--SET-222, Rome---

Swarms of Unmanned Vehicles for Area-Scan: Conceptual and Practical Control Aspects

Jose M. Giron-Sierra, Alina Gheorghita
Universidad Complutense de Madrid

Jose M. Riola, Juan J. Díaz
Planning, Technology and Innovation Under-directorate (SDGPLATIN/DGAM) Spanish MoD

Spain

Introduction

Comments after participation in European Community Projects and EDA Projects:

- How to develop decentralized control, according with the swarm concept that each unit takes own decisions.

- ❑ Some conceptual and practical control aspects: focus on a few ideas
- ❑ Try to clarify some terms
- ❑ Indicate references
- ❑ Some emphasis on “area-scan” (Necsave Project)

Introduction

Resnick (1997): Turtles, termites and traffic jams,…

Bird V formation:

- Silence: no message exchange
- The leader is constantly changing
- The V geometry emerges from local behaviors of each bird

Reynolds (1987): Flocks, herds and schools, distributed behavioral model

Introduction

Brooks (1986): Subsumption architecture

Balch & Arkin (1998): Behavior-based formation control

Jadbabaie, Lin & Morse (2003): Coordination using nearest neighbor rules

Olfati-Saber (2006): Flocking for multi-agent dynamic systems

Introduction

Why considering dynamic systems?

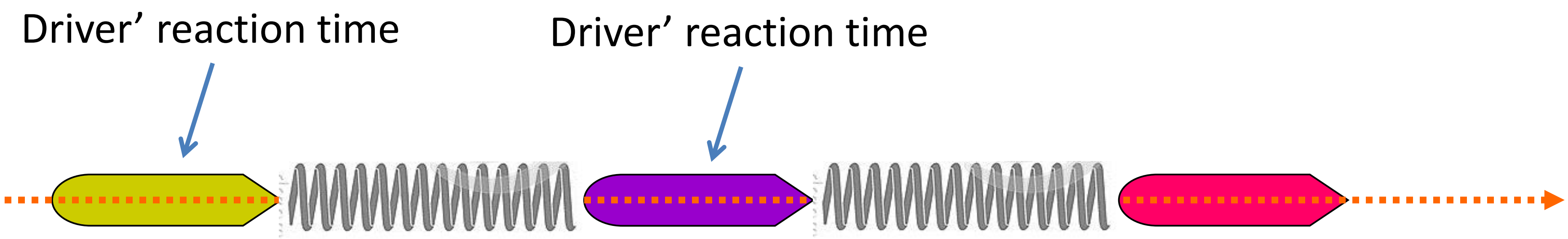
- Simple local control rule: follow the car before you
(a nearest neighbor rule)

There is a kind of consensus on common speed

If a car unexpectedely slows down, crashes behind may occur

Introduction

Simple model: virtual springs

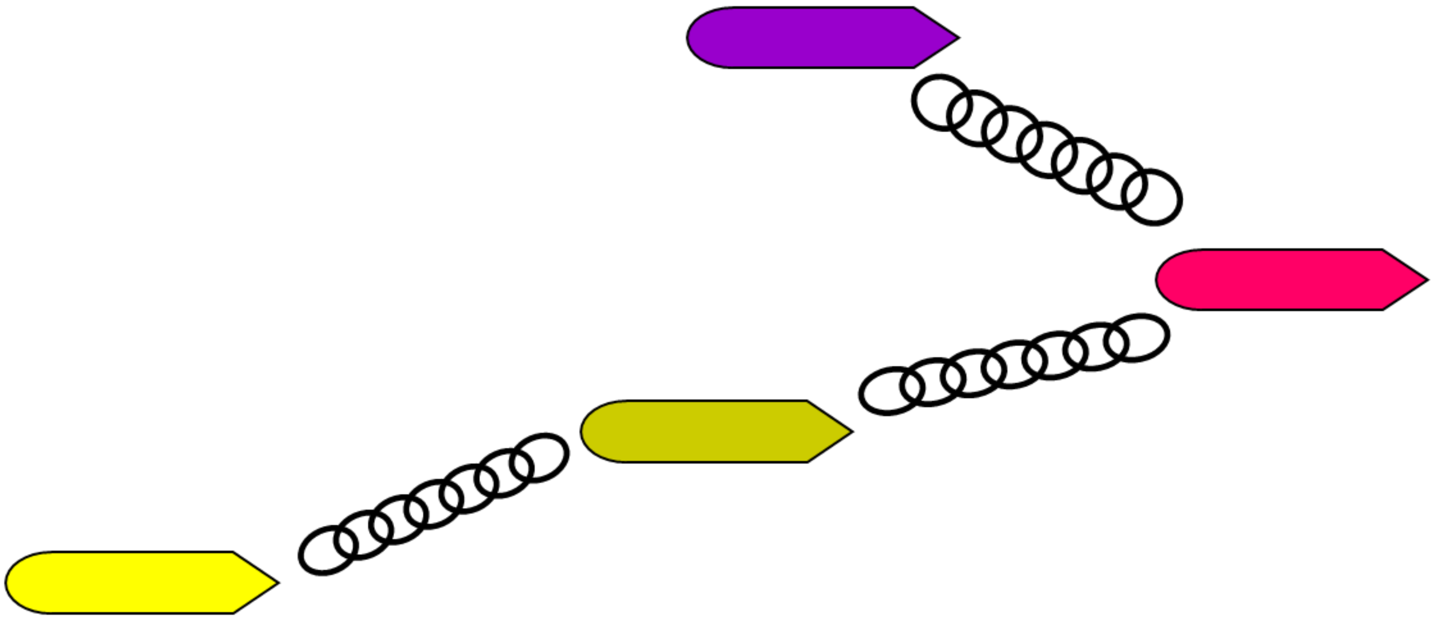


-A chain of two springs tend to oscillate
- More springs: still worse

This requires a delicate local control tuning:
- Fly at different altitudes
- 3D scenarios (UAVs, UUVs)

Introduction

What strategy?

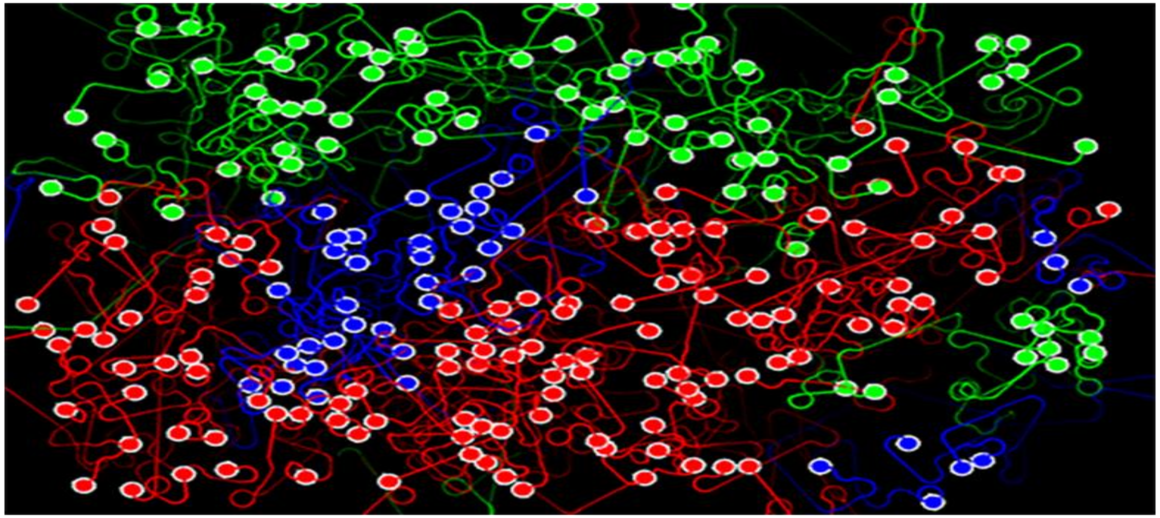


- Follow the leader (you see him?)
- Follow the closest

Introduction

Simulation, models

- Do use simulation before real experiments (no destruction)
- Need of mathematical model
- There are stochastic or Bayesian frameworks



Muniganti & Pujol(2010): Survey mathematical models for swarm robotics

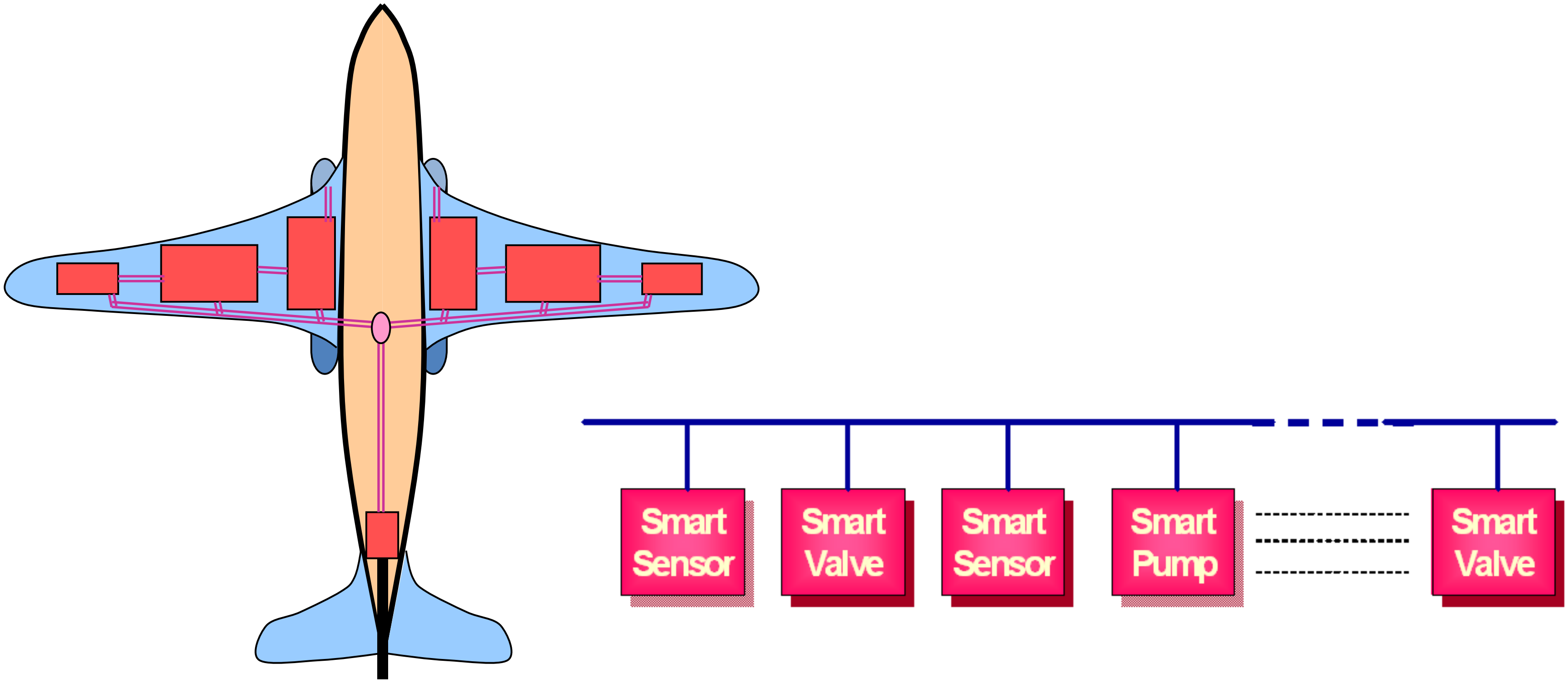
Bird swarm

Decentralization

--SET-222, Rome---

Decentralization

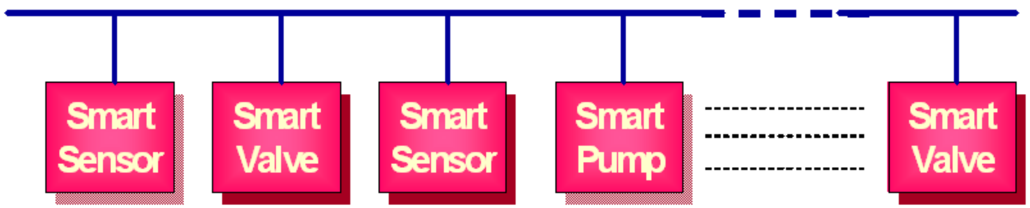
Smartfuel (CEE Project): Decentralized networked system with smart components for aircraft fuel management



Decentralization

Our Laboratory Simulator

Decentralization



Remarks:

- A networked system can perfectly be a centralized system
- In our case there is no computer (for system control)
- Each component takes own decisions:
  - According with system state and current operation mode
  - Support of reconfigurations

The global behavior is a consequence of local behaviors

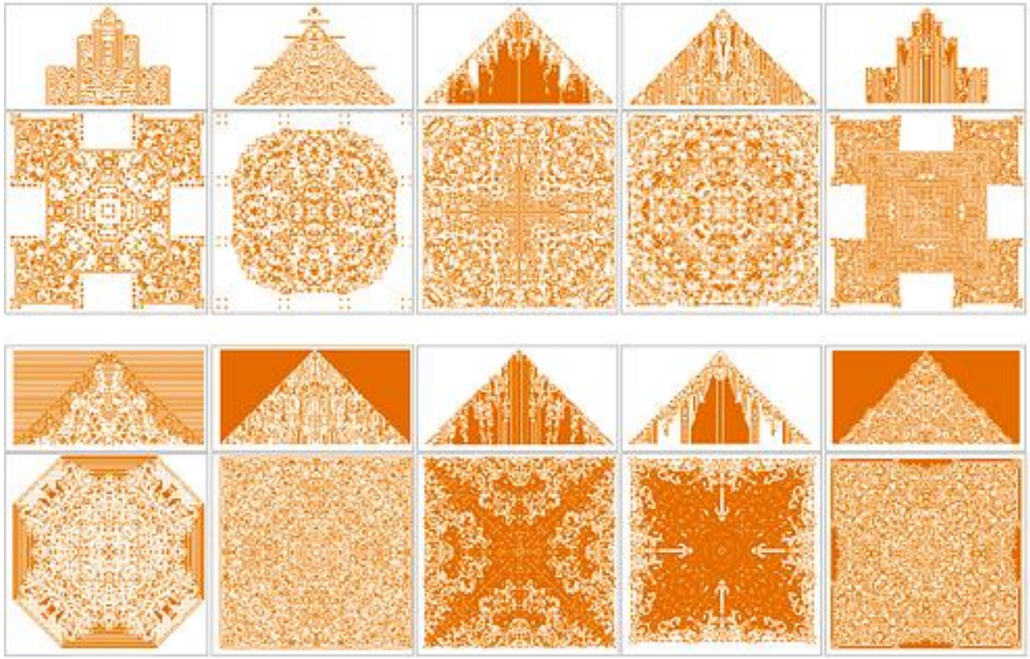
Decentralization

Swarms and cellular automata

Beni (2004): From swarm intelligence to swarm robotics

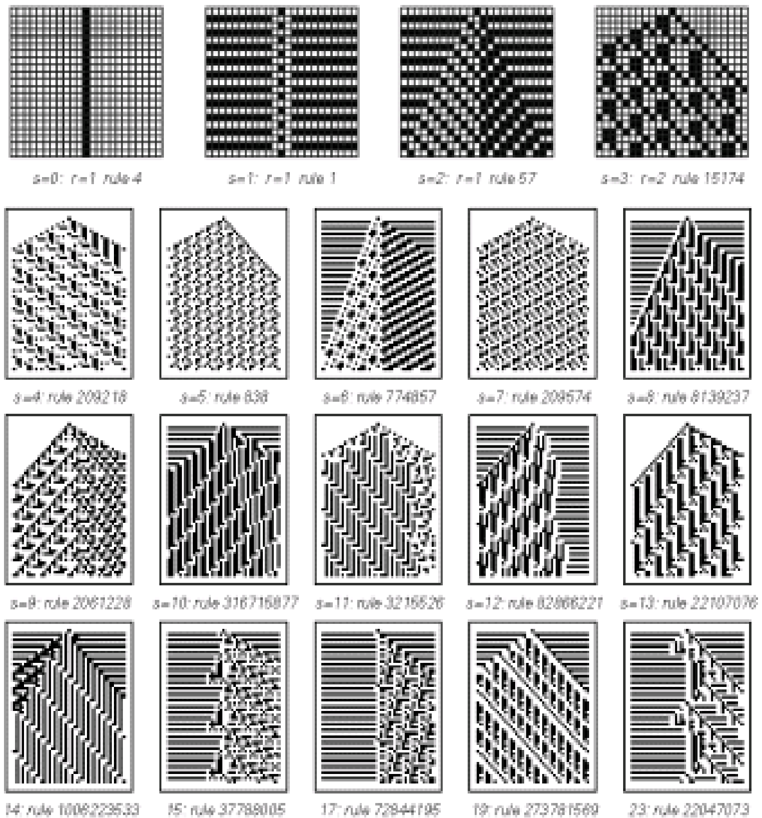
During the discussion of a paper on "cellular robots" someone suggested the term "swarm" as a better buzzword

Simple rules identically replicated on each automaton, lead to complex behaviors along an evolution



Decentralization

Swarms and cellular automata



Stephen Wolfram

Four classes of cellular automata

1- stable evolution, converges to a single state

2- convergence to a periodic and stable trajectory

3- unstable evolution, chaotic result

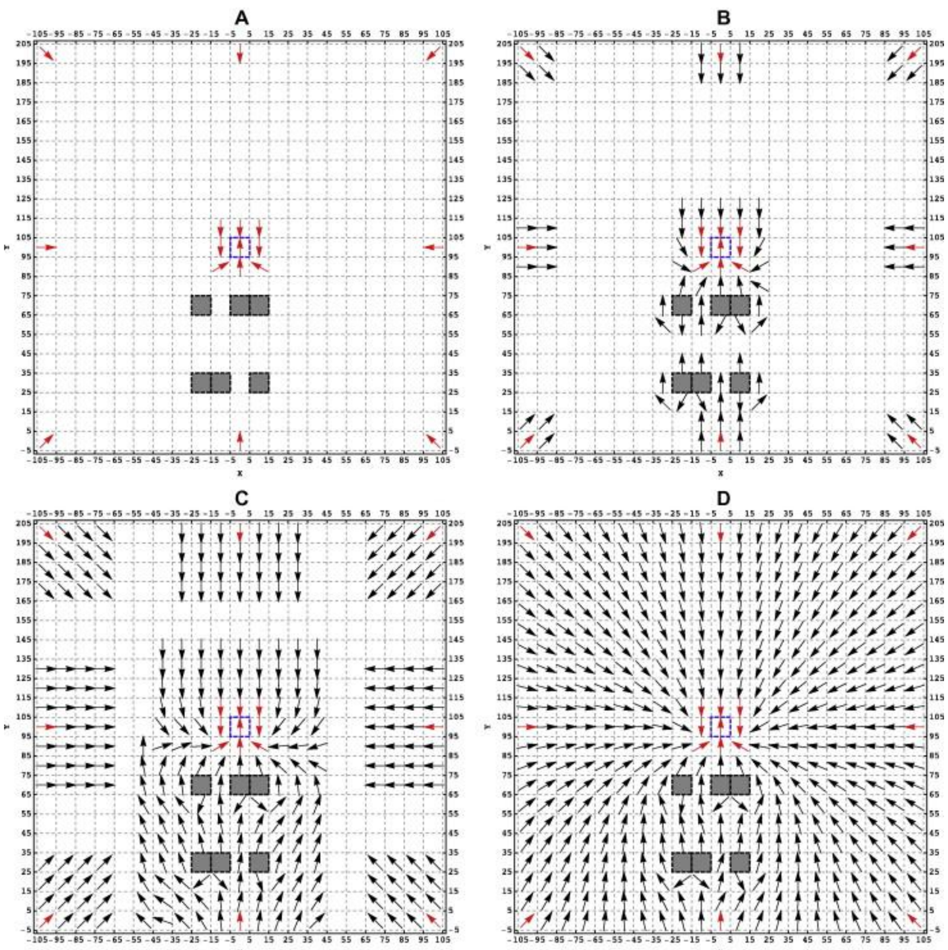
4- converges to a mix of patterns and chaos

--SET-222, Rome---

Decentralization

Swarms and cellular automata

During our research on ship control we combined ant colonies with cellular automata



Initial solutions
for trajectories
that avoid obstacles

Emergence of global
behavior from local rules

NATO
OTAN

--SET-222, Rome---

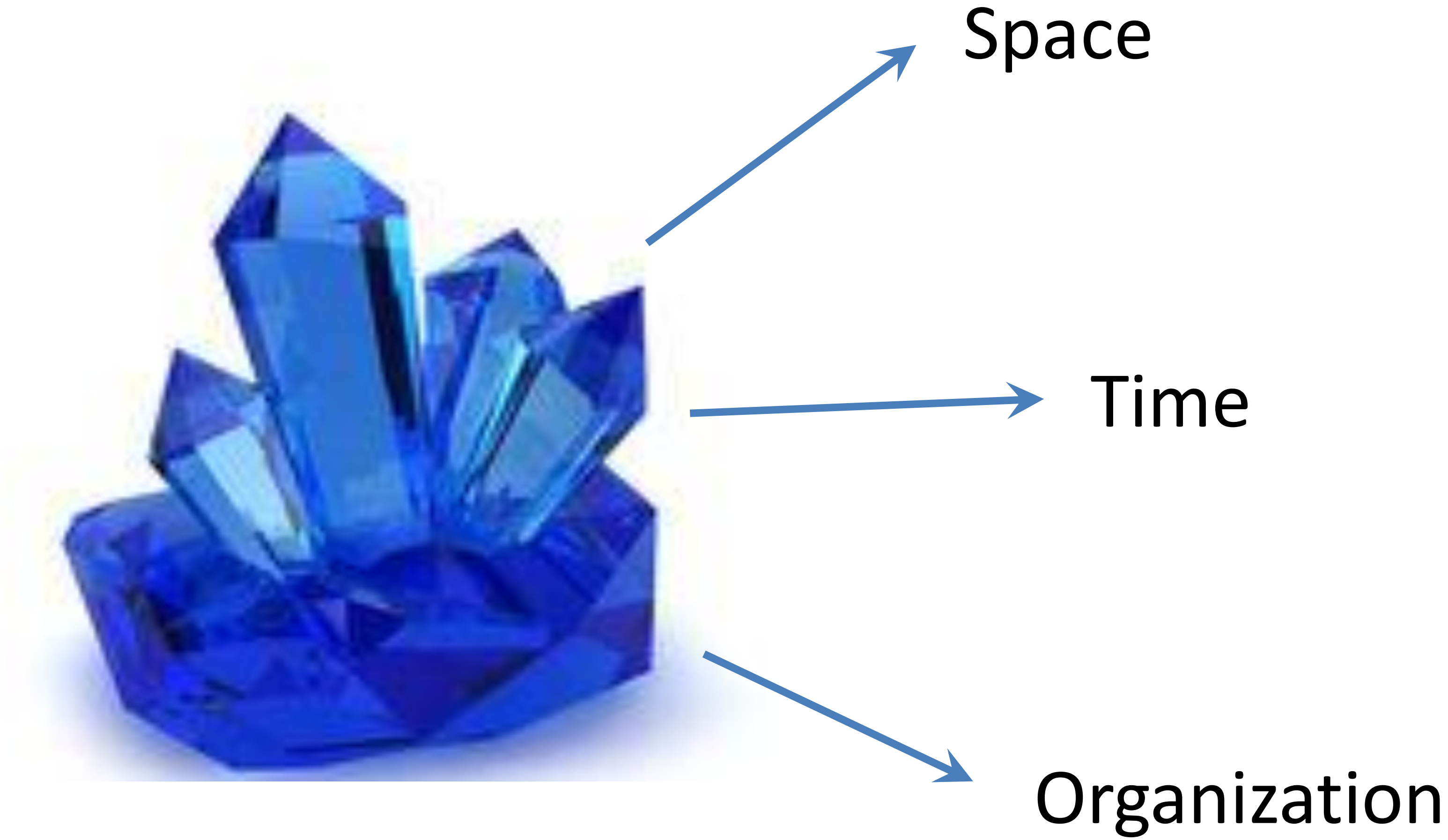
Jellyfish exterminators

Multi-robot teams

--SET-222, Rome---

Multi-robot teams

Facets of order



Multi-robot teams

Cooperation

Roles
(capabilities)

Perhaps dynamic reconfiguration

Multi-robot teams

Temporal coordination

Synchronicity

Scheduling:
tasks/timing/resources

Multi-robot teams

Spatial coordination

Distances
Geometry

More typological analysis in:

Parker (2012): Decision making as optimization in multi-robot teams

Multi-robot teams

What agents know?

Inside building

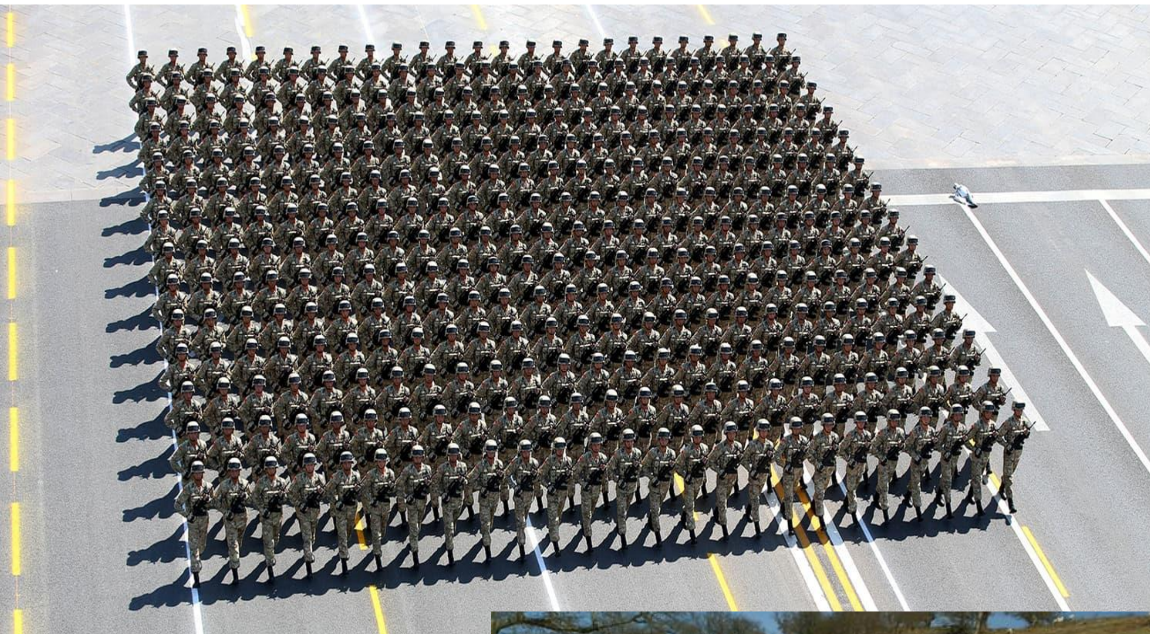
Where I am: "situated agent":
- I have GPS
- I only know relative position

What is happening:
- Global knowledge
- Only local knowledge

Could I decide?

Multi-robot teams

Formations vs. dispersed groups



Formation:
easy to control
as a single-entity

Group:
probably
no-leader

Multi-robot teams

Couzin, et al. (2005): …decision making in animal groups…

A few "informed" individuals are enough to guide the group (migration, food, water, etc.)

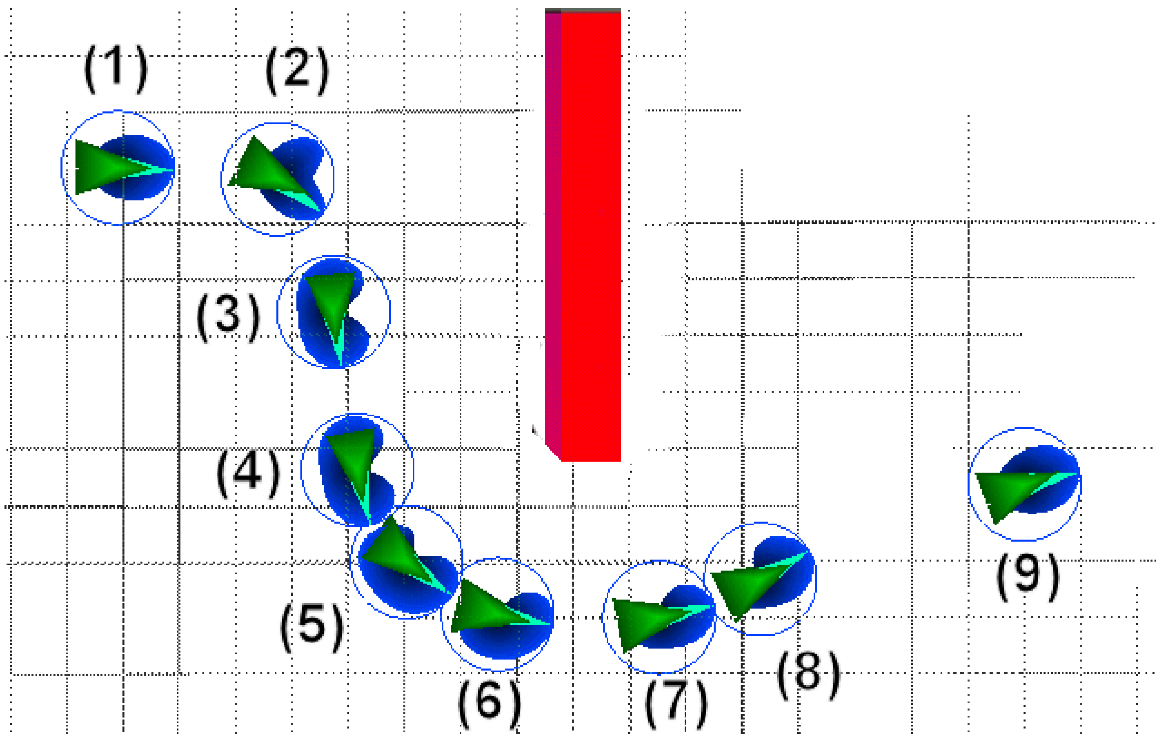
Multi-robot teams

A multi-potential approach

We proposed a combination of several virtual potentials

Potentials for individual navigation:

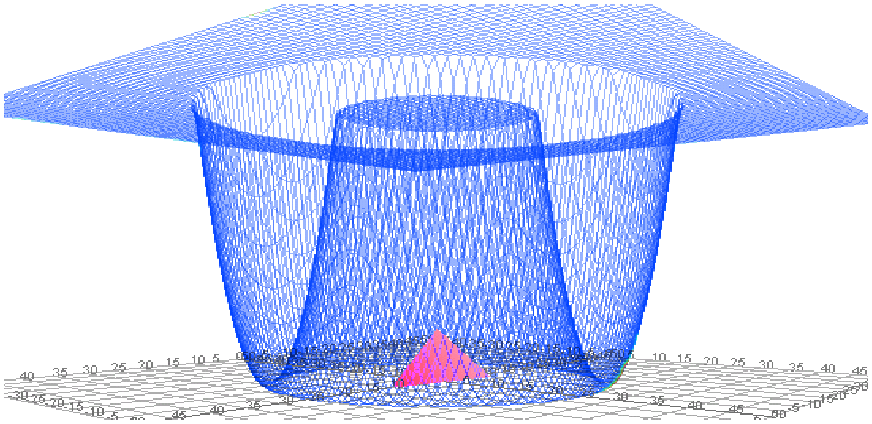
- Go to target
- Obstacle repulsion

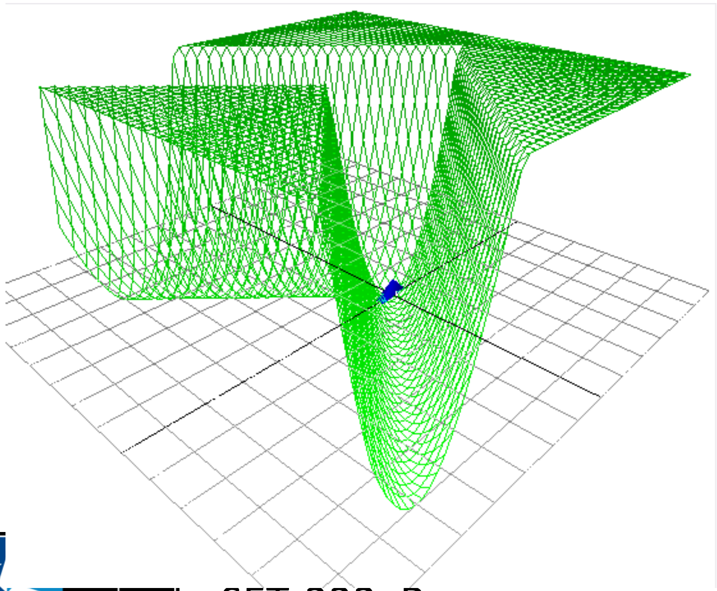


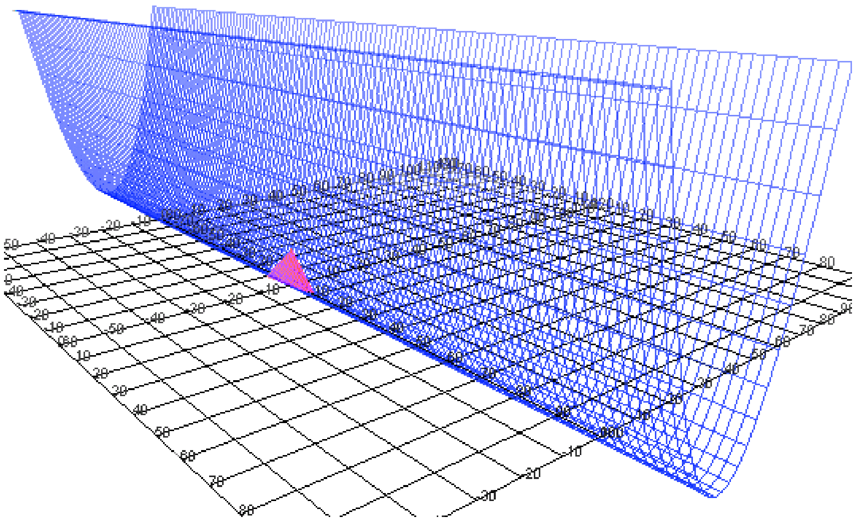
Multi-robot teams

A multi-potential approach

Potentials for anonymous formations
(robots have no I.D.)

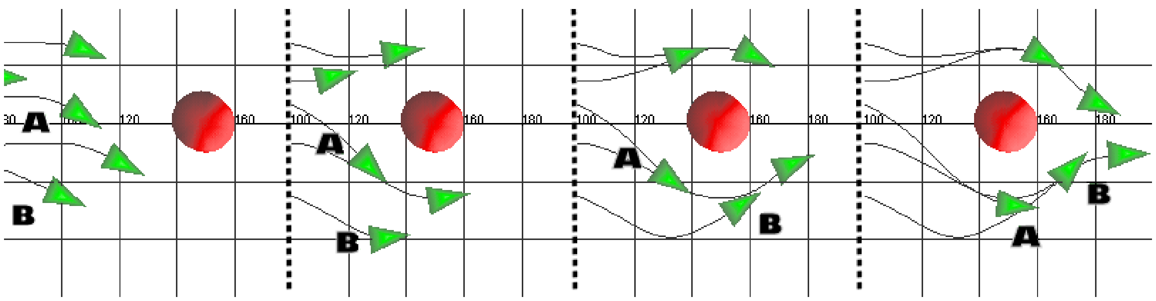




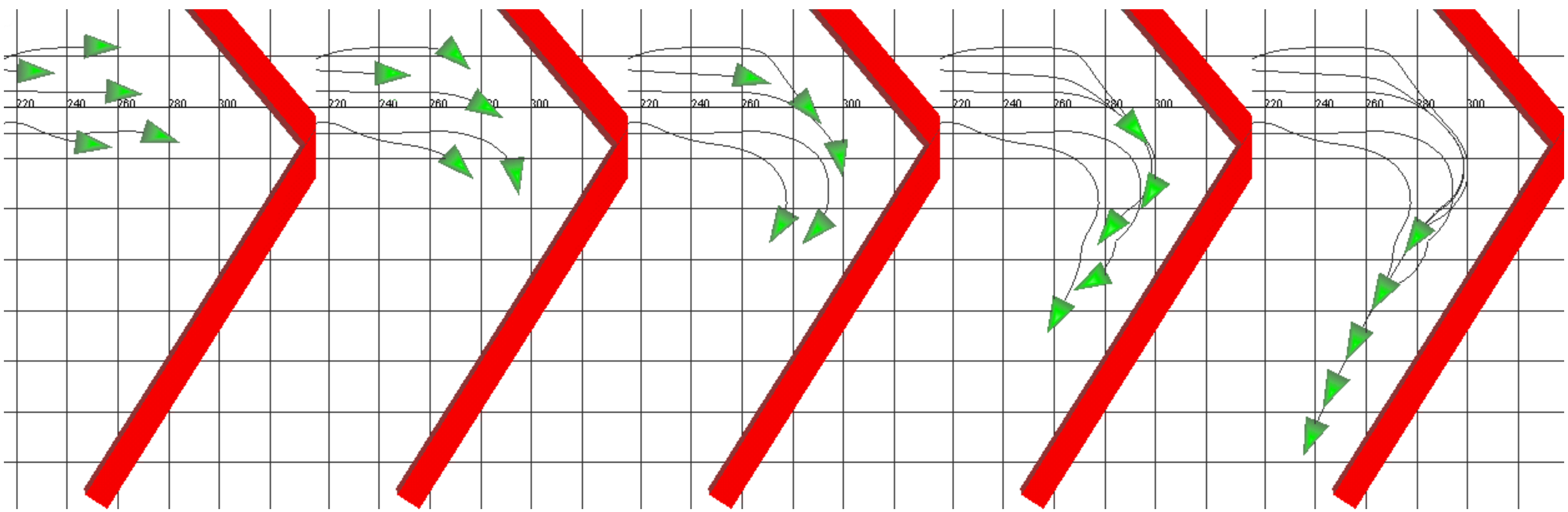


Multi-robot teams

A multi-potential approach



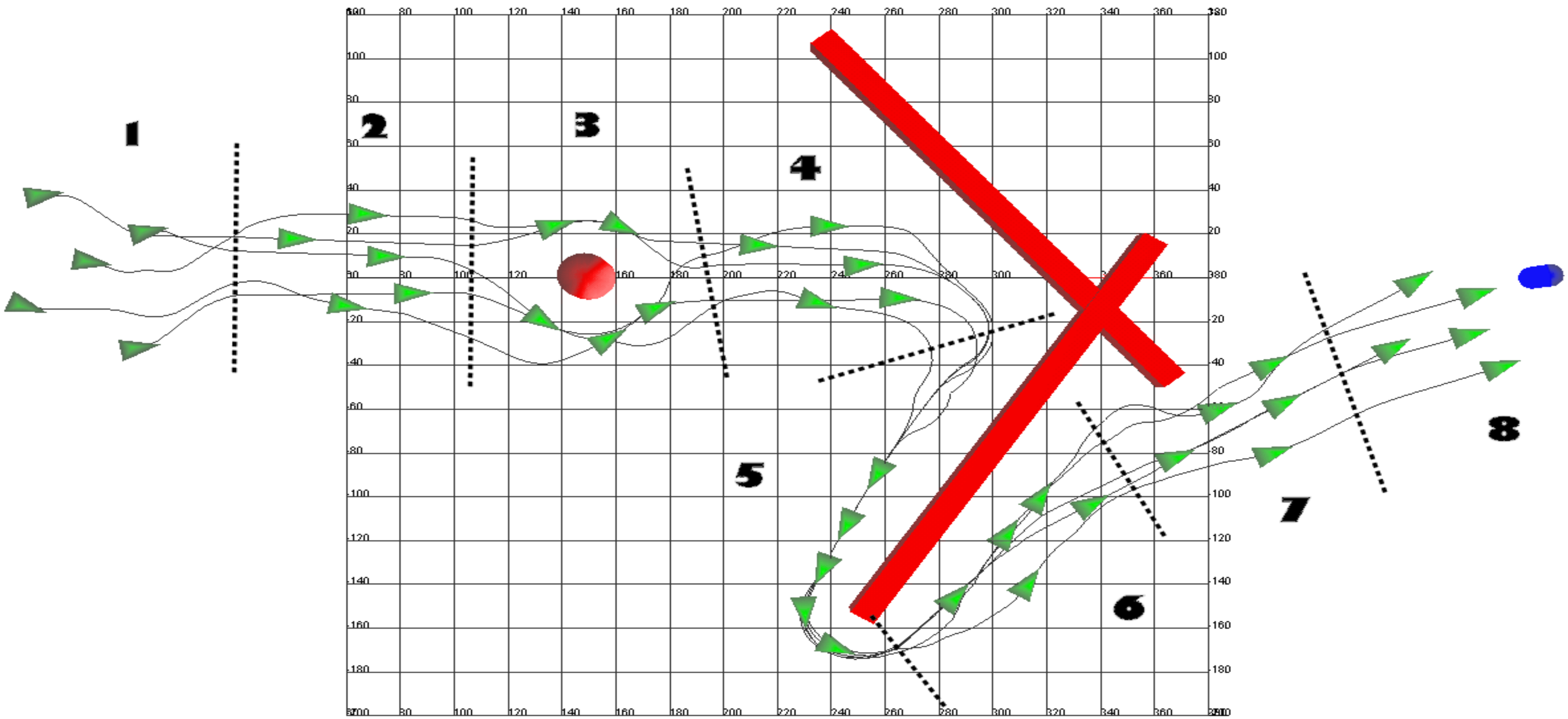
Obstacle avoidance



Formation transitions

Multi-robot teams

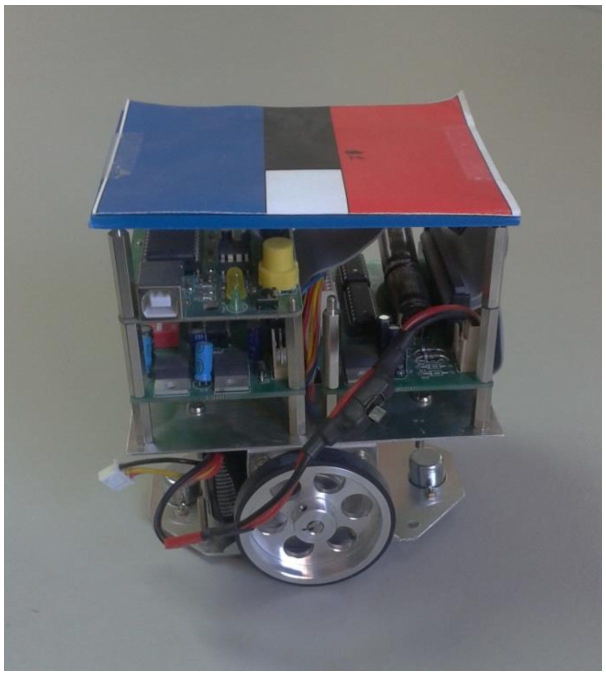
A multi-potential approach



Flexibility

Multi-robot teams

A multi-potential approach



Motion of the group:

- No leader to follow
- The motion of the group is a result of the motion of each member

Local rules:

- Several ways to enter in the formation
- While avoiding obstacles and other members

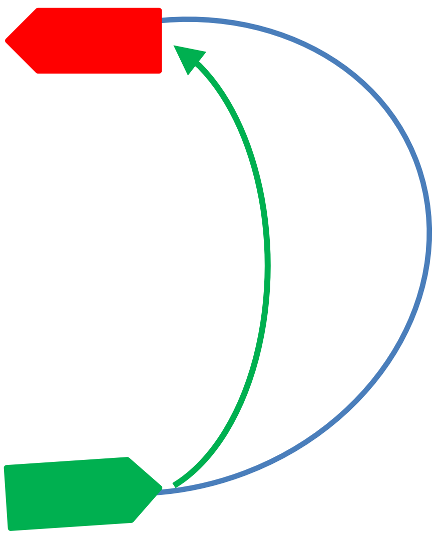
Multi-robot teams

Autonomous USVs

We developed a series of USVs with the same on-board control unit (Different ship scales)

Multi-robot teams

Formation control

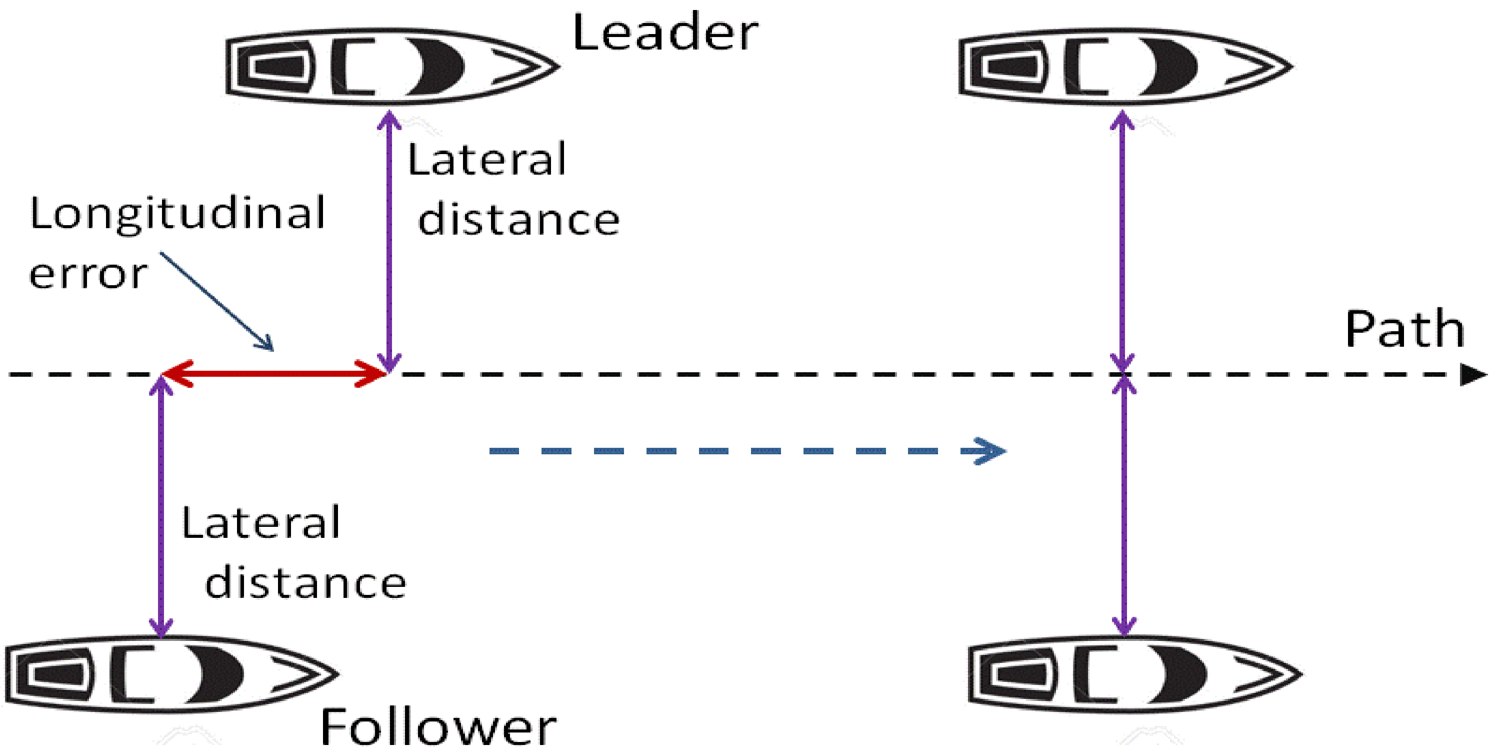


We experimentally found several drawbacks of follow-the-leader approach:

- Virtual leaders could be sometimes too fast
- The follower tend to short-cut curved trajectories of the leader

Multi-robot teams

Formation control

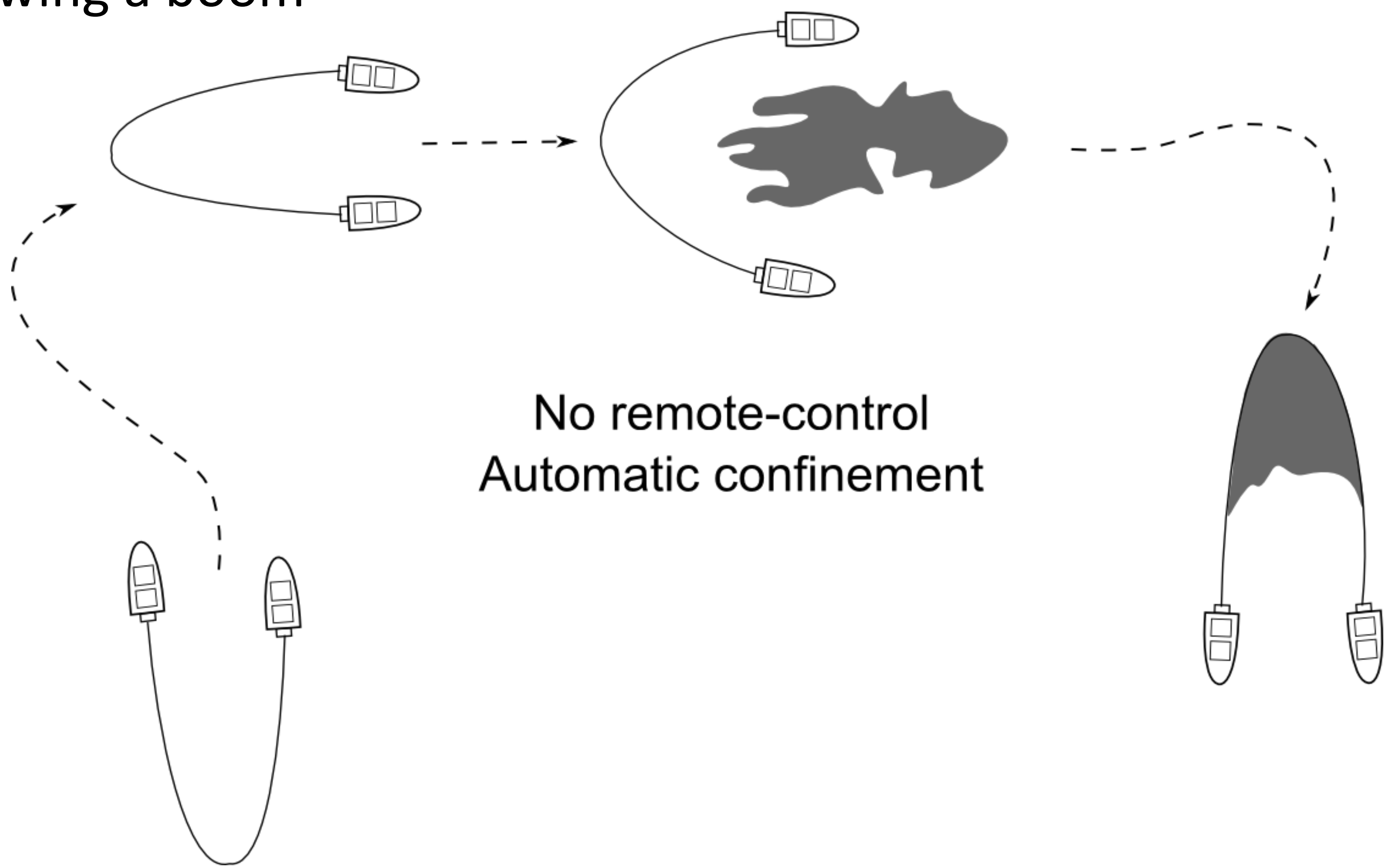


We combine path-following
and leader-following

Multi-robot teams

Physical interaction

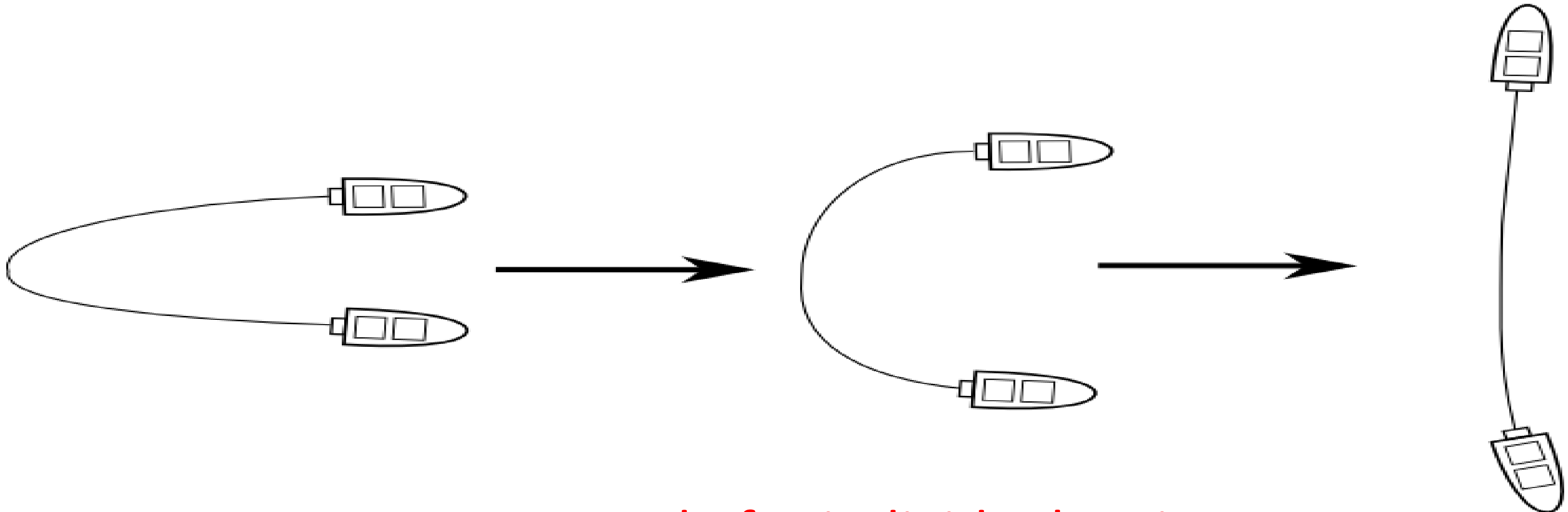
Two USVs towing a boom



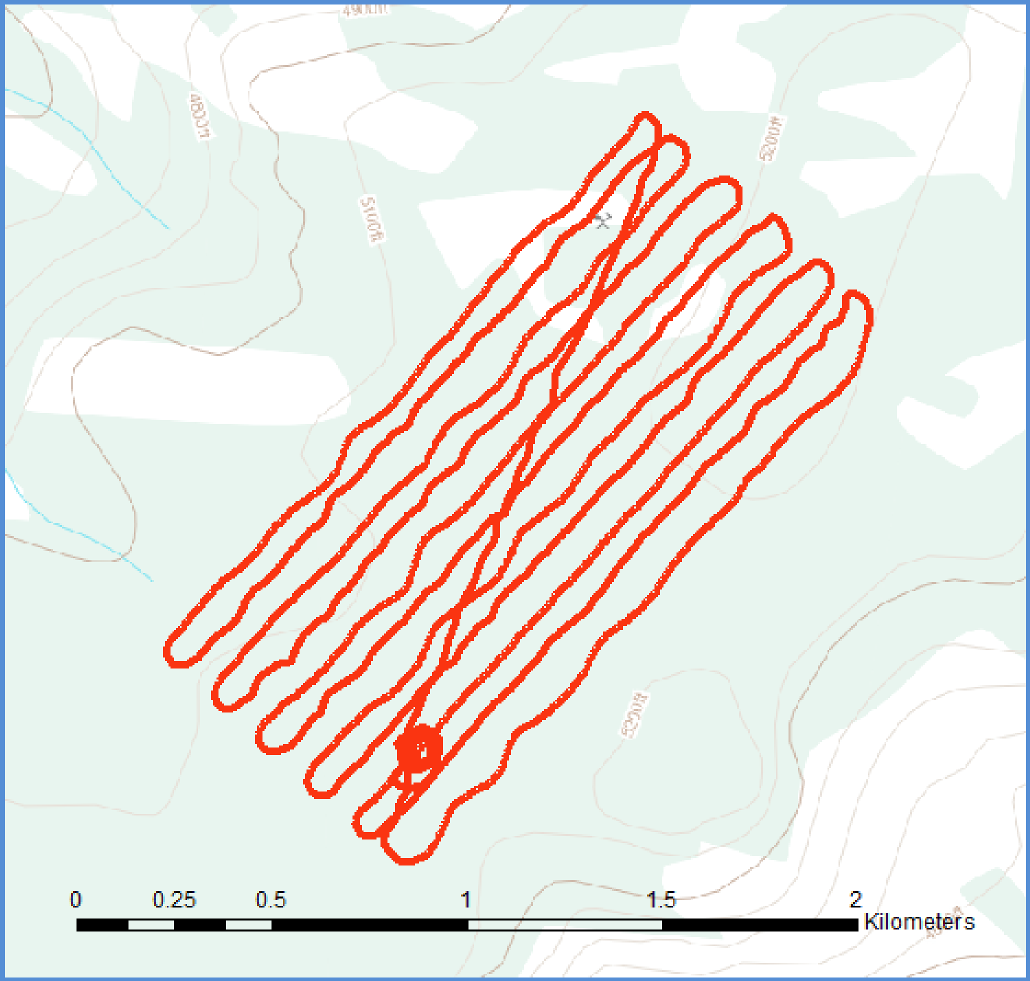
Multi-robot teams

Physical interaction

Two USVs towing a boom → Problem: tug-of-war



Lesson: USVS are made for individual action –
A new software layer should be added
for physical interaction control



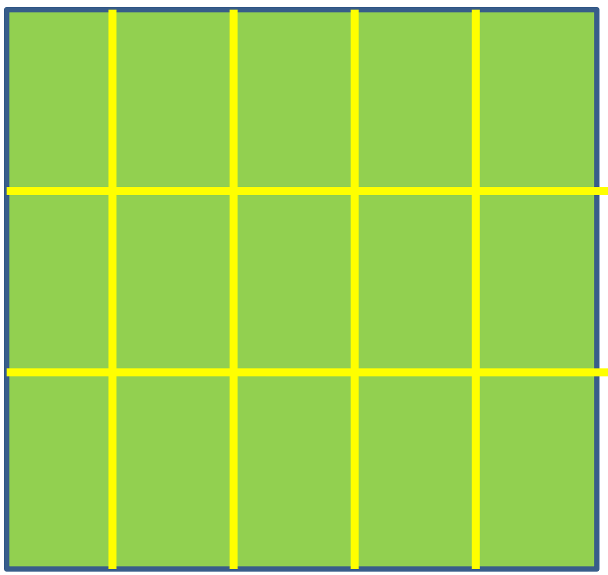
Scan-area

Scan-area

Cooperative work of several UUVs and USVs

Compatibility problems

EDA Necsave Project: To establish networked systems of several types of unmanned vehicles



One of the scenarios is area scan for detection of mines:

- Division into 3D boxes
- Several UUVs, possibly some UAVs
- Scan reconfiguration in case of failures

A Necsave software adapter is under development

Scan-area

After receiving a succint mission plan (scan this area) the USV decided to divide the area into two sections

Experimental result, top view (GPS traces)

Scan-area

Studies for swarm application

The intuition is that swarms involve many individuals

- Hundreds of real robots: not easy
- Work in simulation (pros and cons)
- Learn from human crowds

Scan-area

Learning from human crowds

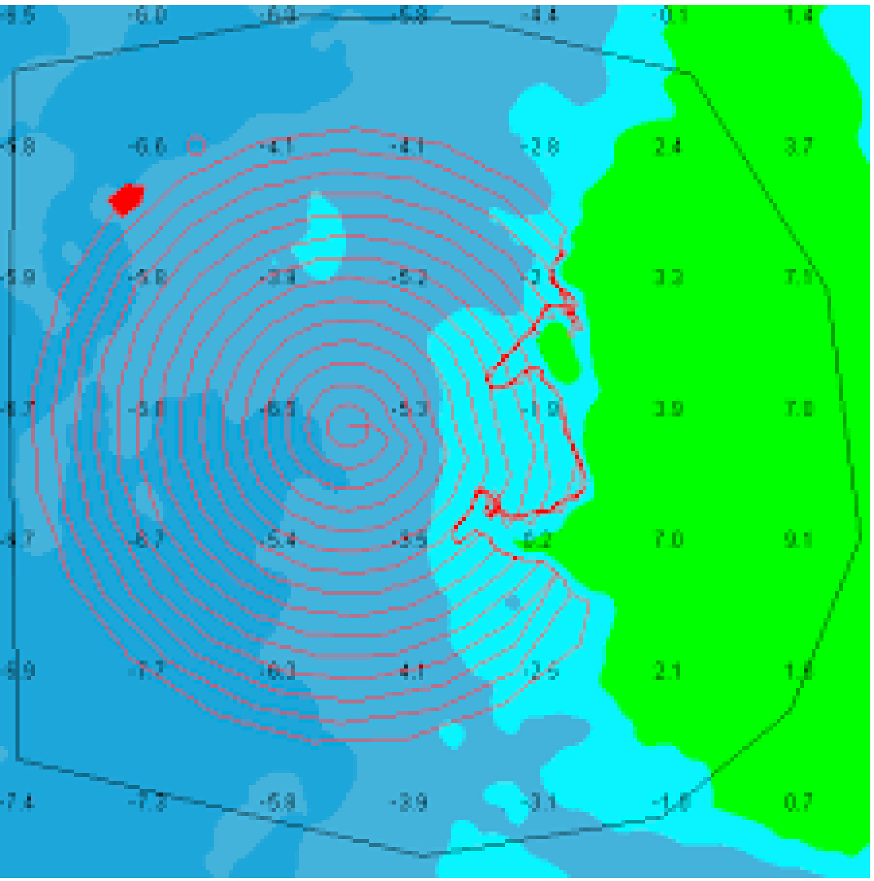
Palmer, et al. (2003: …humans as testbed for swarm algorithms…

Treuille, et al. (2006): Continuum crowds

Emergence of global behaviors

Scan-area

In case of searching, what humans do? (1)



Suppose a plane crash on sea:

- Urgent search for survivors
- Spiral path
- Take into account current and wind

Scan-area

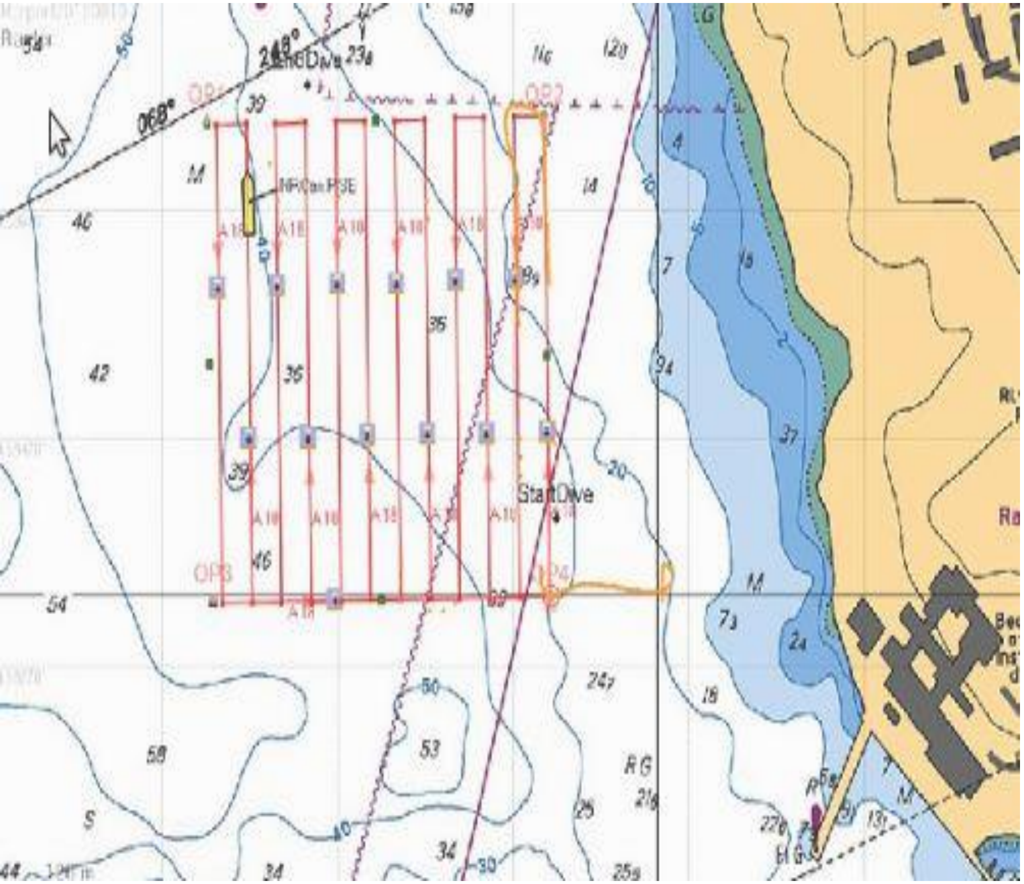
In case of searching, what humans do? (2)

Searching something in field

- Exhaustive exploration
- Dense parallel formation

Scan-area

In case of searching, what humans do? (3)



Locating submerged mines

- Lawn mower path

Scan-area

In case of searching, what humans do? (4)

Earthquakes:

- Unstructured groups
- Around places of interest

Scan-area

The term “coverage”

There are many papers using this term
It has at least three meanings:

- Blanket coverage: Continuous coverage of every point in the area (example: give coverage to mobile phones or networked robots)
- Sweep coverage: Makes an exhaustive pass over the area (example: grid searching)
- Barrier coverage: Nothing can pass a fixed perimeter

20 references on this aspect, including the use of swarms

Ant colonies

Ant colonies

Bio-inspired path optimization

Dorigo, et al. (1999): Fant algorithms for discrete optimization
Dorigo & Blum (2005): Ant colony optimization theory: A survey

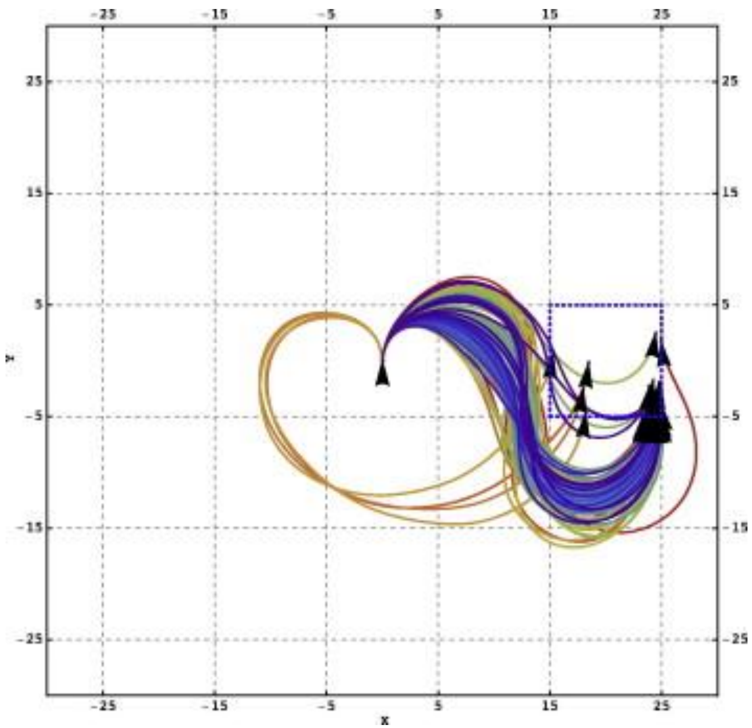
Robotic versions using “digital pheronomes”

Our proposal:

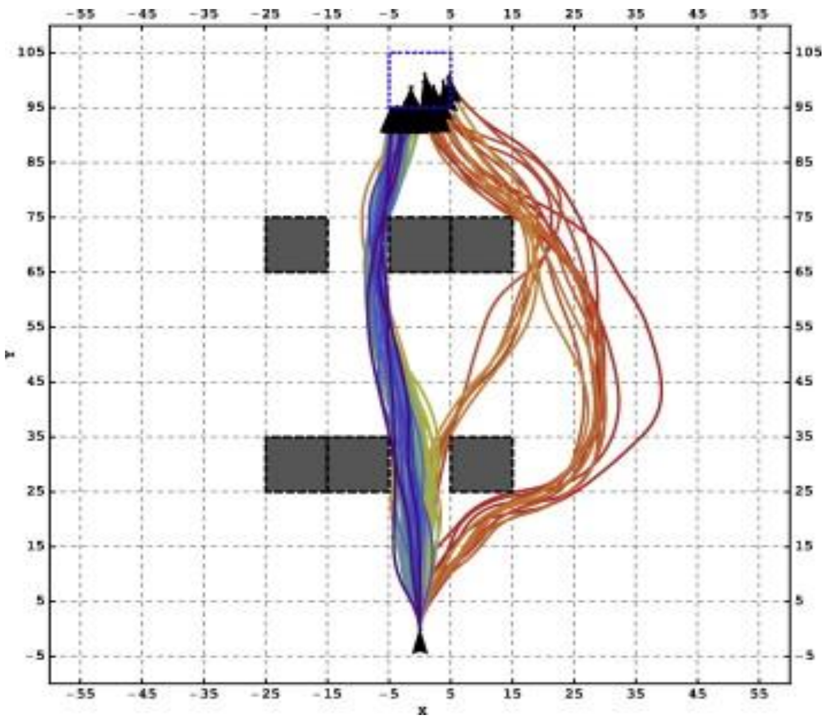
- Explorer ants
- Forager ants

Ant colonies

Application to ship maneuvering



Going to port platform

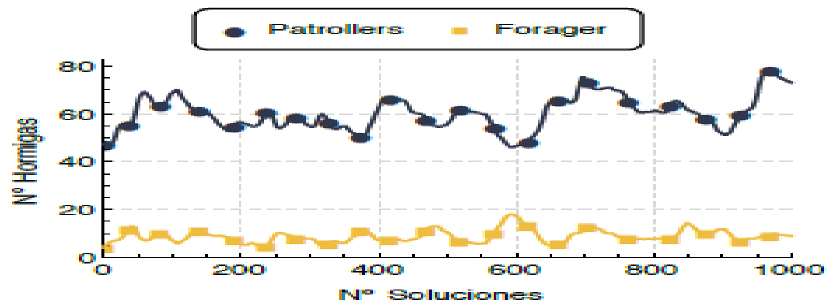


Advancing through obstacles

Ant colonies

The process evolution produces more explorers when the searching space is larger

TSP (51 towns)

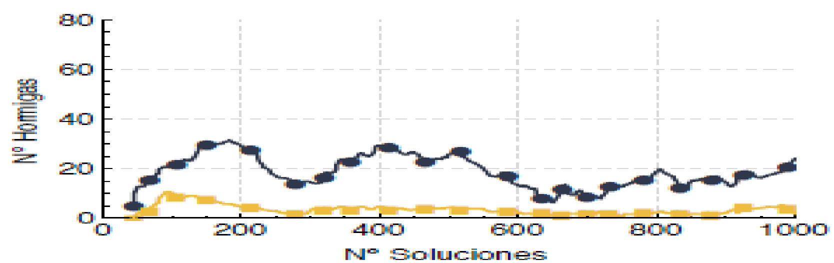


Explorers

Foragers

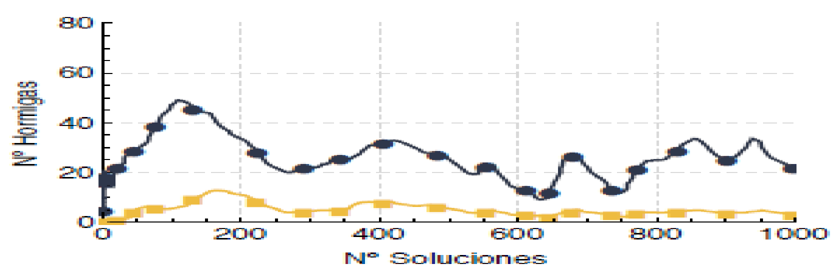
(a) Instancia del TSP de 51 ciudades.

Santa Fe trail



(c) Programación genética: "Santa Fe, artificial ant trail".

Ship maneuvering



(e) Planificación de una maniobra de 100m con obstáculos.

NATO OTAN

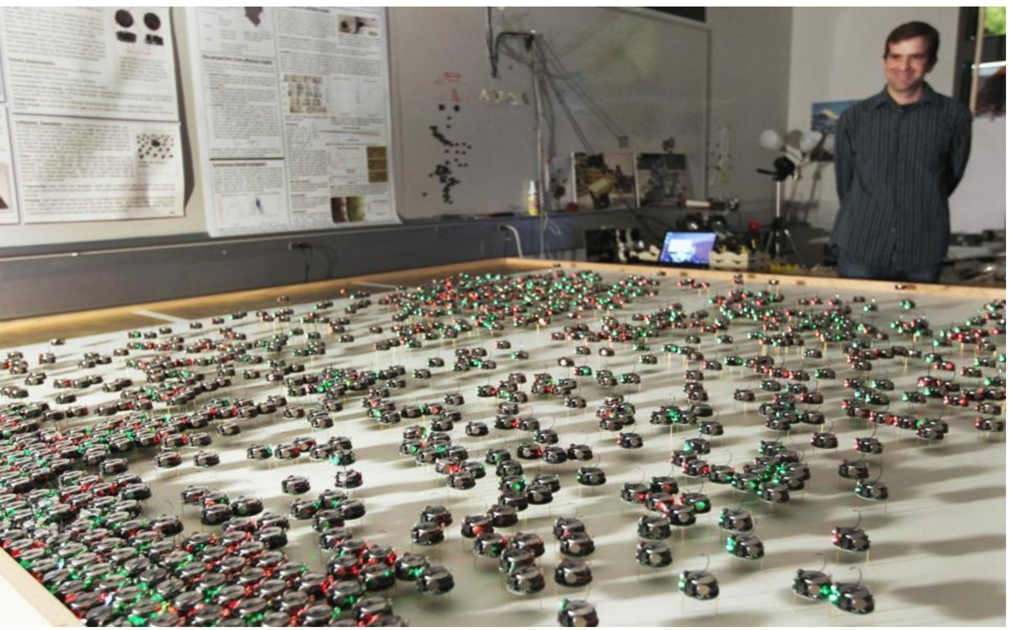
Fishes

Swarms

Swarms

Bio-inspired topic, abundant literature

Sahin (2004): Swarm robotics….
Hoff III (2011): Multi-robot foraging for swarms of simple robots (Thesis, Harvard Univ.)



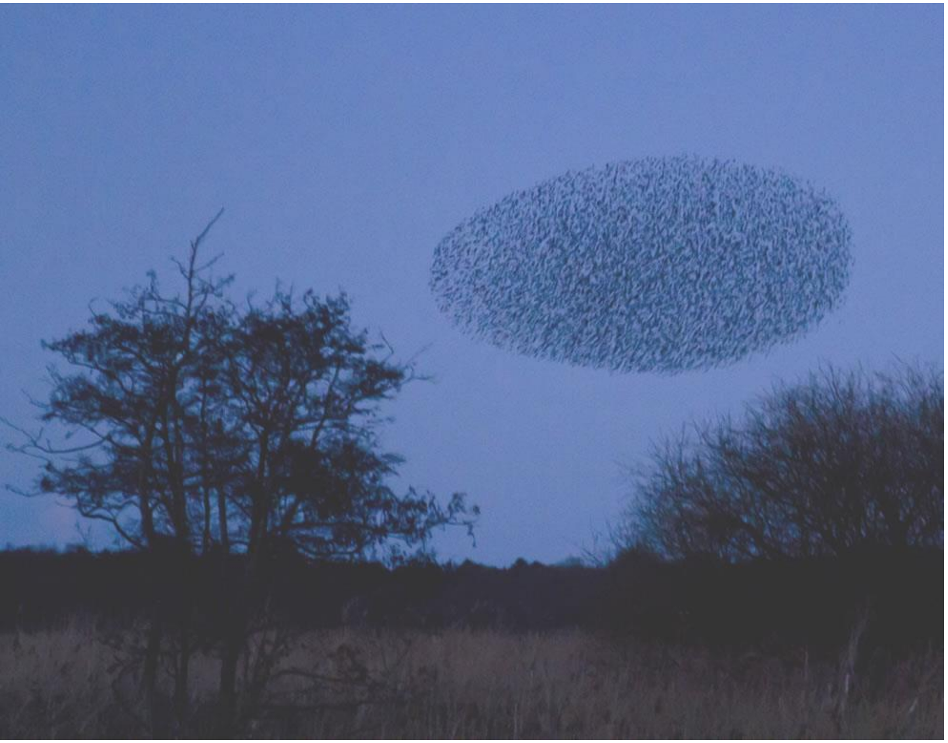
1000 robots, Harvard Univ.

Lines of research:

- Analysis of natural swarms
- Building of robotic swarms
- Imitate/use natural swarm principles
- Human-swarm interaction

Swarms

Size stability. Launching and dispersion



- Attraction and repulsion forces
- Gas metaphor
- Rapid and adequate dispersion after launching

Beal (2015): Superdiffusive dispersion and mixing of swarms

Swarms

Aspects of robotic swarms

- Recent survey of human-swarm interaction:

  Kolling, et al. (2015): Human interaction with robot swarms: A survey

- Swarm engineering :

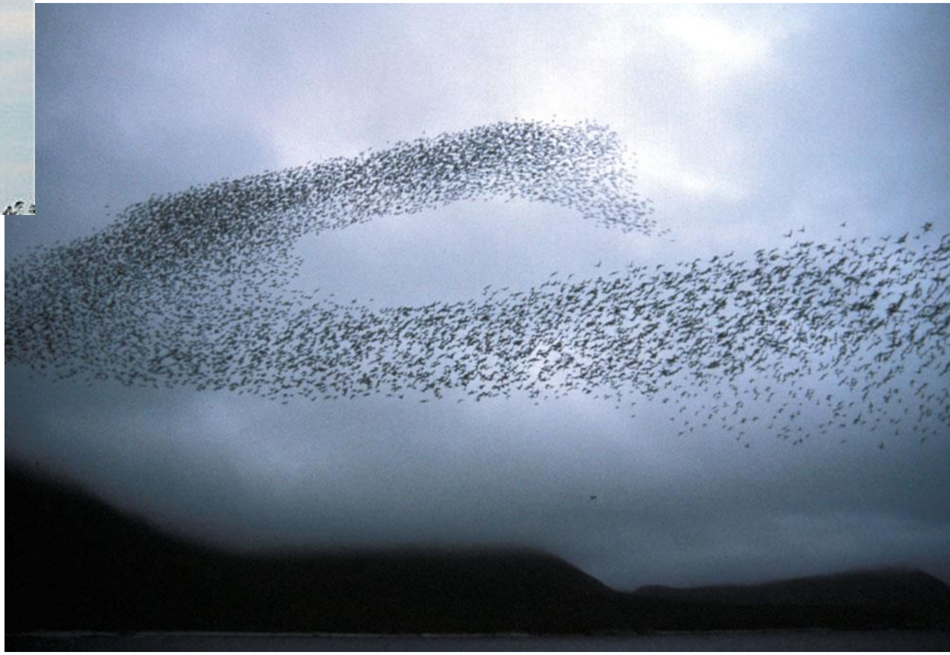
  Brambilla, et al. (2013): Swarm robotics: A review from the swarm engineering perspective

- Recent advances of swarm robotics:

  Tan & Zeng (2013): Research advance in swarm robotics

Swarms

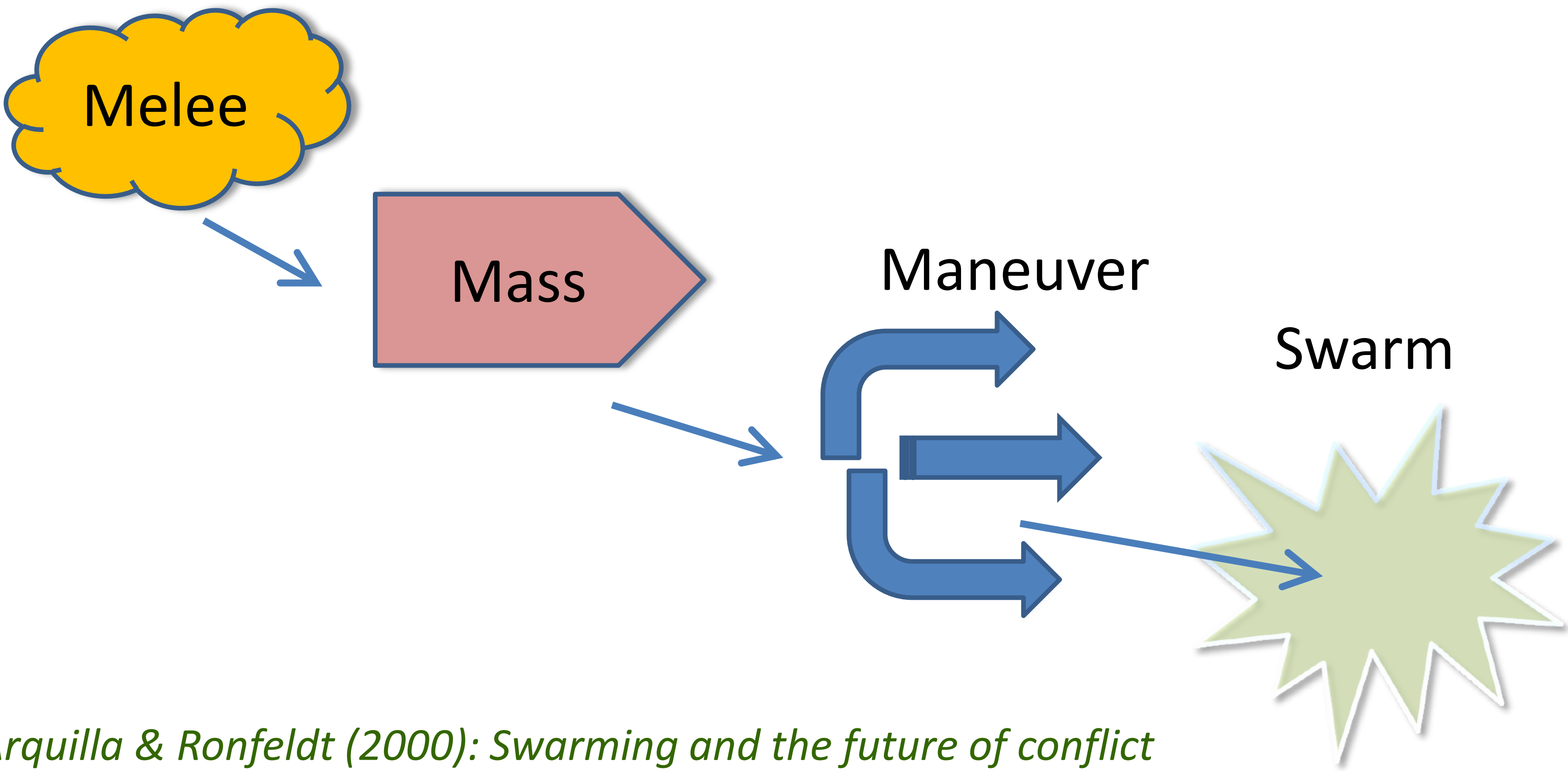
Some images



Military Perspective

Military perspective

A new paradigm



Arquilla & Ronfeldt (2000): Swarming and the future of conflict

Military perspective

Example: Iran's asymmetric Navy

Military perspective

How to handle robot swarms?

- Exerting control on swarms:

  Kira & Potter (2009): Human control over decentralized robot swarms

- Swarm mission planning :

  Lamont (2008): Swarm mission planning development using…

- Countermeasures:

  Beaudoin, et al. (2011): Potential threads of UAS swarms and the countermeasures needed

Military perspective

A radical example

One desires to experimentally demonstrate swarm behaviors

- One buys 100 quad-copters
- They come with 100 R/C consoles
- One hires 100 R/C pilots

Problems

- What is my drone?
- How coordinate each other?
- Measurable results?

A software layer should be added

Military perspective

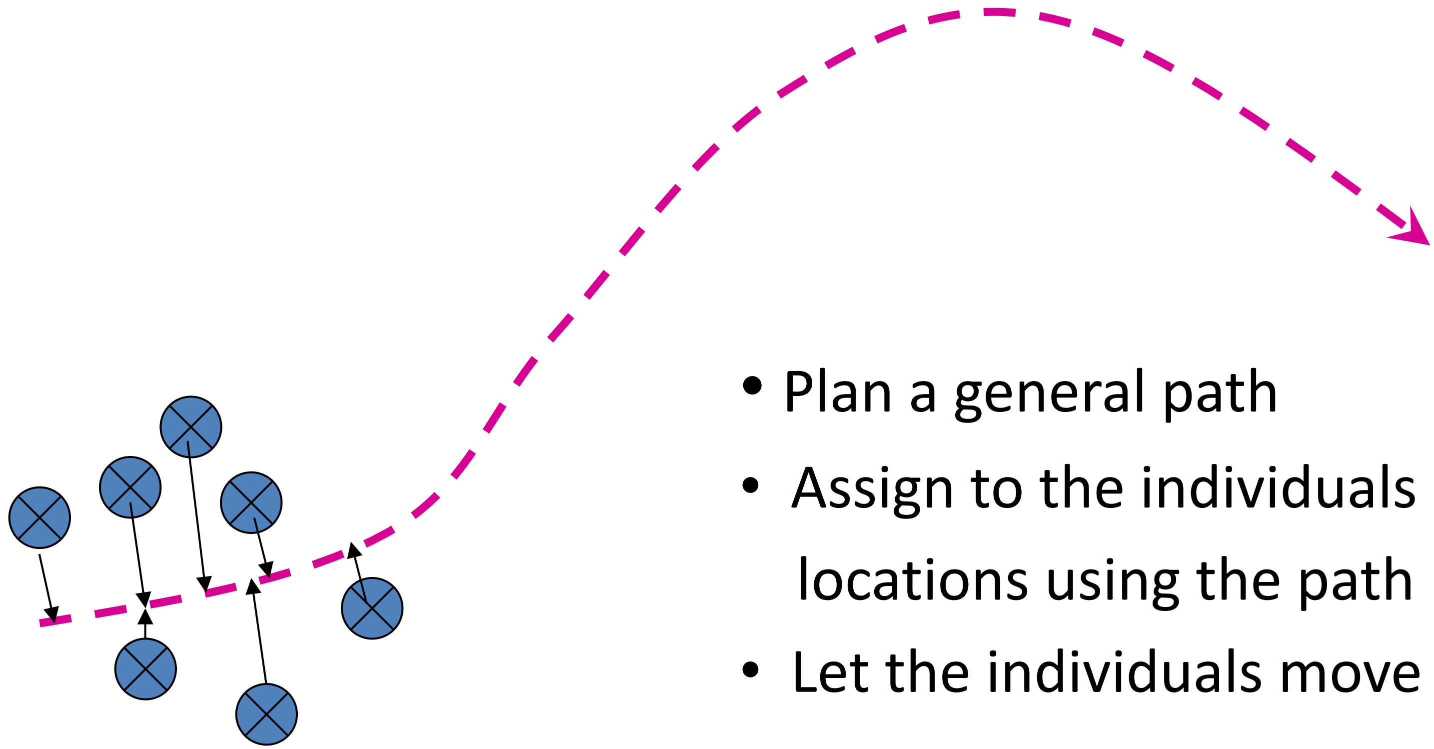
A "classical" approach

Formations of formations

Kushleyev, et al. (2013): Towards a swarm of agile micro quadrotors

Military perspective

What we could preliminary suggest



- Plan a general path
- Assign to the individuals relative locations using the path
- Let the individuals move

Conclusion

Conclusion

Summary:

- ❑ Decentralization
- ❑ Cooperation / temporal coordination / spatial coordination
- ❑ Anonymous formations / Multi-potentials
- ❑ Aspects of formation control (traffic; boats)
- ❑ Scan-area / learn from people
- ❑ Ants
- ❑ Swarms
- ❑ Military perpsective

Thank you