**JNRR 2015 Journées Nationale de la Recherche en Robotique**
**Cap Hornu, Octobre 2015**

# Coopération multi-robot

# Enjeux et défis scientifiques

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# Outline

I. Challenges with robot cooperation

II. Issues and complexity

III. Illustration on two problems

    Multi-robot exploration and Traffic optimization

IV. Concluding remarks

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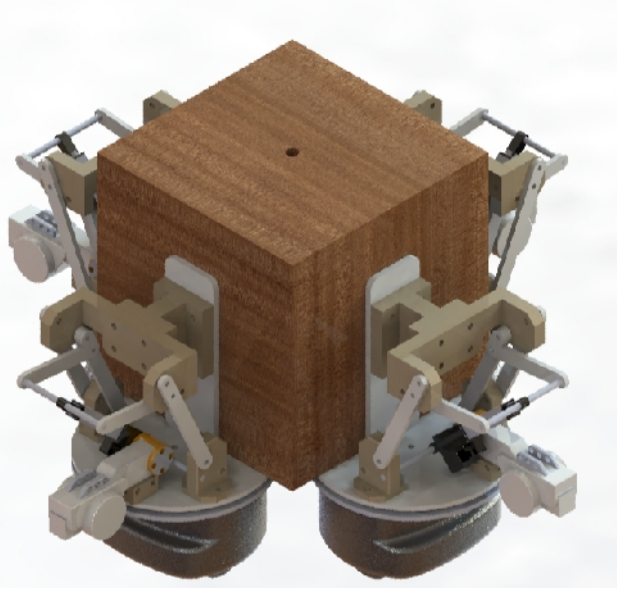
# Context : multi-robot cooperation

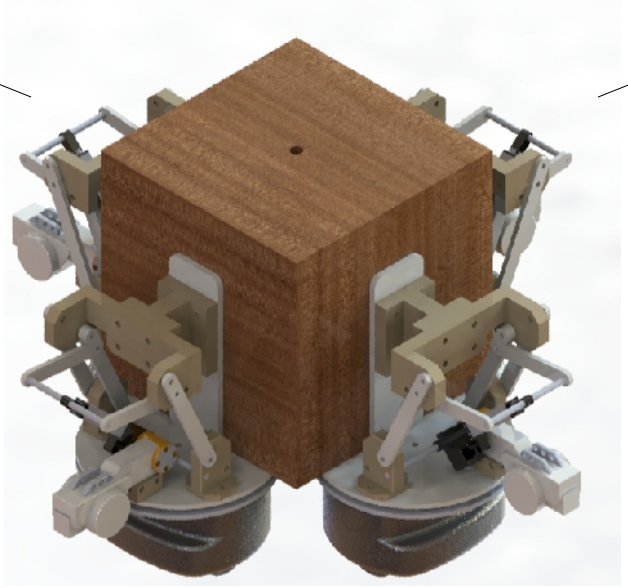


C3Bots project - Institut Pascal, IFMA, Clermont Ferrand
[Hichri et al 2015]

# Context : multi-robot cooperation

Doing something impossible for a single robot

Improving robustness & efficiency



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Requires : coordination, synchronization, communication, ..

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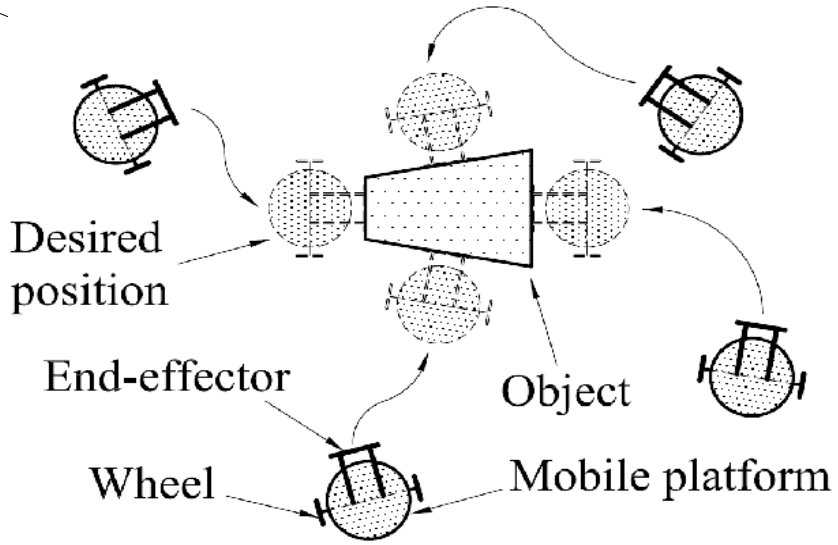


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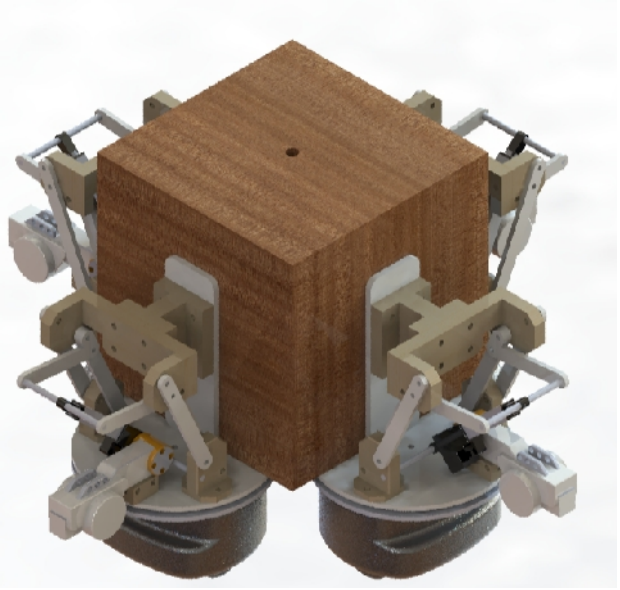
Requires : coordination, synchronization, communication, ..

# Which topics are concerned ?

Mechatronics

perception

Distributed
Decision-making



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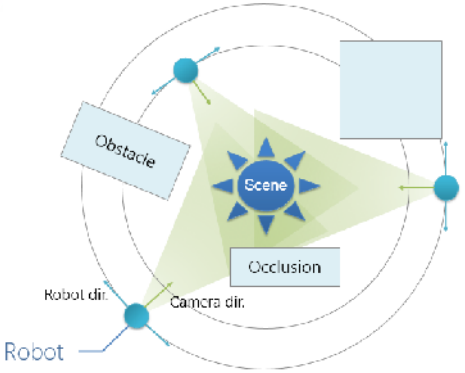
Multi-robot planning
& navigation

Multi-robot
communication

# Which application domains ?

Transport
Surveillance
Exploration
Rescue
Assistance
…

in
Factories
Urban env.
Post-disaster env.
Home/human env.
...




# Multi-robot cooperation in IROS 2015

- **Multi-Robot Coordination**
- **Multi-Agent Coordination**
- **Planning, Scheduling and Coordination**
- **Path planning for Mobile Robots and Agents**
- **Autonomous Agents**
- Distributed Robot Systems
- **Networked Robots**
- **Cloud Robotics**
- **Swarm Robotics**
- Cellular and Modular Robots
- **Micro/Nano Robots (2)**
- Cooperative Manipulators
- Biologically Inspired Robots (5)
- Biological Applications of Micro Robots

19 tracks over ~ 180

**+ 5 Workshops over ~ 50.**

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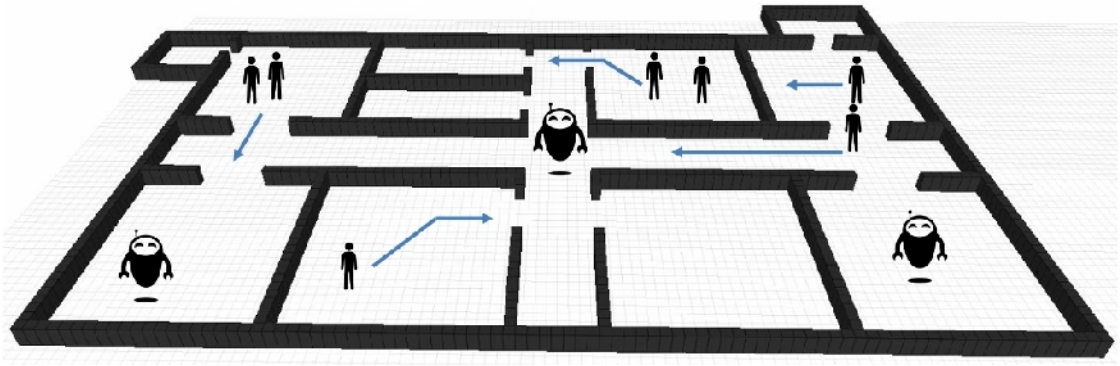
# Factors of complexity

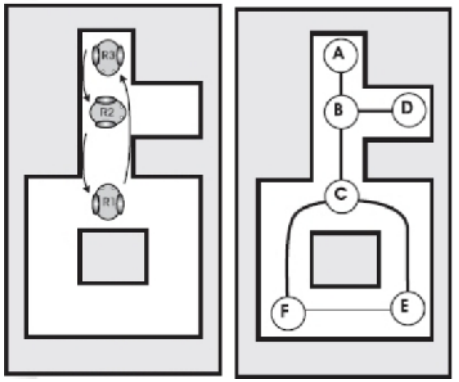
**# robots** (agents) + topology of the **environment** + **uncertainty** →

- Coordination → interactions → local & limited sol.
- Decision (optim.) → state space → combinatorial explo.
- Sharing data → messages → combinatorial explo.

Multi-robot path-planning : PSPACE [see eg. L. Parker 2010]
Robot freezing pb.



Robot-waiters pb. [Saraydaryan et al. ARSO 2015]




[Peasgood 2008]

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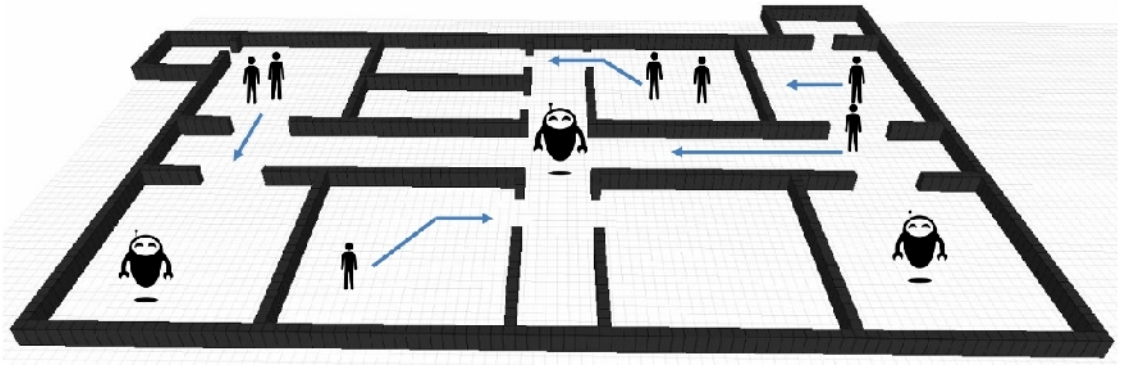
**Gain of cooperation vs. Cost of computing coop.**



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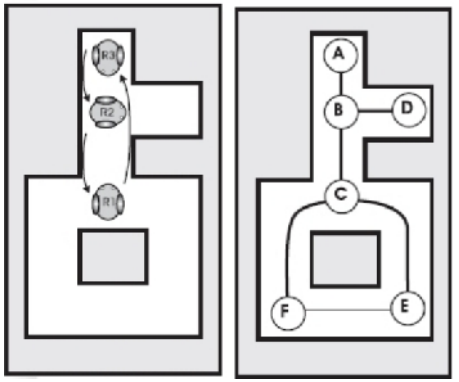



[Peasgood 2008]

# Challenge in decision : scalability

## Centralized vs. Decentralized approaches

**Centralized optimization techniques** → limited/no scalling

- Requires global information → optimal sol.
- Seq. decision process models (eg. MDP) → memory & time consuming

**Decentralized techniques** → scale up

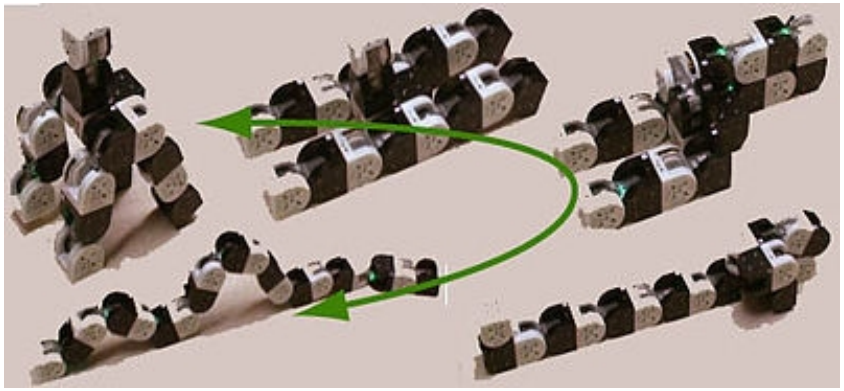
- Local information/decision (heuristics) → real time
- (Emergent) global behavior → no optimal sol.

**Objective : optimality & real time decision**

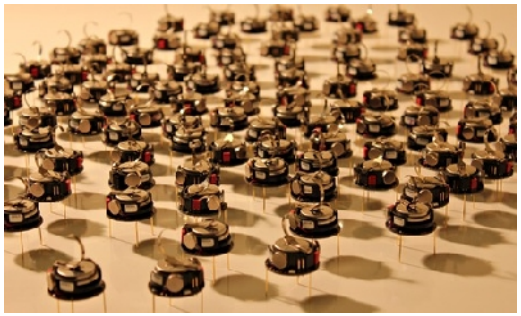
- Concice (approx.) optimal policy [Dibangoye et al. 2015]
- Mixing decentralized decision and optimization techniques [Tlig et al. 2014]

# Decentralized → collective navigation and self-config.

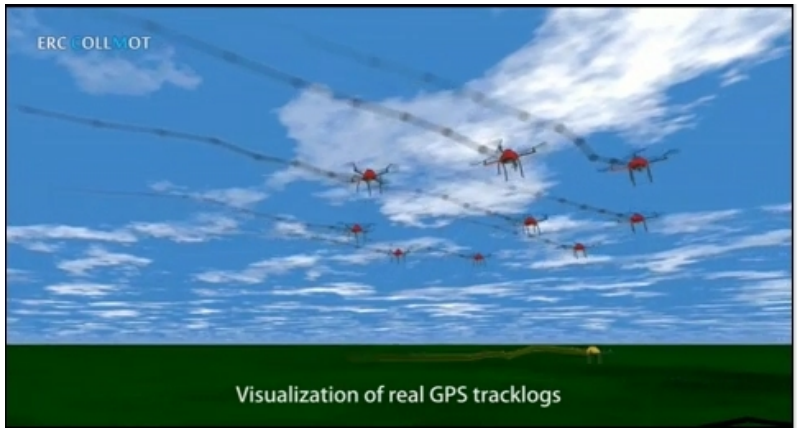
Box-pushing 1988



Self-configurable robots (M-TRAN III) 2005



Kilobots (2011)

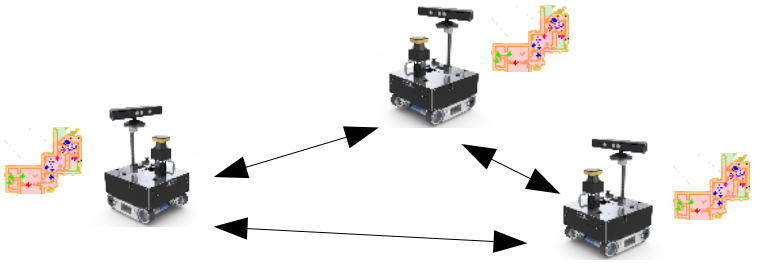



CollMot project (UAV **flocking**) Pennsylvania 2012

# Complexity of communication ?

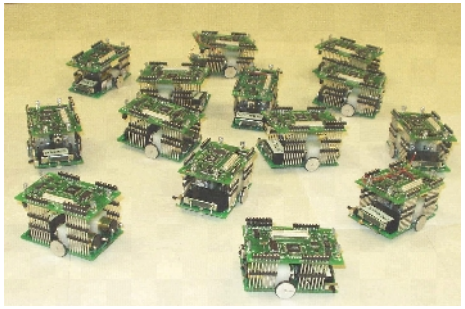
Multi-robot systems

- 1-1, 1-n communication
- Ad hoc networks, wifi ..



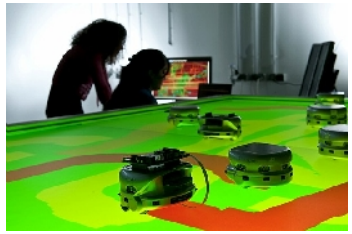
Networked robot

- Robotics & Network technology
- Robots guided by their communication



Swarm robotics

- No communication
- Indirect communication (bio-inspired)



# Role of middlewares

Issues with communication

- Maintaining/reparing **connectivity** eg. [A. Franchi IROS DEMUR 2015]
- Connection to other heterogeneous robots / devices (interoperability)

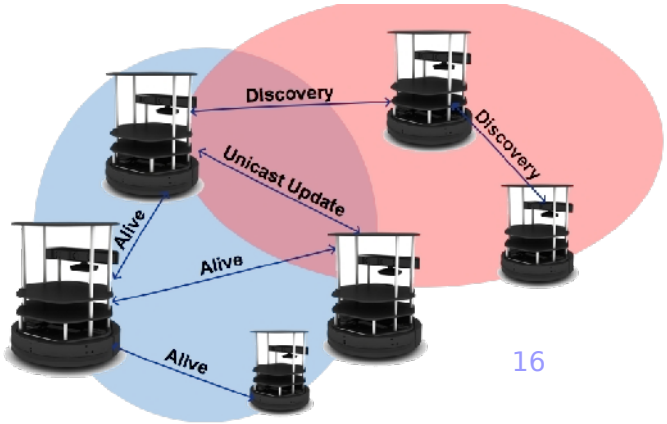
→ Middleware

- Transfering functionalities to low layers (risk with overhead)
- Monitoring and helping behaviors programming

example : SDfR protocol (Service Discovery for Robots) [Chitic et al 2014].

→ Cloud Robotics

- Externalizing memory/capacity, Cloud of robots



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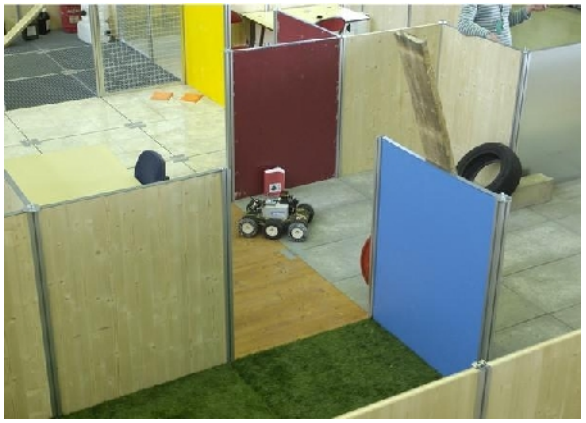
# I. Exploration and mapping



# Exploration and mapping

**The *Carotte* Challenge** (ANR/DGA) 2009-2012

- **Exploration and mapping** with autonomous and communicating robots
- A 120m² unknowm indoor environment
- 30' max to finish the mission

The **Cartomatic** project

- LISA-Angers & MAIA team INRIA Nancy
- A **multi-robot** SLAM approach
  (Local decision & shared global map)

Competitiion between 5 french consortiums

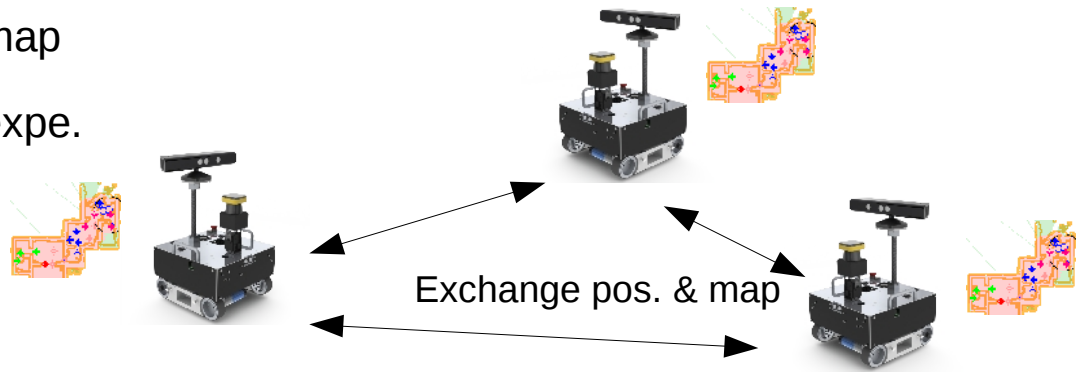
# Cartomatic : a multi-robot approach

***Multi-robot advantages***

- **Speed up** the exploration (cooperation)
- **Robusteness** to robot failures
- **Help each other** (cooperation)

The **Cartomatic** project

- **Frontier-based** algorithm [Yamauchi 98]
- **Broadcast** of navigation map
- Up to **6** Minirex robots in expe.
  Kinect and SLAM fn.



# Exploration : frontier-based approaches

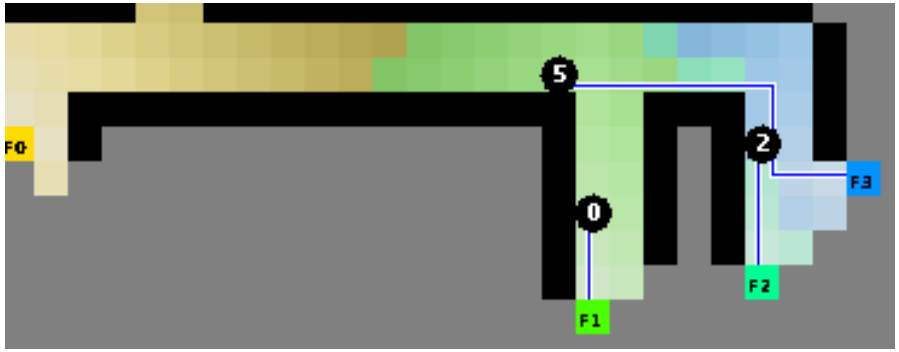
**Criteria**

- Optimization only based on robot-frontier distances ($C_{ij}$)
- *n* robots, *m* frontiers
- Computing affectation $\alpha_{ij}$ : minimizing

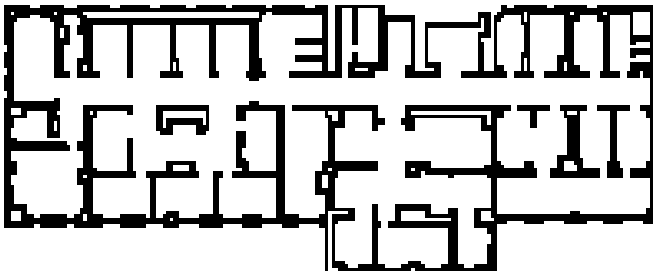
  → static view of the problem

$$\sum_{i=1}^{n}\sum_{j=1}^{m}\alpha_{ij}\,C_{ij} \quad , \quad \max_{\forall i}\sum_{j=1}^{m}\alpha_{ij}\,C_{ij}$$

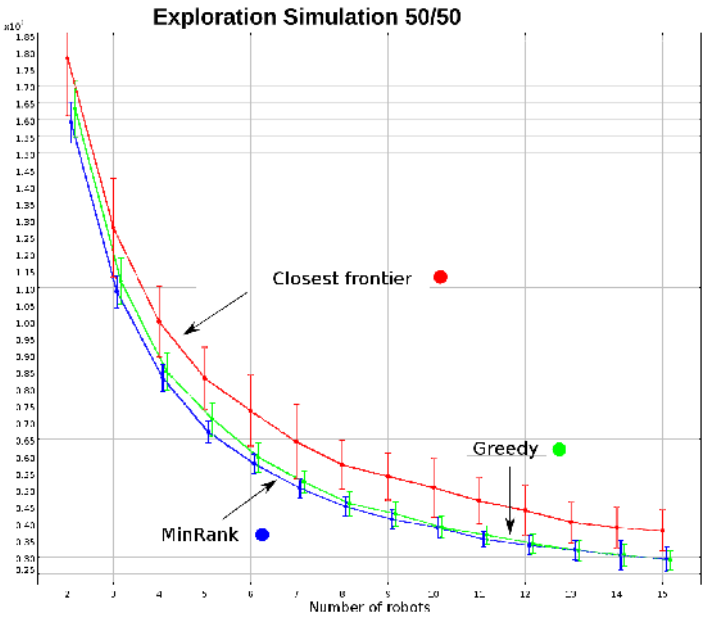
**Greedy assignation** eg. [Burgard *et al* 02]
**MinRank** : local and fair [Bautin et al. 12]
**TSP based assignation** [Faigl et al. 12]
...



# Influence of #robots on time exploration

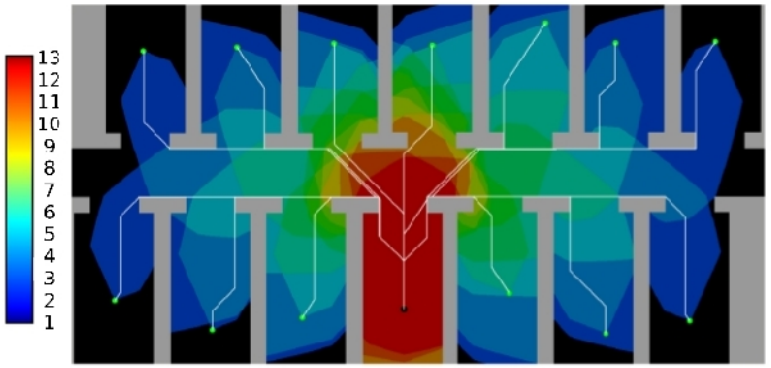


Hospital env.

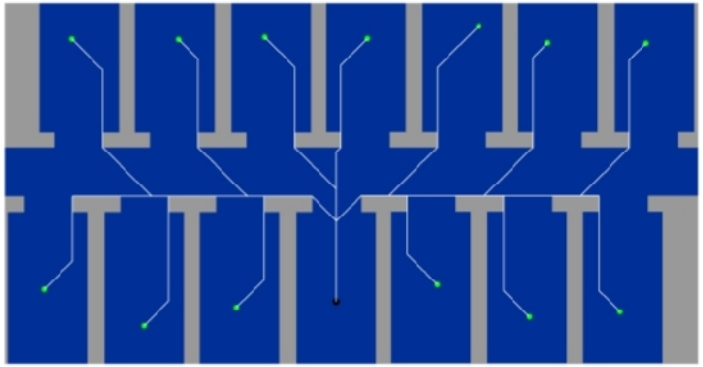



MinRank [Bautin et al. 12]

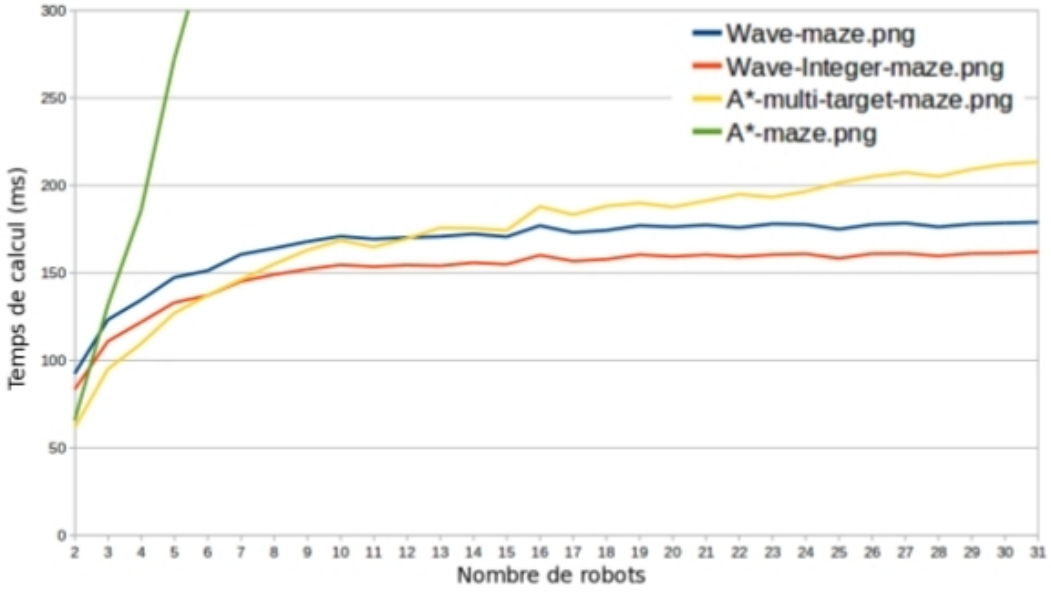
# Cost comp. : wavefront vs. A* based computation




A* / multi-A* [Stewart and White 1991]

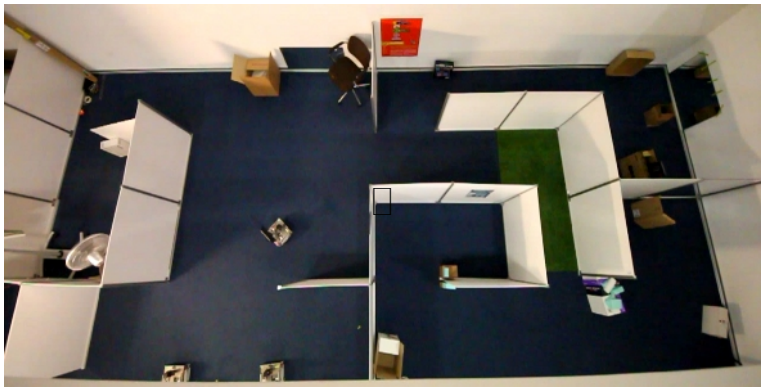


Wavefront comput. [Barraquand Langlois Latombe 91]

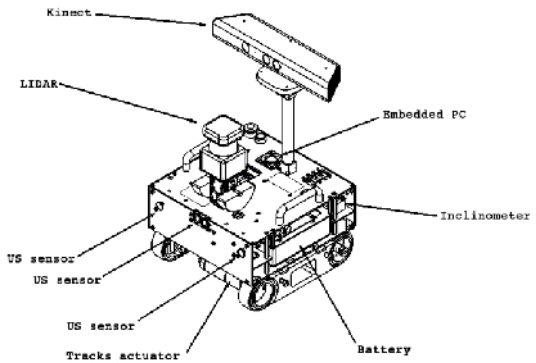



[Bautin et al 2013]

# Experiments



INRIA Maia team, LORIA Nancy




[Lucidarme et al 2012] [Bautin PhD 2013]

# Robustness and efficiency in practice

Carotte Challenge Final 2012
Cartomatic team

Multi-robot SLAM with Cartomatic

- Robustness to robot failure/danger
- Carotte : First place ! (2012)
- 3D map (Kinect)

# II. Cooperation between autonomous vehicules

# Traffic optimization

**Cooperation**

- **in intersections**
  - Vehicle coordination (autonomous vehicles)
  - Different crossing strategies [Tlig et al. 13]
- **in platoons**
  - train of autonomous vehicles (+ leader)

**Communication**

- V2V, V2I

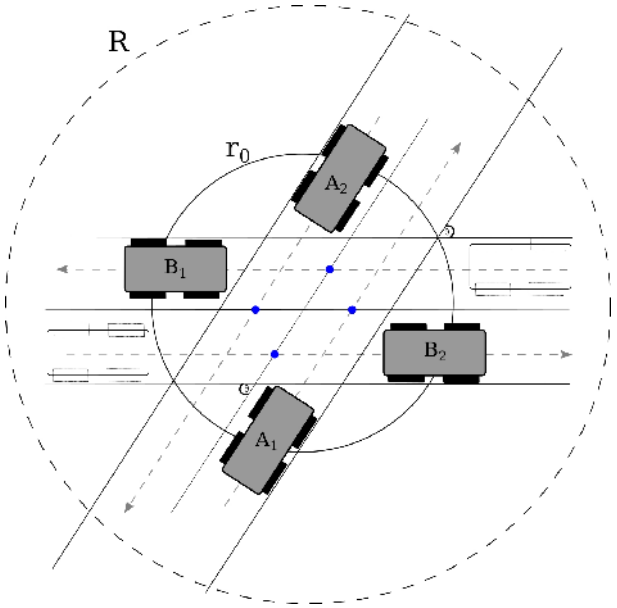
**Societal challenges**

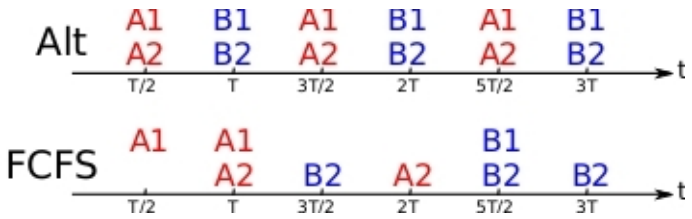
- Optimizing transportation time
- Reducing polution and energy consuming
- Improving passengers' security

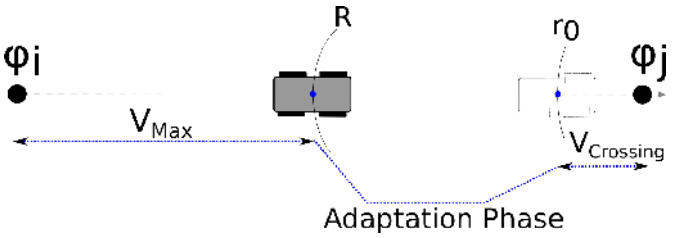
# Traffic optimization

**Cooperation at each intersection**

- **Non stop strategies :**
  - First Come First Serve (**FCFS**)
    [Dresner Stone, 2005]
  - **Alt**ernate [Tlig et al 2013]



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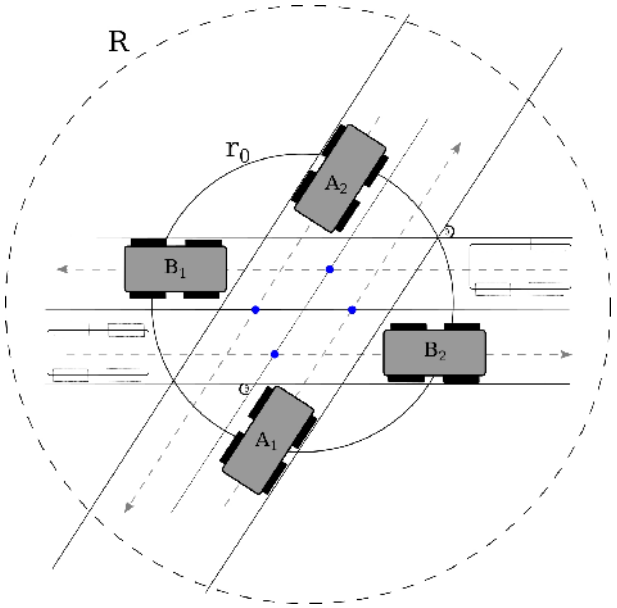
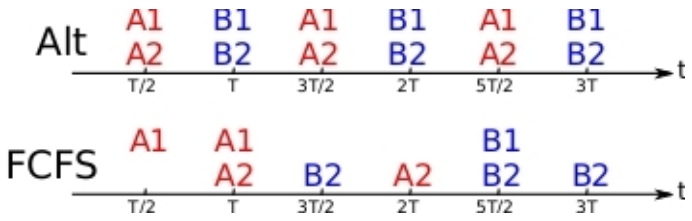
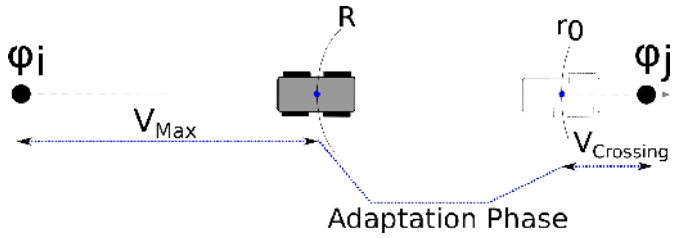


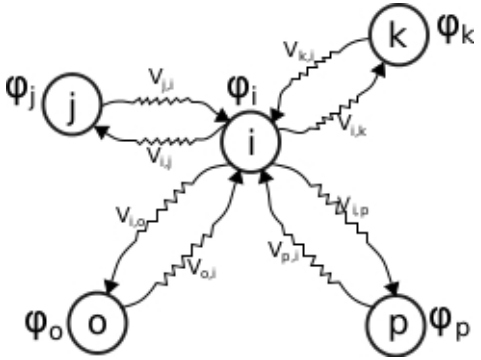



# Traffic optimization

**Cooperation between intersections**

- Decentralized (global) optimization → emergence of **green waves**
  → Hill Climbing, ρ–DSA
- Optimizing time / energy → **online adaptation** to traffic changes



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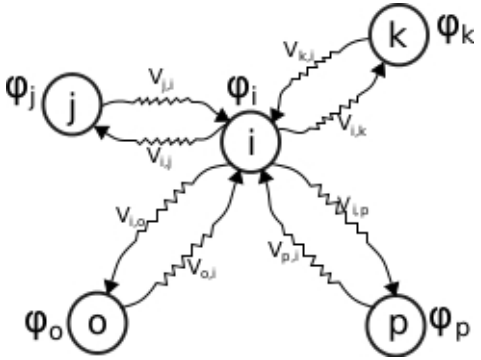

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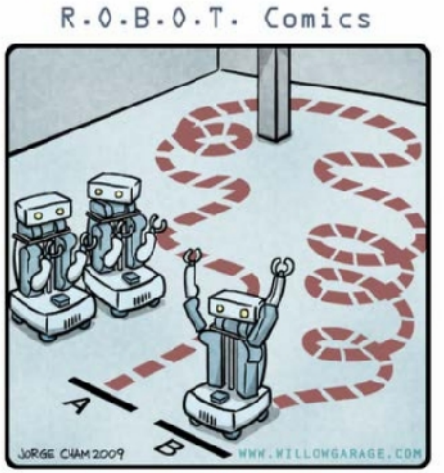


Challenge with multi-robot cooperation

- Multidisciplinary issues
- Scalability and applicability of models

  → Mixing local decision and optimization
- Dependance on communication
- Need of specific tools (soft) → standards ?

A societal challenge

- Connecting robots and intelligent objects
- Robots and Humans : evolving and working together

→ Cooperation is intelligence !

# Merci de votre attention

**Equipe Inria Chroma :** **https://team.inria.fr/chroma/**
Cooperative and human-aware robot navigation in dynamic environments

Maia → Larsen (Nancy, F. Charpillet)  eMotion → Chroma (Grenoble/Lyon, O. Simonin)

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