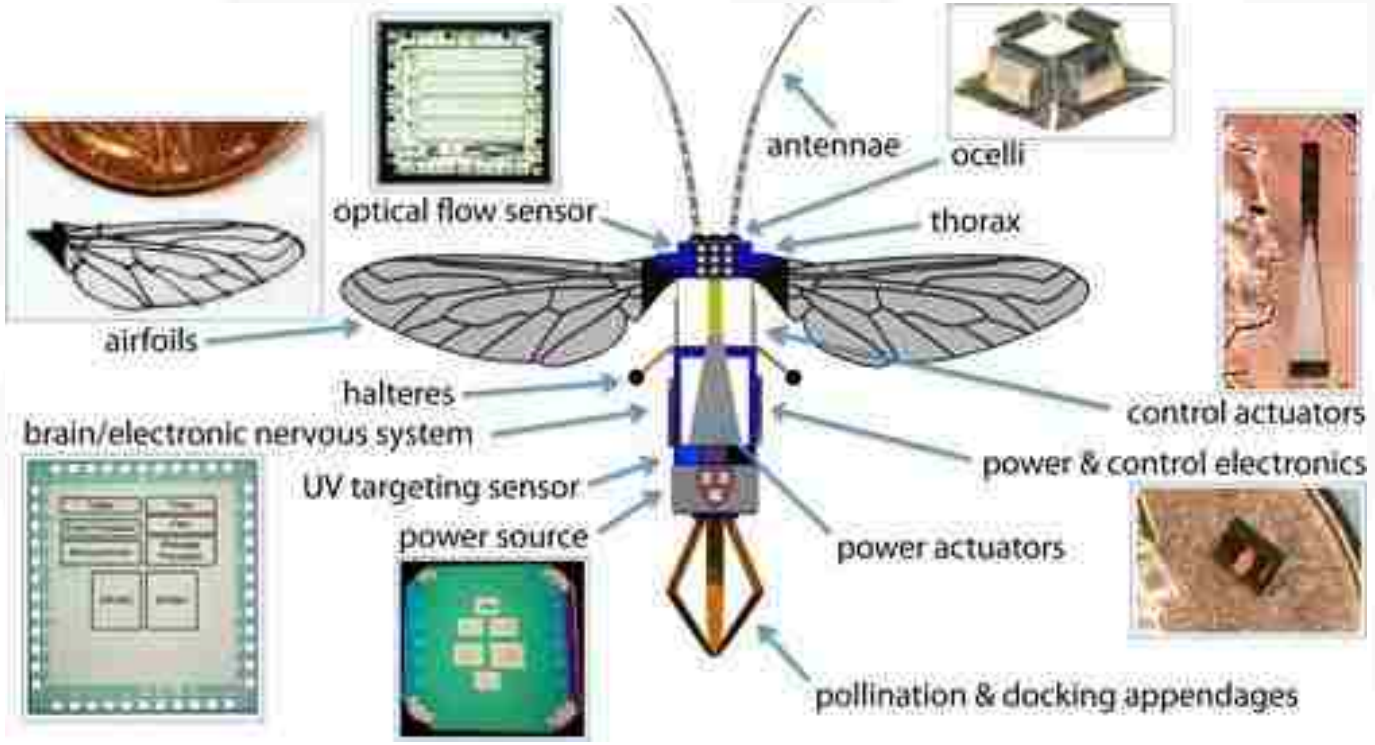
• MRS Applications: Smart Sensors



Source: European plastic electronics industry flexes its muscles

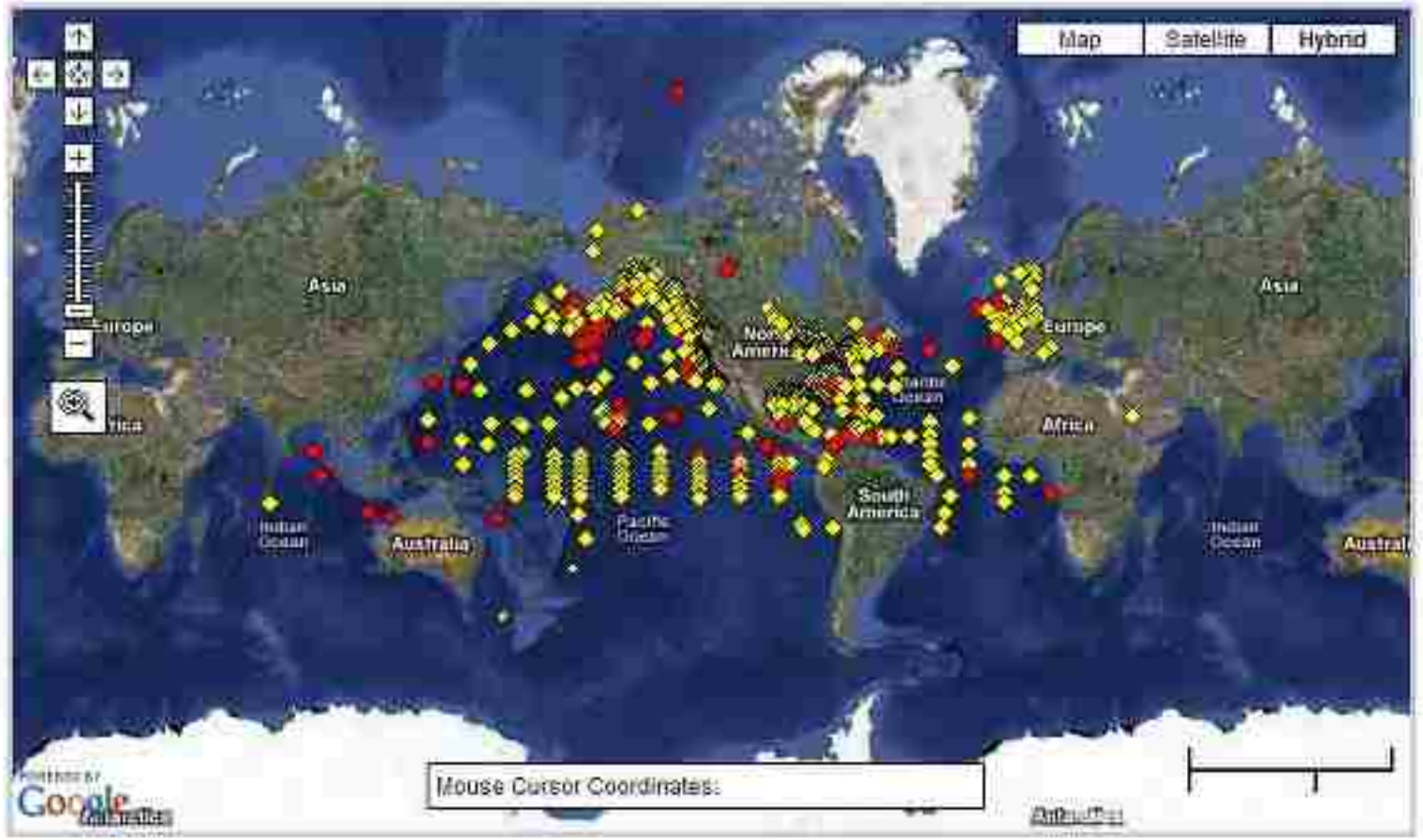
• MRS Applications: Smart Sensors

ROBOBEES project: The objective of this project is to design “smart” sensors; and refine coordination algorithms to manage multiple, independent machines.
Potential applications: Pollination; search and rescue missions, particularly after natural disasters; surveillance; high-resolution weather and climate mapping; traffic monitoring and environmental monitoring.



http://wyss.harvard.edu/viewpressrelease/110/

• MRS Applications: Sensor Web



Alaa Khamis: [Sensor Interoperability and Accessibility]

- Stations with recent data
- Stations with historical data only
- Stations with no data in last 8 hours (24 hours for tsunami stations)
- Tsunami station in event mode (within previous 24 hours)

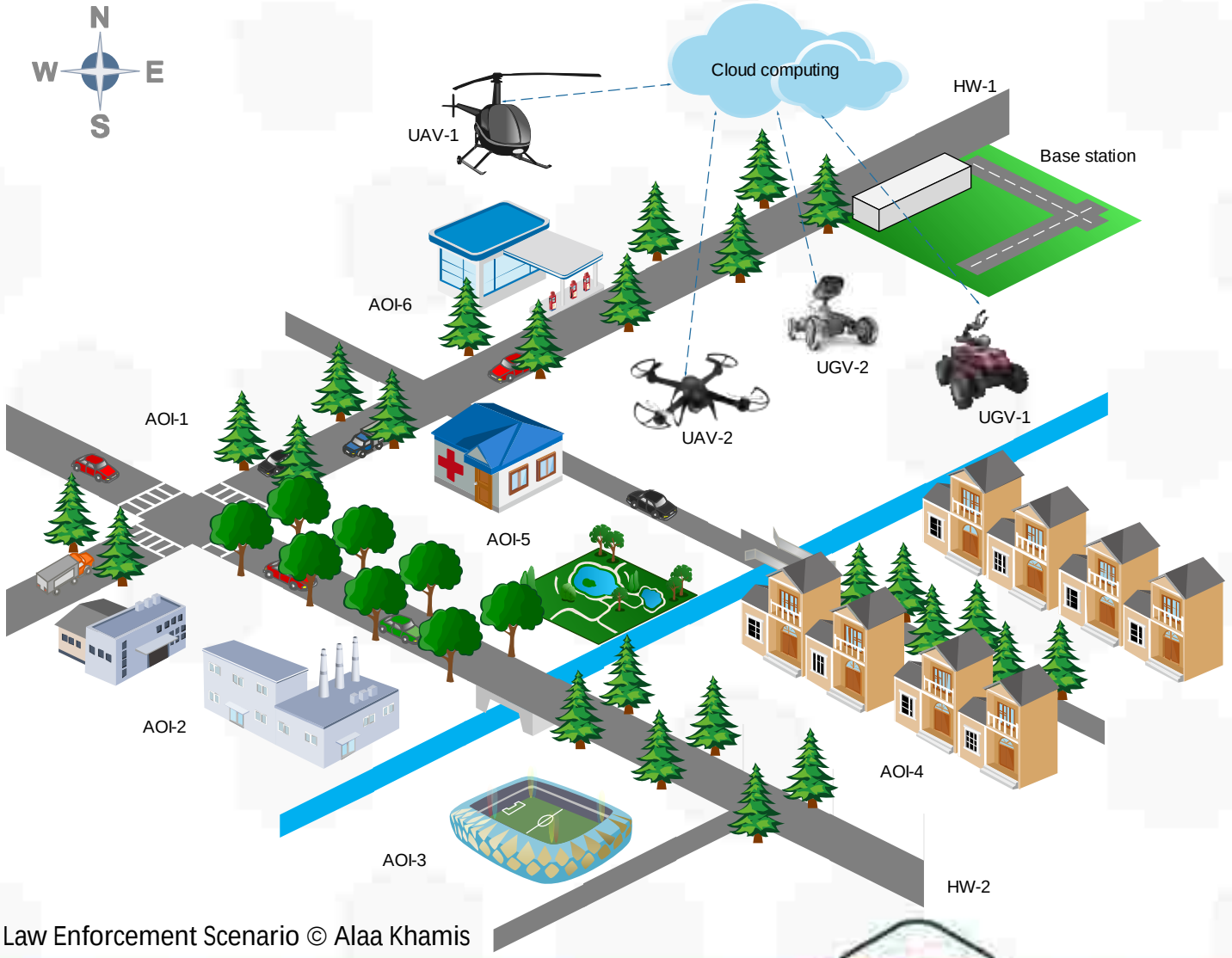
1028 stations deployed
850 have reported in the past 8 hours

http://www.ndbc.noaa.gov/

• MRS Applications: Cloud Robotics

Using the cloud, a robot could improve capabilities such as speech recognition, language translation, path planning, and 3D mapping.

- http://spectrum.ieee.org/automaton/robotics/robotics-software/cloud-robotics
- http://www.google.com/events/io/2011/sessions/cloud-robotics.html



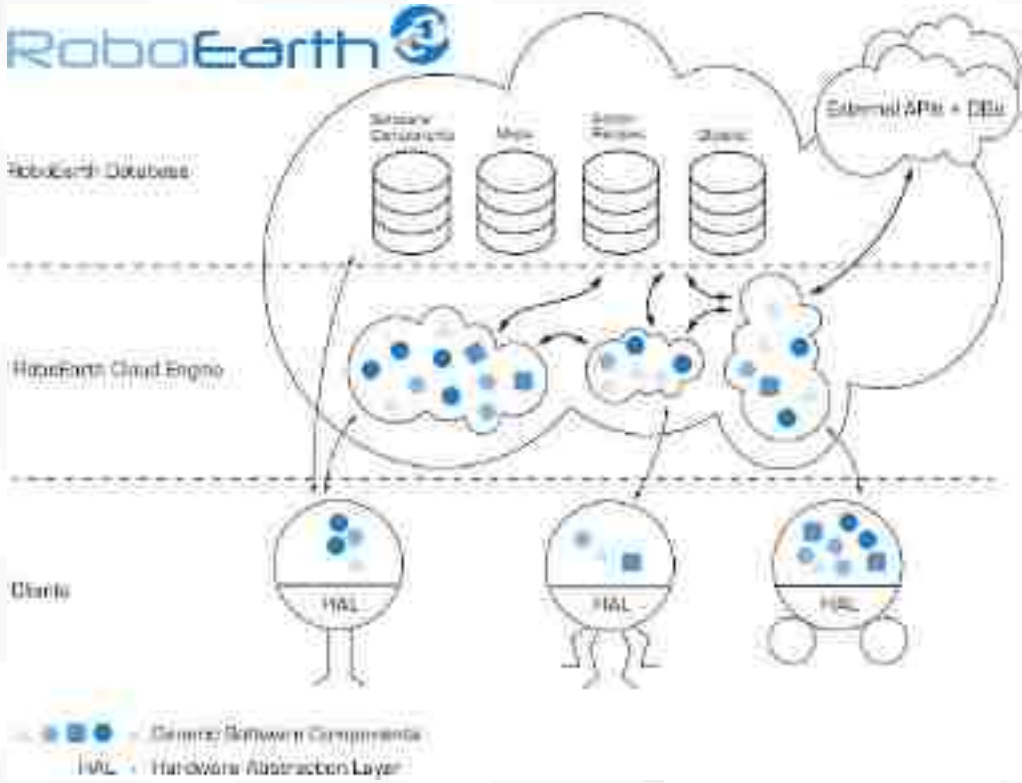
Law Enforcement Scenario © Alaa Khamis

- # MRS Applications: Cloud Robotics

RoboEarth is a World Wide Web for robots: a giant network and database repository where robots can share information and learn from each other about their behavior and their environment.

RoboEarth offers a complete Cloud Robotics infrastructure, which includes everything needed to close the loop from robot to RoboEarth to robot.

http://www.roboearth.org/



• Commercial Robots for MRS testbeds

- ◊ Flexible and open modular architecture
- ◊ Easy to operate
- ◊ Fully programmable
- ◊ Low cost
- ◊ Small size
- ◊ Low weight
- ◊ Great indoor and outdoor mobility
- ◊ Transparent integration within existing networks

http://www.k-team.com/

Koala II

Kilobot

Khepera II

K-Junior

Hemisson

Khepera III

KoreBot II

http://www.wifibot.com/

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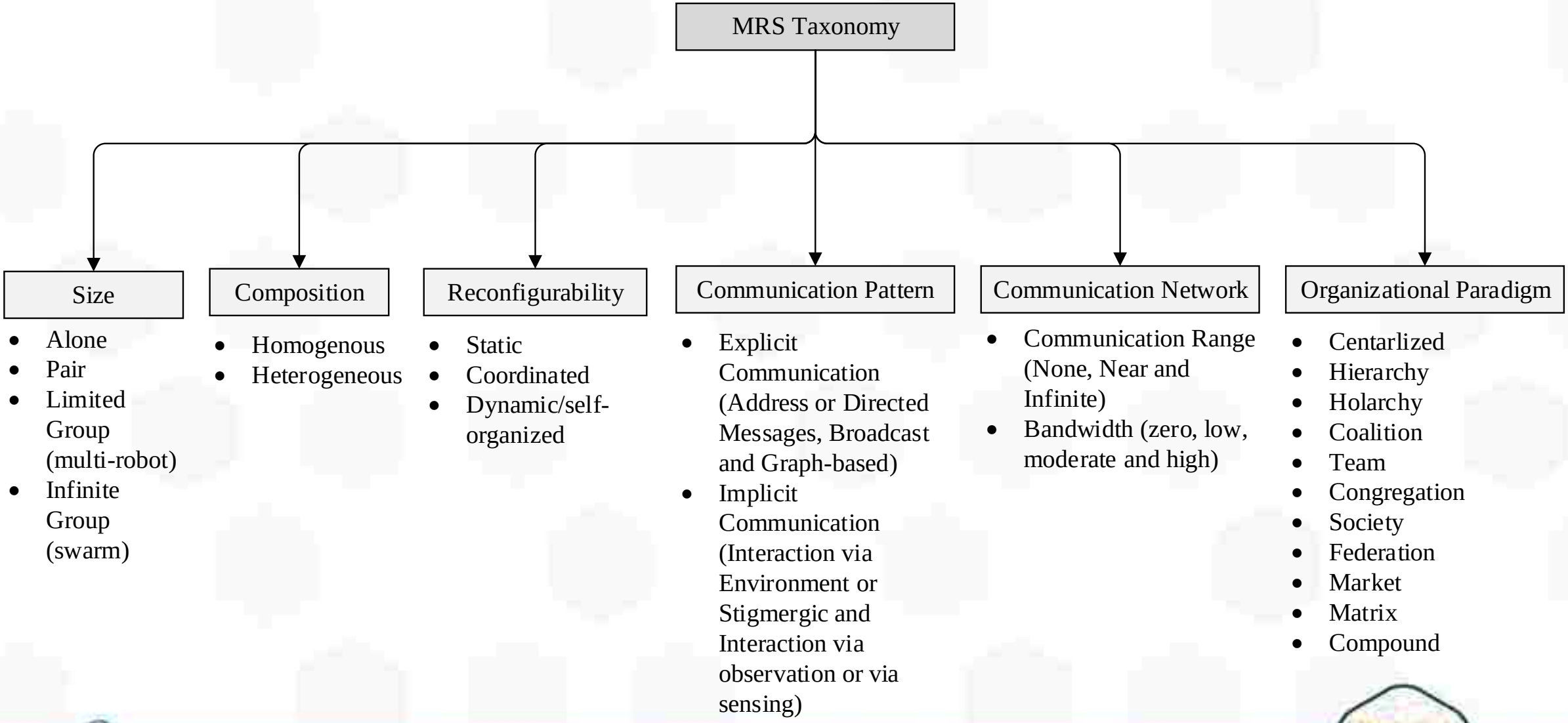
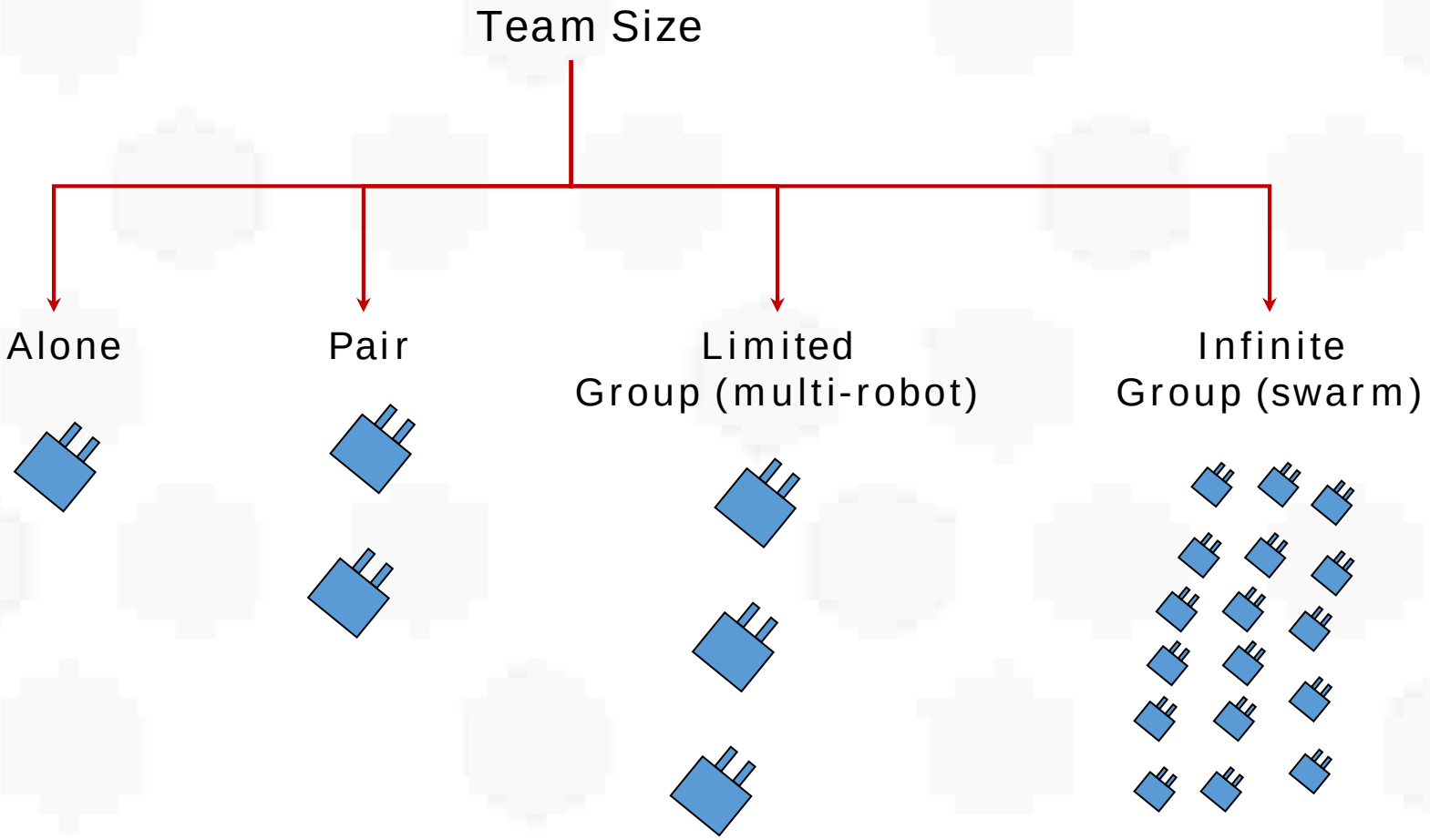
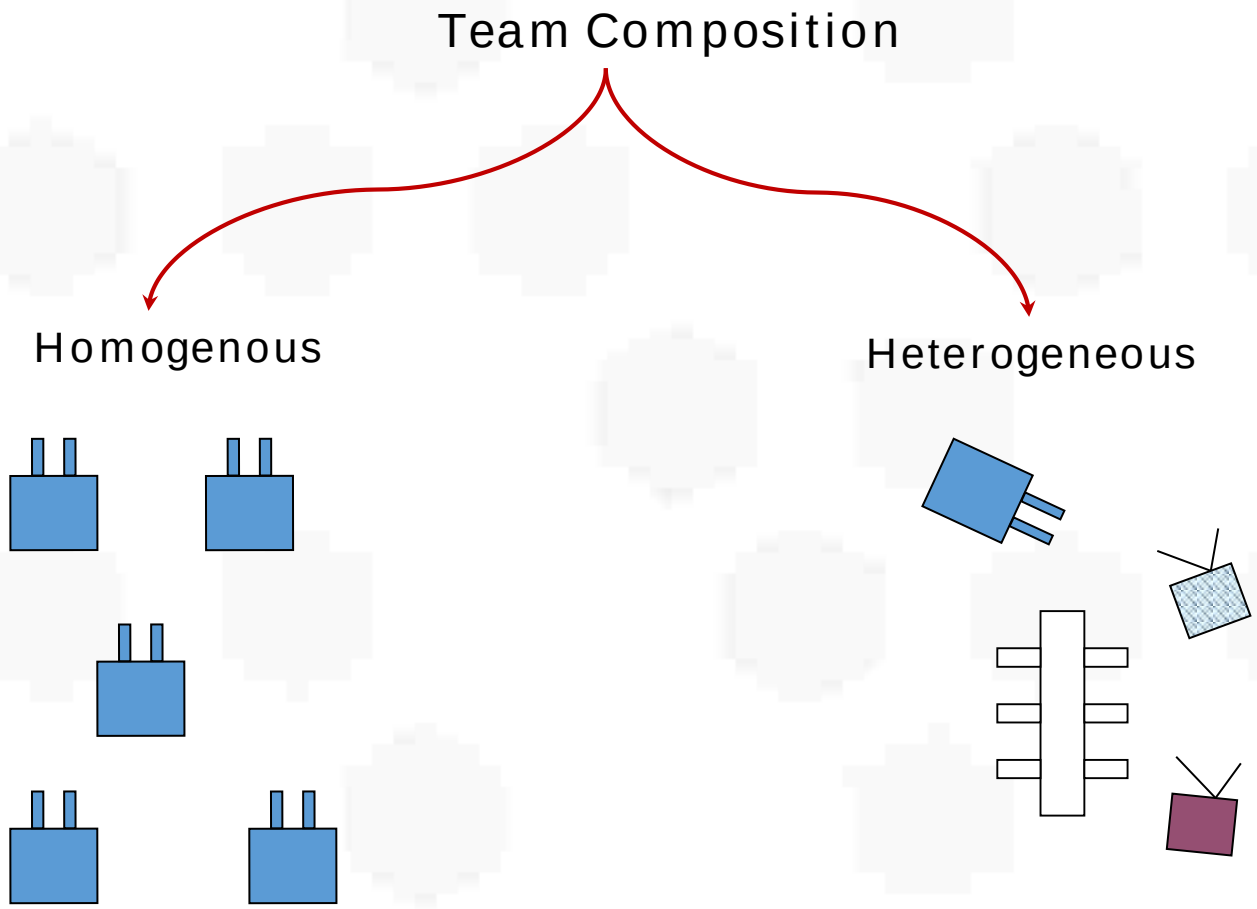
• MRS Taxonomy



• MRS Taxonomy: Team Size



• MRS Taxonomy: Team Composition



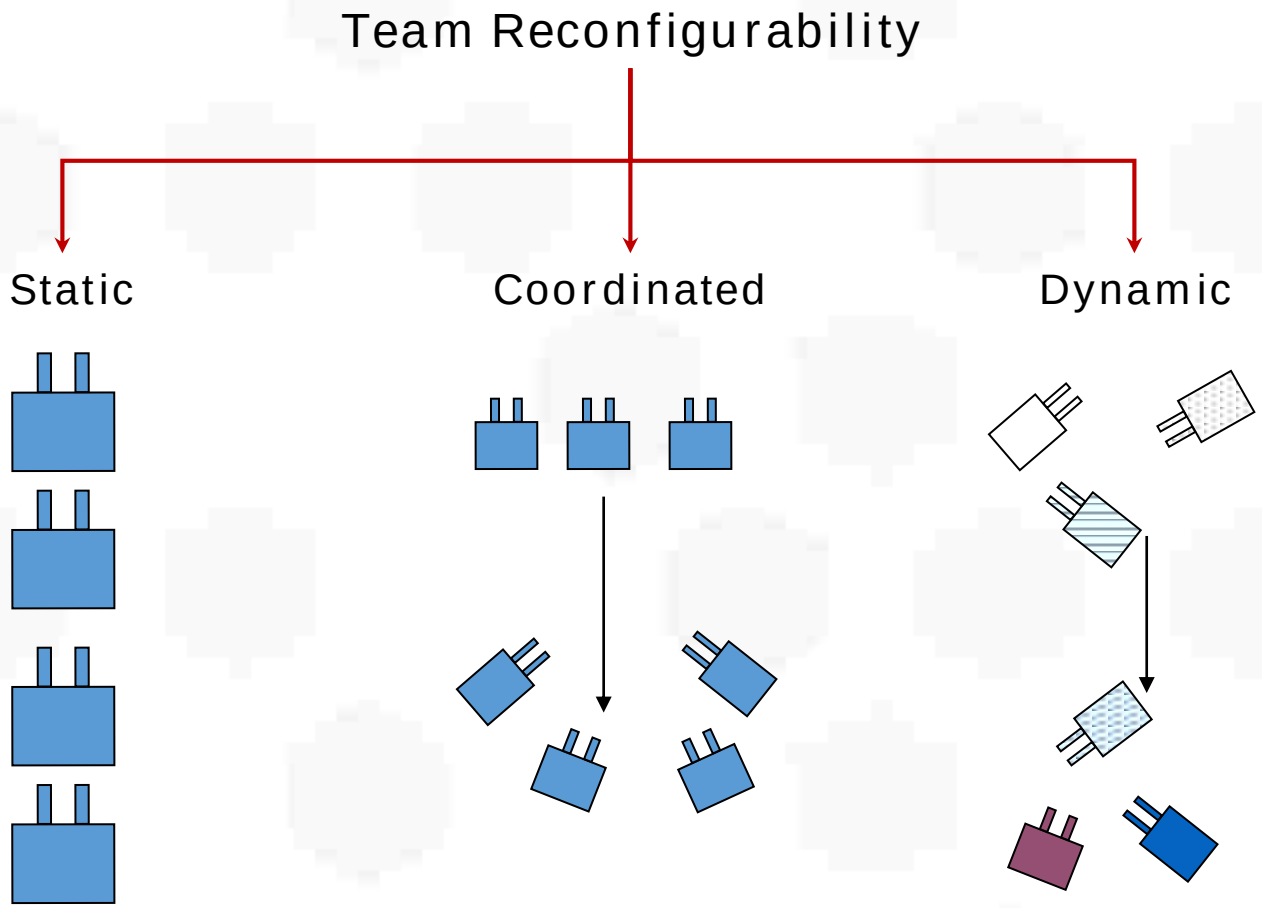
• MRS Taxonomy: Team Composition

Team Composition

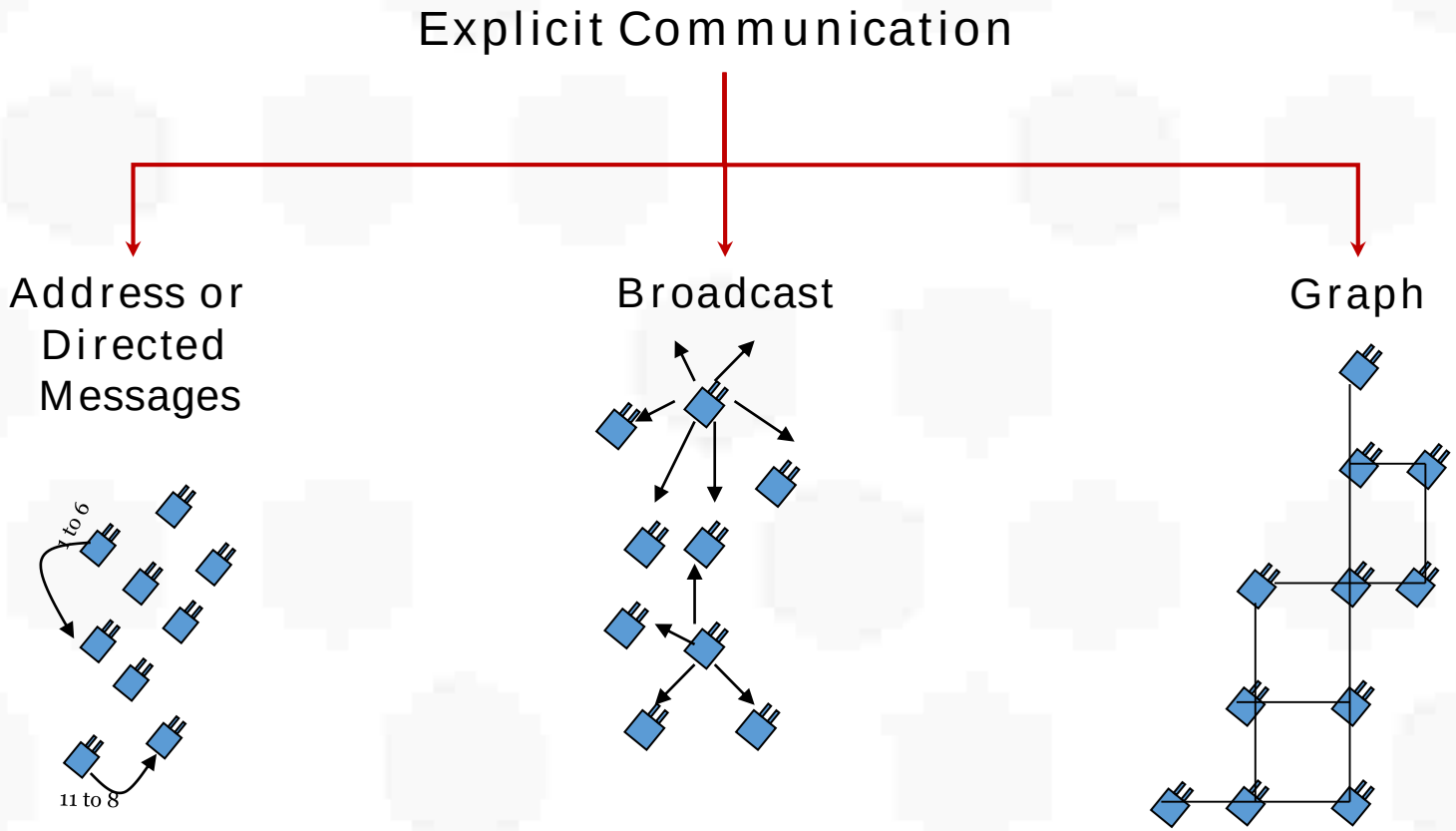
Homogenous

Heterogeneous

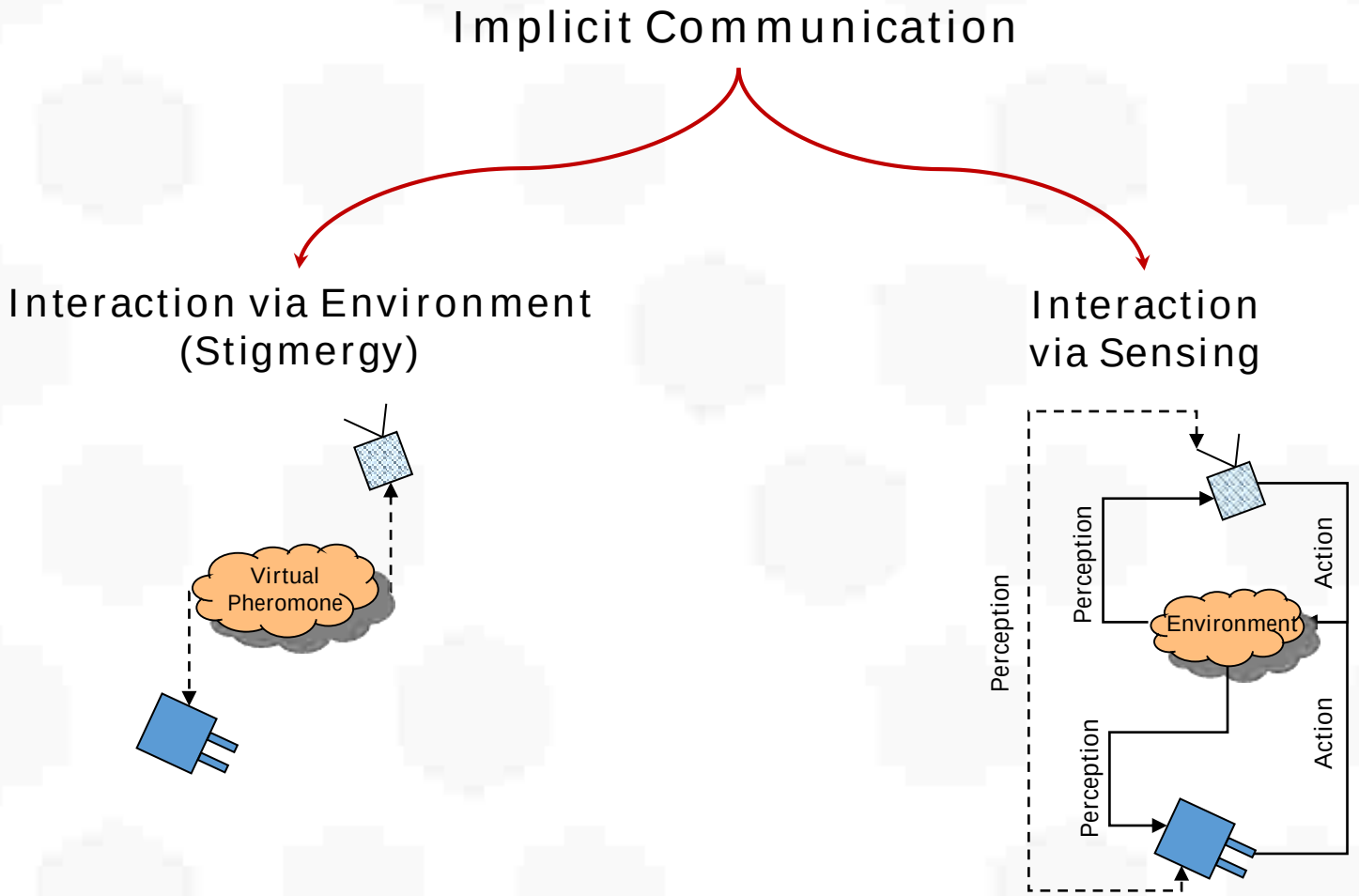
• MRS Taxonomy: Team Reconfigurability



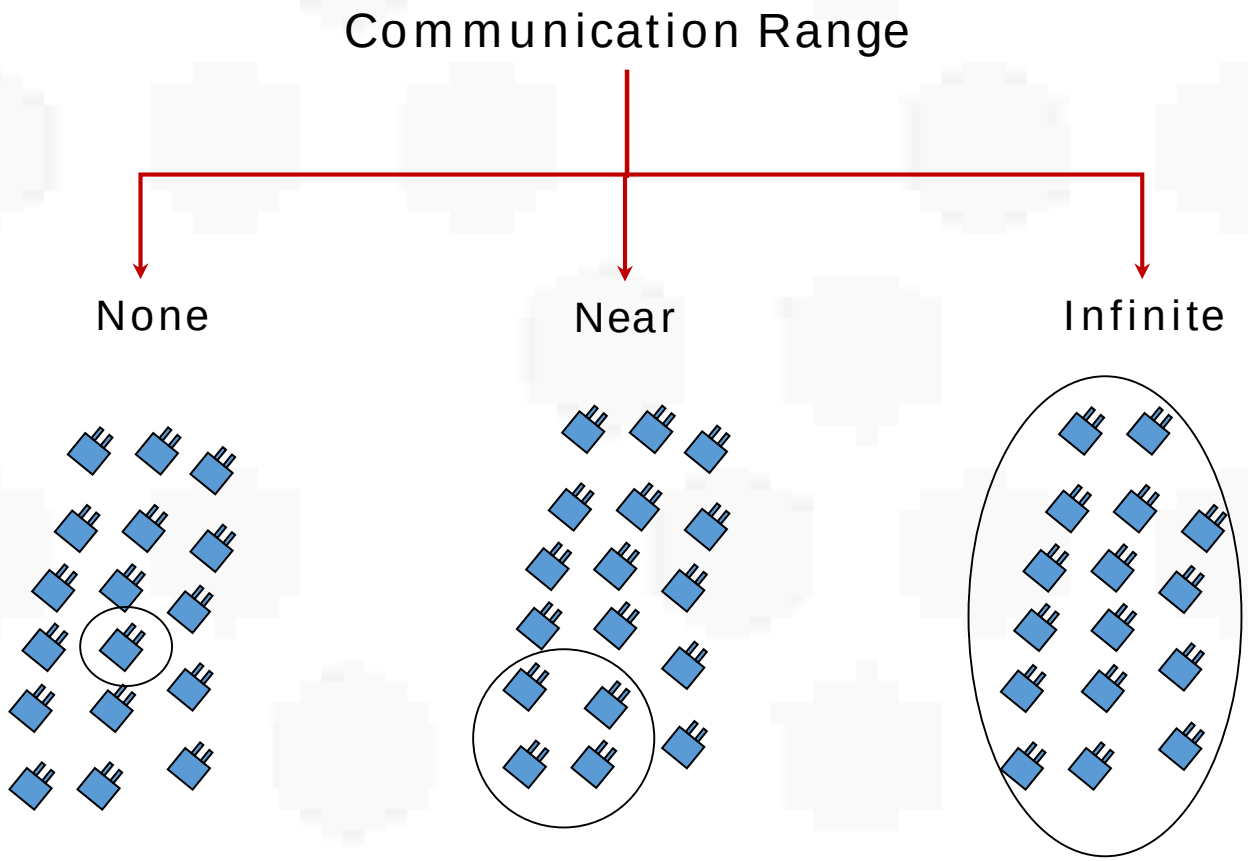
• MRS Taxonomy: Communication Pattern



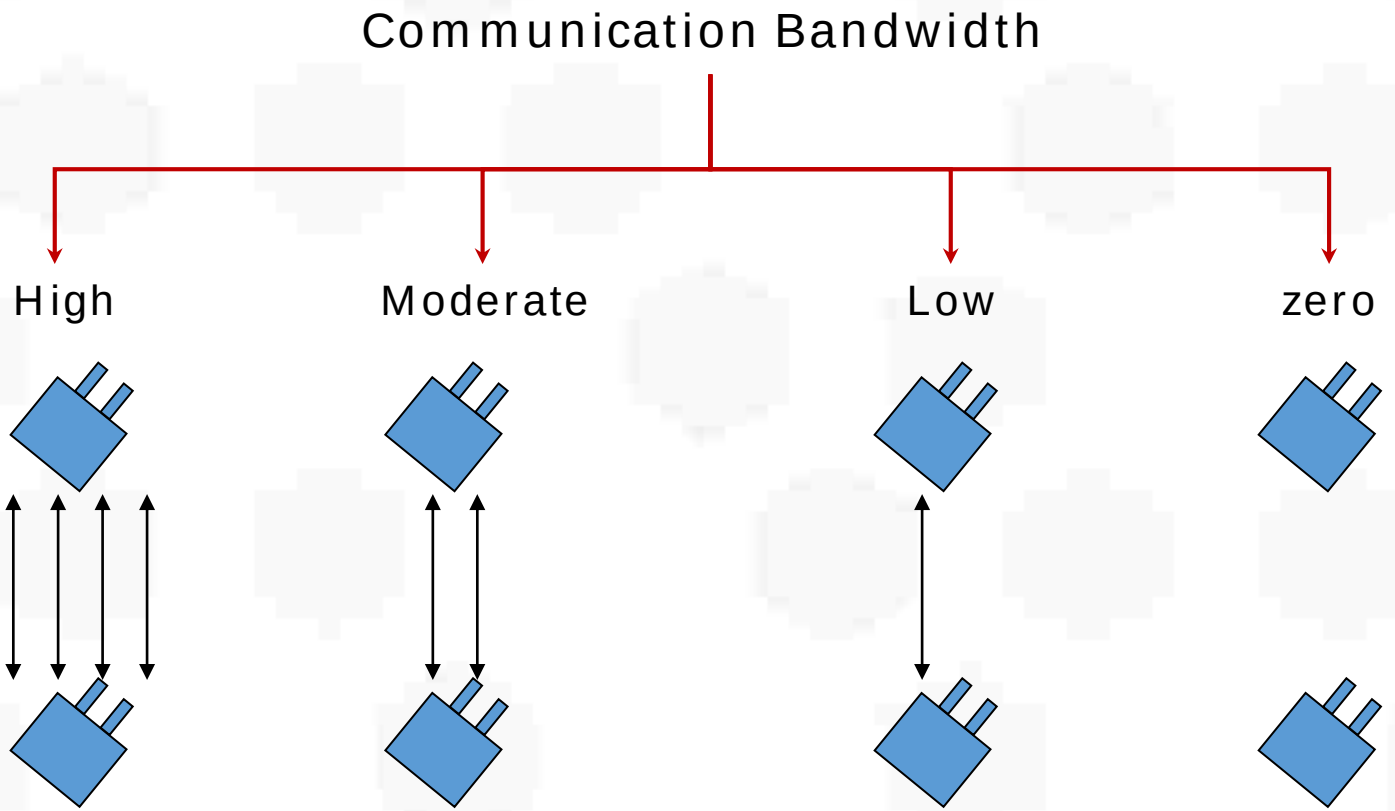
• MRS Taxonomy: Communication Pattern



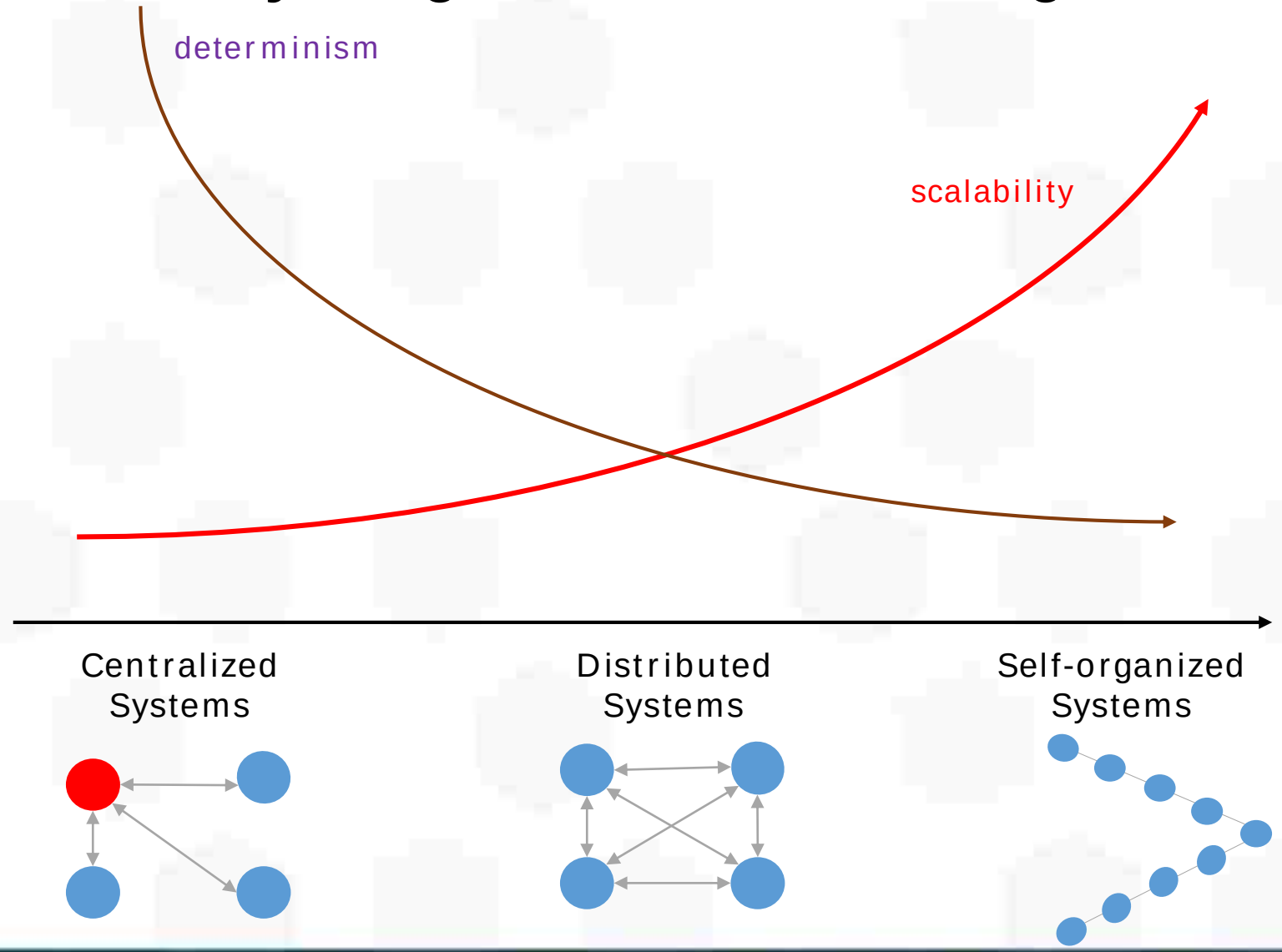
• MRS Taxonomy: Communication Range



• MRS Taxonomy: Communication Bandwidth



• MRS Taxonomy: Organizational Paradigm



Source: Falko Dressler. *Self-Organization in Sensor and Actor Networks*. Wiley, 2007

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• Benchmark Problems of Multi-robot Systems

High-level Functions

- Partially understood
- Not fully localized

- Perception
- Situation awareness
- Natural Language Understanding
- Pattern Discovery
- Reasoning
- Decision Making
- **Planning**
- Learning
- etc.

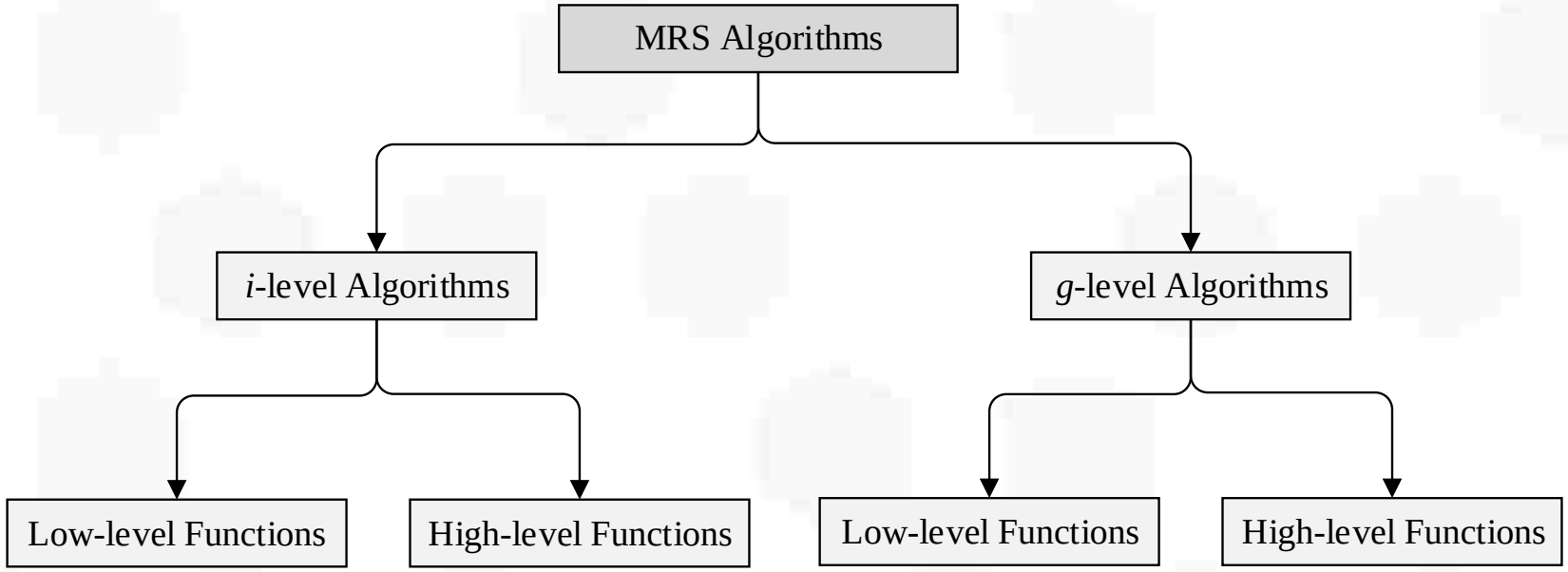
Low-level Functions

- Fully understood
- Localized

Sight Hearing Smell Taste Touch

Alaa Khamis, Machine Intelligence: Promises and Challenges, Techne Summit 2015.

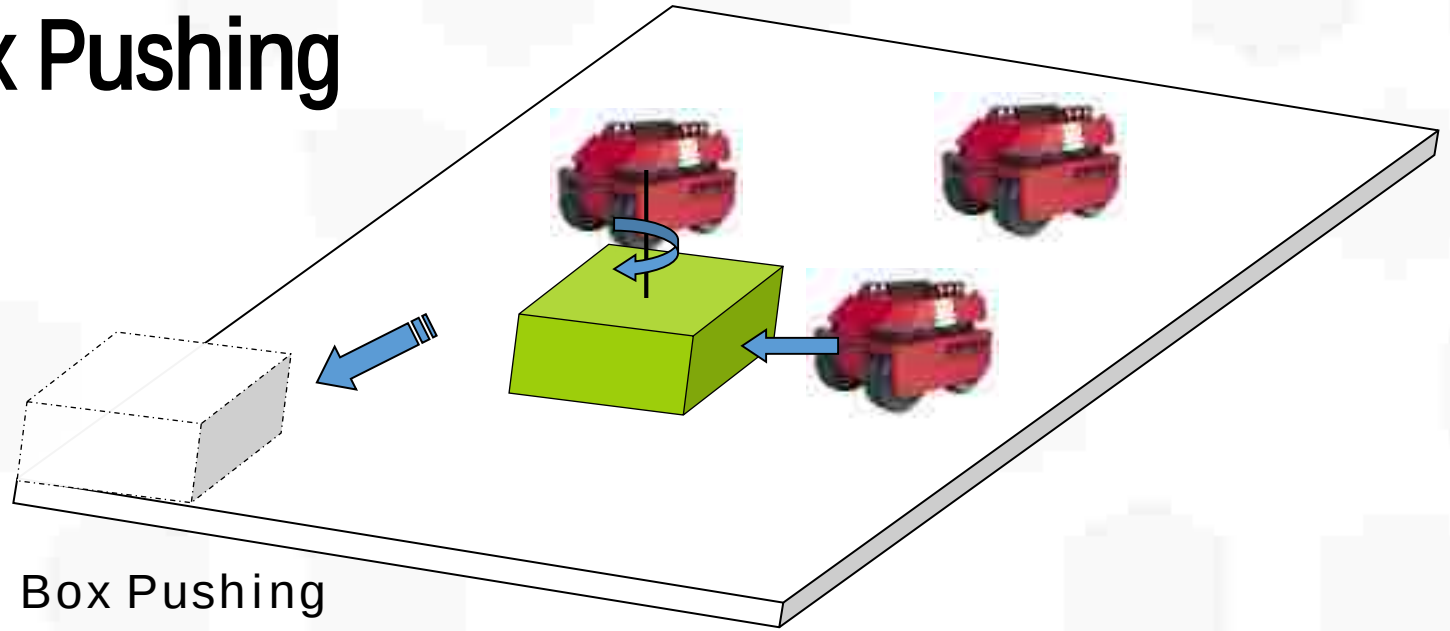
• Benchmark Problems of Multi-robot Systems



- **Benchmark Problems of Multi-robot Systems**
  - Box Pushing and Object Transportation
  - Exploration and Formation Control
  - Division of Labor
  - Foraging
  - Object/Area/Radio Coverage
  - Soccer Tournaments
  - Cooperative perception
  - Cooperative Target Cueing and Handoff
  - Cooperative Mapping
  - ...

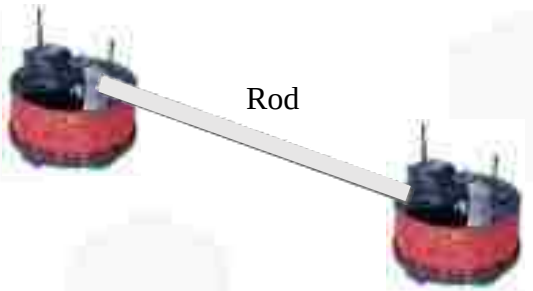
• Benchmark Problems: Box Pushing

Box Pushing and Object Transportation problem's concern is about a group of robots try to push a box to a certain point.



Box Pushing

Applications include transportation of heavy objects in industrial environments or assembly of large-scale structures, such as terrestrial buildings or planetary habitat.



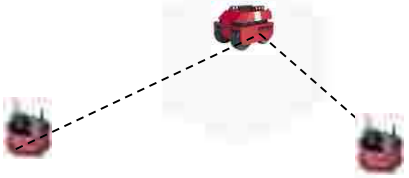
Object Transportation

• Benchmark Problems: Exploration and Formation Control

In the exploration task the robots must be spread in the environment in order to collect as much information as possible about the surrounding area.

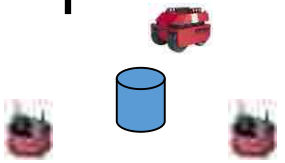
The formation task is focused on having the robots move in the environment forming particular shapes.

Line Formation



Triangle Formation

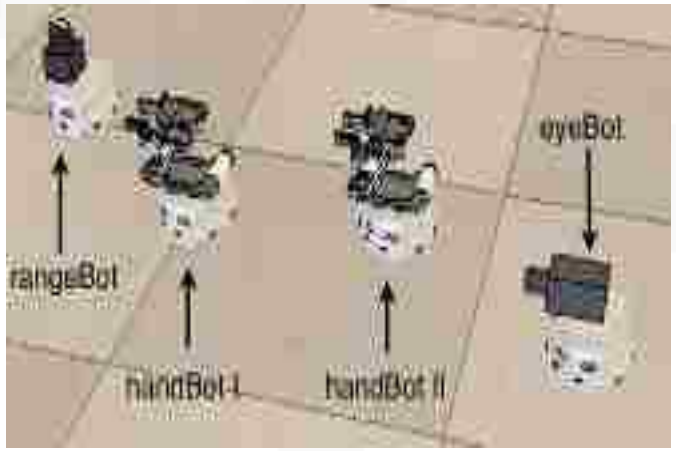
Zigzag Formation

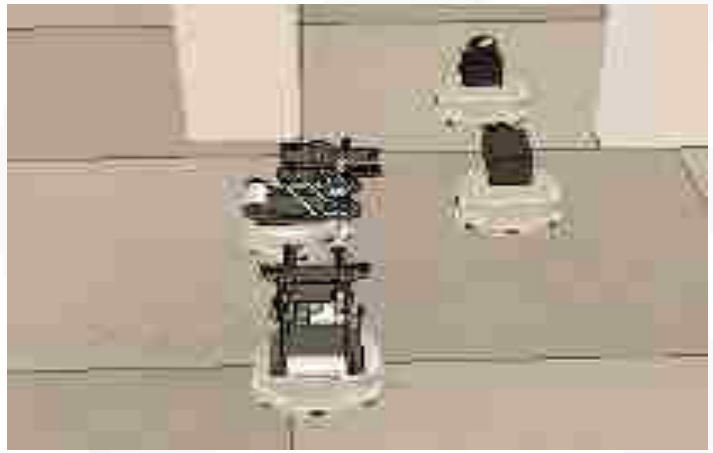


Multi-angle Formation

Multi-zoom Formation

Binocular Stereopsis Formation





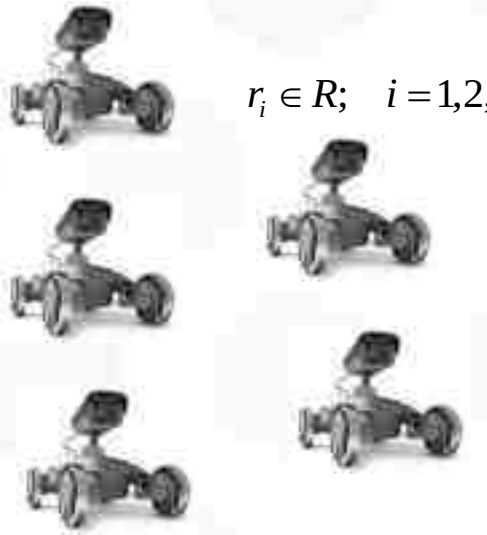
Ahmed Shehata and Alaa Khamis, "Adaptive Group Formation in Multi-robot Systems," Advances in Artificial Intelligence Journal, 2013.

• Benchmark Problems: Division of Labor

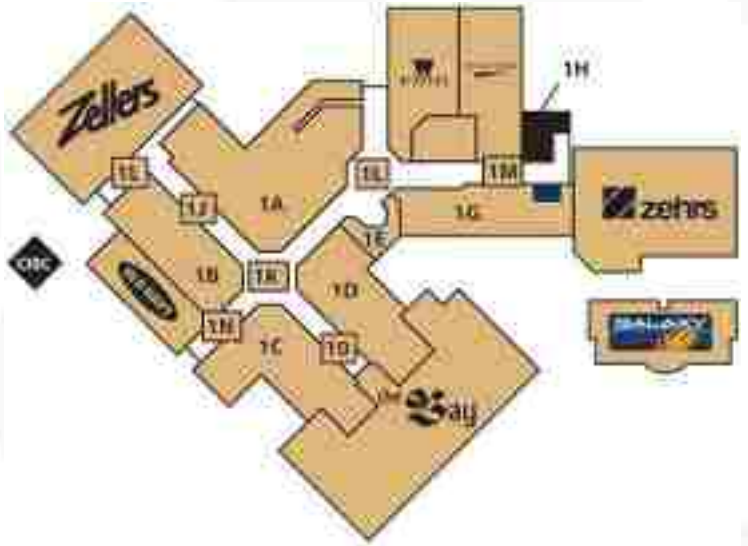
This cooperative behavior addresses how to dynamically assign a set of tasks to a set of robots to maximize overall expected performance.

$t_j \in T; \quad i = 1,2,..., m$

$r_i \in R; \quad i = 1,2,..., n$



$A: T \rightarrow R$



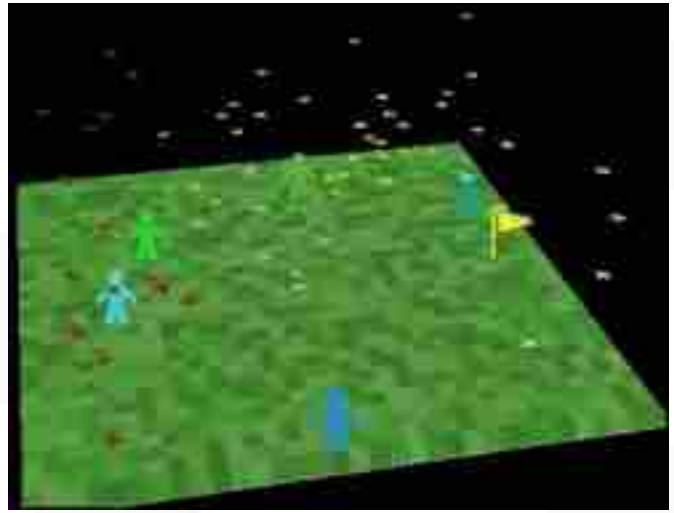
A set of n mobile Sensors: R

A set of m surveillance tasks: T

Alaa Khamis, Ahmed Elmogy and Fakhreddine Karray, "Complex Task Allocation in Mobile Surveillance Systems," Journal of Intelligent and Robotic Systems, Springer, DOI: 10.1007/s10846-010-9536-2, 2011 .

- **Benchmark Problems: Communication Relaying**

  This cooperative behavior consists in establishing communication through relaying in order to dramatically increase radio coverage or expand communications links, primarily over rugged, mountainous or urban terrains.



NetLogo simulation environment with 60 UAVs, 5 ground targets and a base station

Mohamed Wakid and Alaa Khamis. *Communication Relay for Unmanned Aerial Vehicles in Autonomous Search and Rescue Mission*.

- **Benchmark Problems: Communication Relaying**

Soccer playing is challenge problem for studying coordination and control in multirobot systems. This domain incorporates many challenging aspects of multirobot control, including:

◊ Collaboration,

◊ Robot control architectures,

◊ Strategy acquisition,

◊ Real-time reasoning and action,

◊ Sensor fusion,

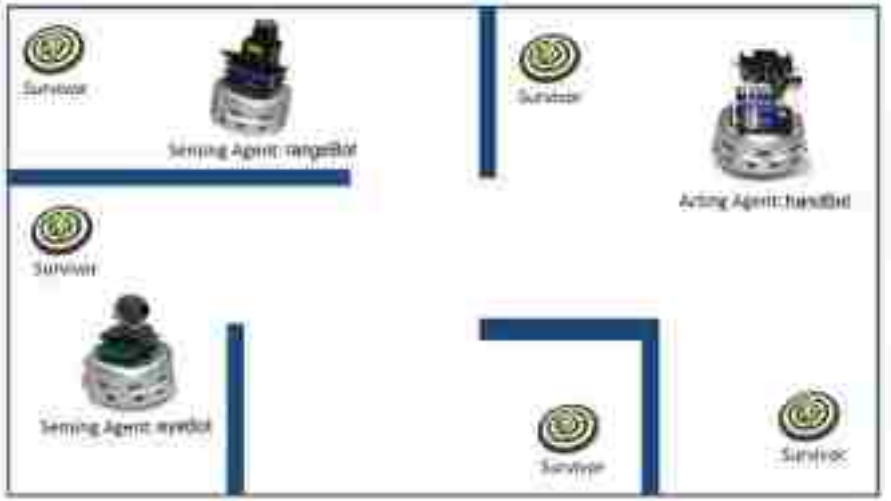
◊ Dealing with adversarial environments,

◊ Cognitive modeling, and Learning.

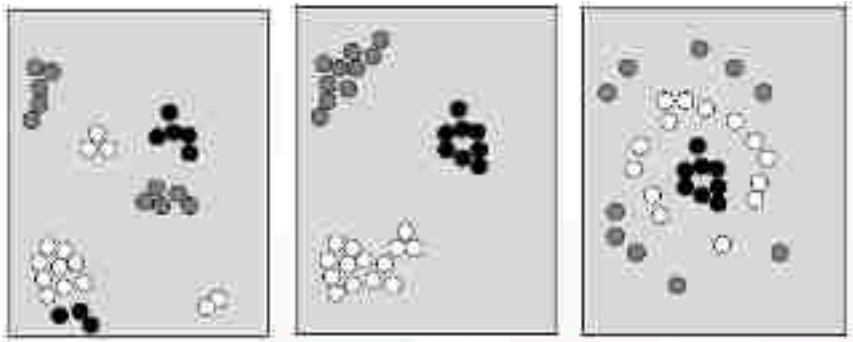
http://www.robocup.org/ & http://www.fira.net/

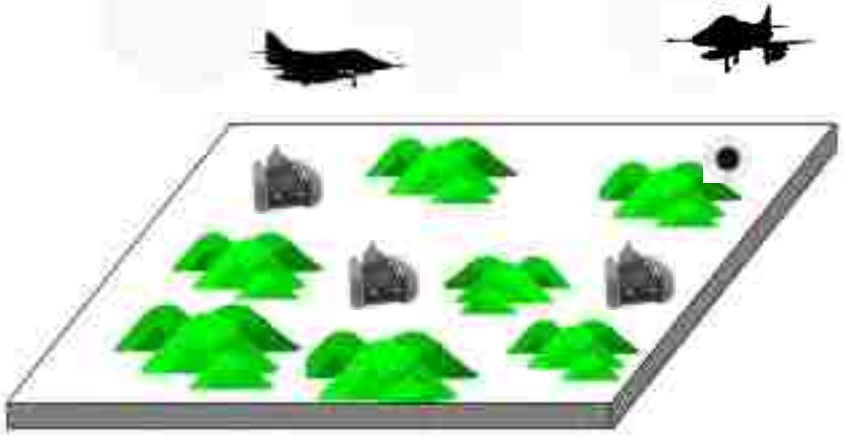
• Benchmark Problems: Other problems

- ◊ Search and Rescue
- ◊ Sorting
- ◊ Cooperative perception in robotics
- ◊ Cooperative Mapping
- ◊ Collective Robotic Search
- ◊ ...



Ahmed Hussein, Mohamed Adel, Mohamed Bakr, Omar M. Shehata and Alaa Khamis, "Multi-robot Task Allocation for Search and Rescue Missions," 11th European Workshop on Advanced Control and Diagnosis (ACD 2014), Berlin, Germany, 13 - 14 November 2014.





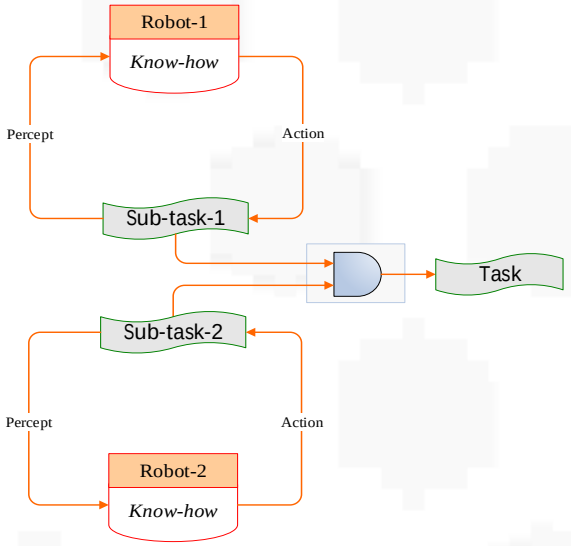
Outline

- Introduction to Multi-robot Systems (MRS)
- MRS Taxonomy
- Benchmark Problems of MRS
- Cooperative Multi-robot Systems
- Multiple Minesweepers

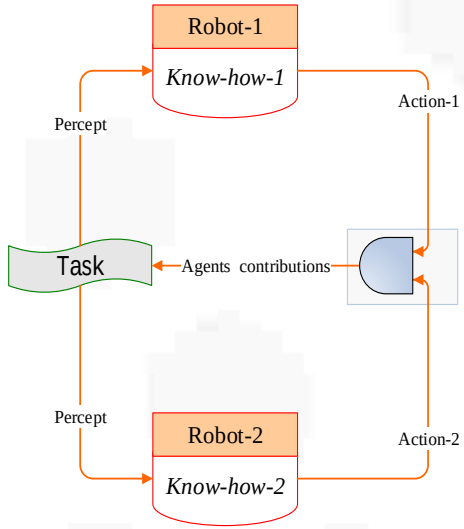
• Cooperative Multi-robot Systems

Forms of Cooperation

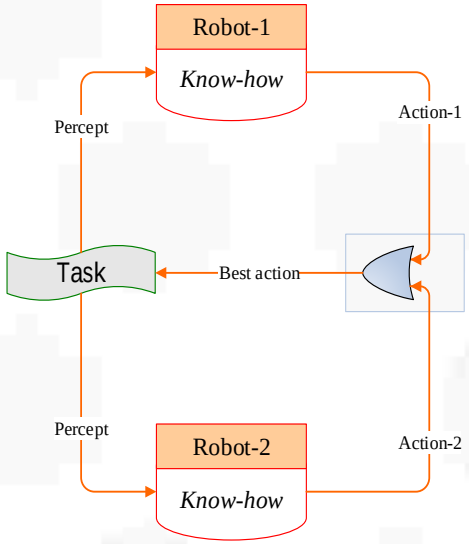
Augmentative



Integrative



Debative



- Alaa Khamis, “Cooperative Sensor and Actor Networks in Distributed Surveillance Context,” 10th International Conference on Practical Applications of Agents and Multi-Agent Systems (PAAMS'12), Salamanca, Spain, 2012.
- A. Benaskeur, A. Khamis, H. Irandoust, "Augmentative Cooperation in Distributed Surveillance Systems for Dense Regions," International Journal of Intelligent Defence Support Systems, 4(1): 20-49, 2011.
- Alaa Khamis. Conceptual Foundations of Cooperation in Distributed Surveillance. Technical Reports, Thales Canada, Naval Division, 2010.
- Alaa Khamis, Mohamed Kamel and Miguel Angel Salichs, "Cooperation: Concepts and General Typology," The 2006 IEEE International Conference on Systems, Man, and Cybernetics, Oct. 8 - Oct. 11, 2006 - The Grand Hotel, Taipei, Taiwan.

Outline

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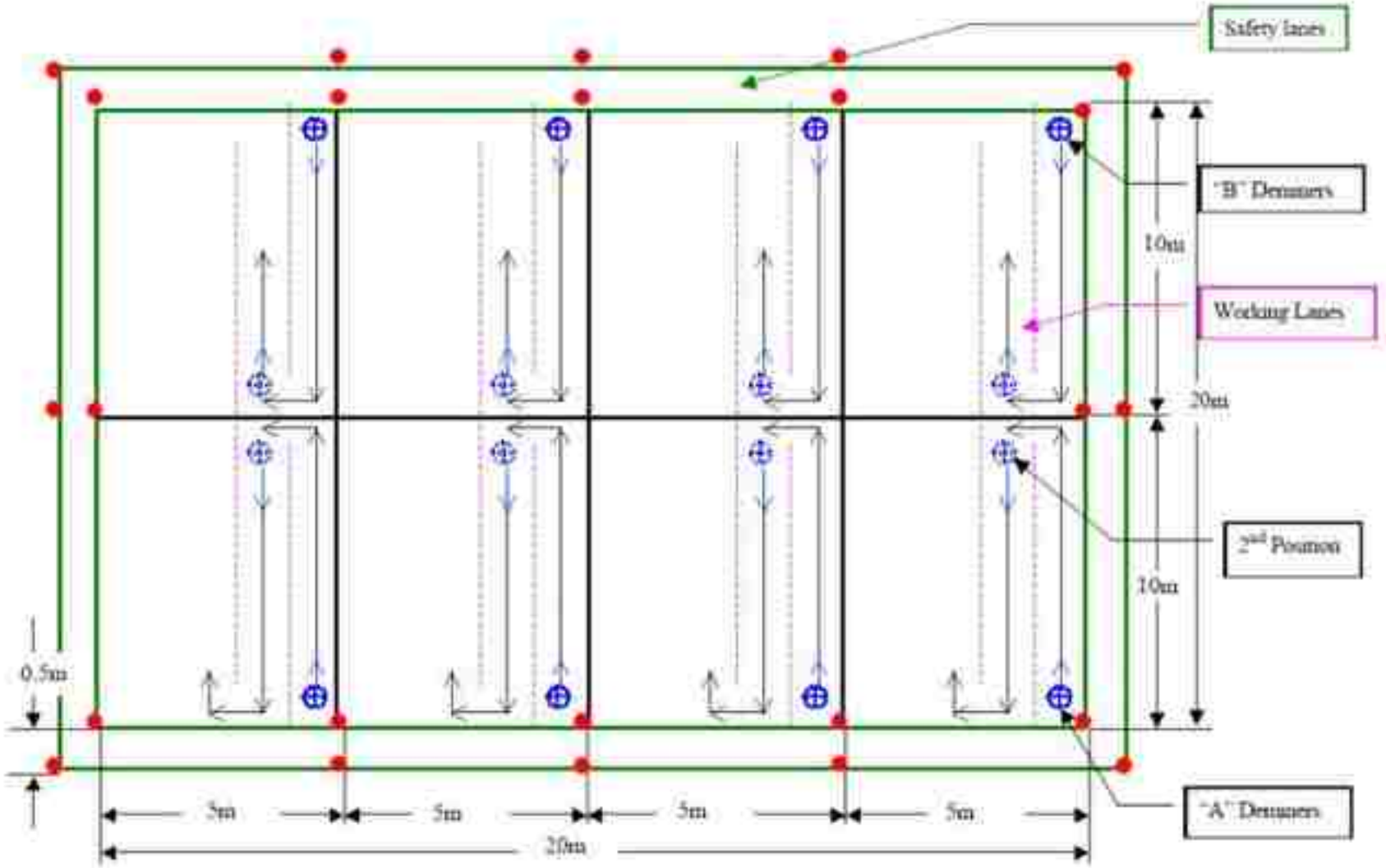
- **Multiple Minesweepers**

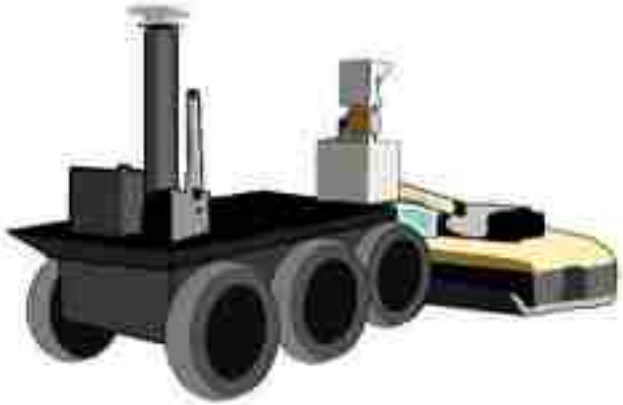
Standard Operating Procedures (SOPs): Human deminers use metal detectors to identify targets, which are then flagged for subsequent digging by a supervisor.

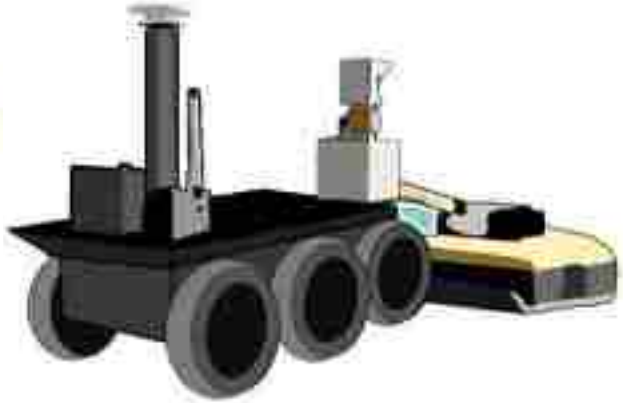
- **Multiple Minesweepers**



- **Multiple Minesweepers**

The objective of this category is to mimic the conventional mag-and-flag approach or SOP using multiple unmanned teleoperated and autonomous vehicles.





One or more teleoperated vehicles play the role of human deminers

An autonomous vehicle is used to mimic the supervisor's role

- **Multiple Minesweepers**

Minesweepers 2016 will take place in October 27-30 at Zewail City of Science and Technology in conjunction with Second International Workshop on Recent Advances in Robotics and Sensor Technology for Humanitarian Demining and Counter-IEDs (RST).

http://www.rstech.org/

Thank you ☺

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