UNIVERSITY OF LIVERPOOL

COMP 532
Machine Learning and BioInspired Optimization

Lecture 25: Swarm Intelligence

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Overview

- What is Swarm Intelligence?
- Particle Swarm Optimization
- Ant Systems and Ant Colony Optimization
- Bee Colonies and Swarm Robotics
  - Bee-inspired algorithms
  - Swarm Robotics
    - Fireflies (synchronization)
    - StiCo (coverage)
    - Bee-Inspired Foraging

Foraging Task

- **Foraging**: the problem of efficiently locating and collecting items at unknown location within the environment

- Contains elements of many real world tasks such as network routing, task and role division, transportation, patrolling, …

- Two main **sub-problems**:
  1. path construction/planning
  2. path eploitation/repair

Foraging Task

- Two main **sub-problems**:
  - path construction/planning
  - path eploitation/repair

- In **Ant**-inspired systems:
  - random exploration
  - pheromone deposit and evaporation

- In **Bee**-inspired systems:
  - Lévy flight and Path Integration
  - direct communication (dancing)

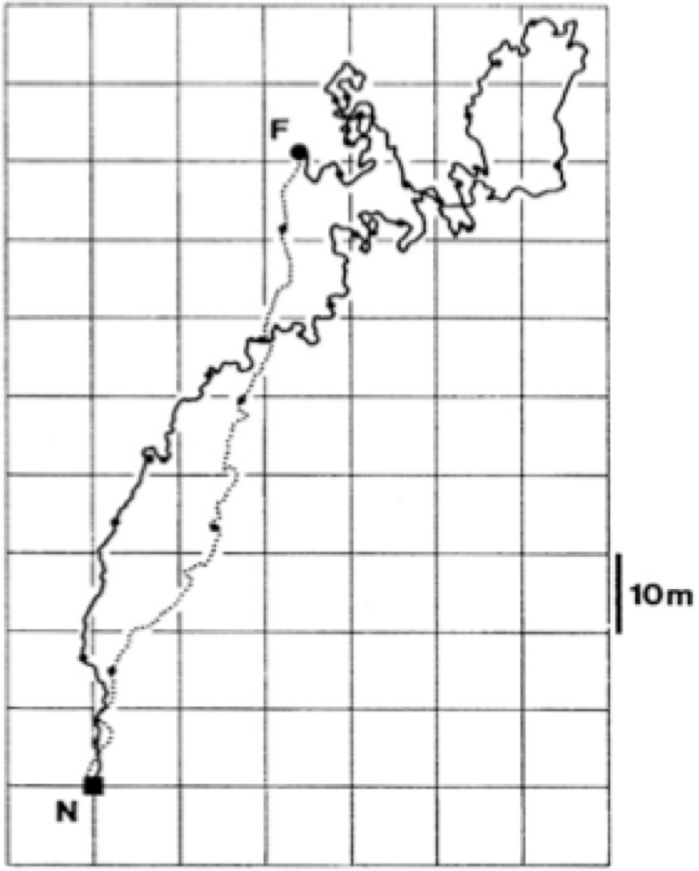
Bee System

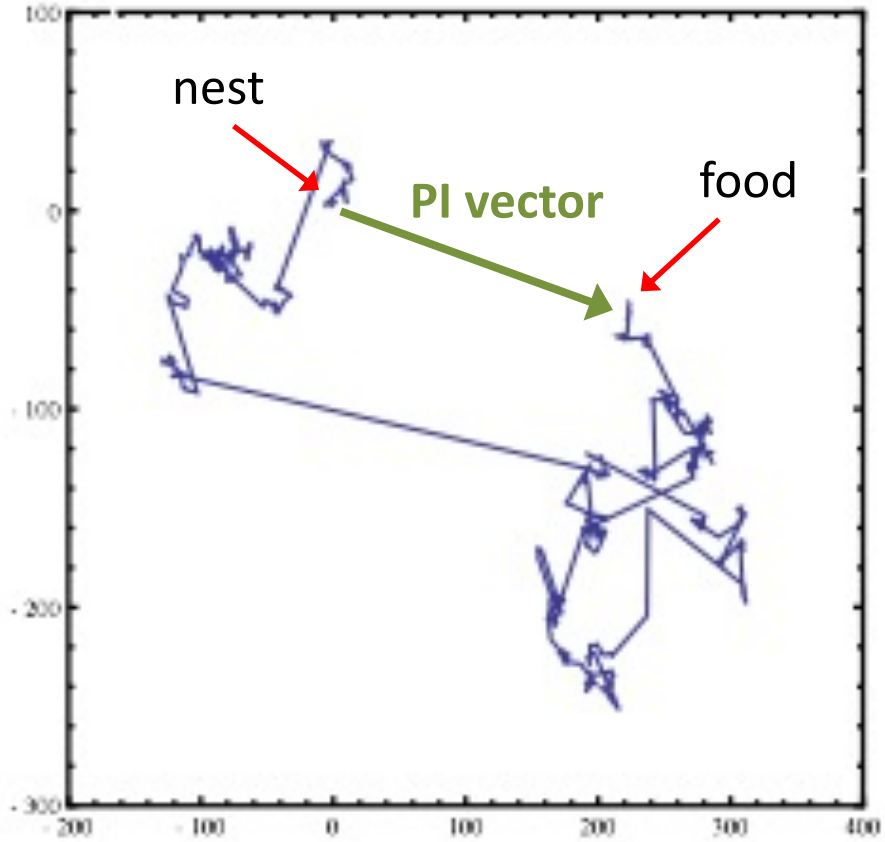
- Exploration using **Lévy flight**
  - random angles and heavy-tailed distribution over distance
  - combines thorough local search with long distance hops
  - use **path integration** to “compute” straight line back to nest

- **Path integration (PI) vector** represents bee’s knowledge of angle and distance to food

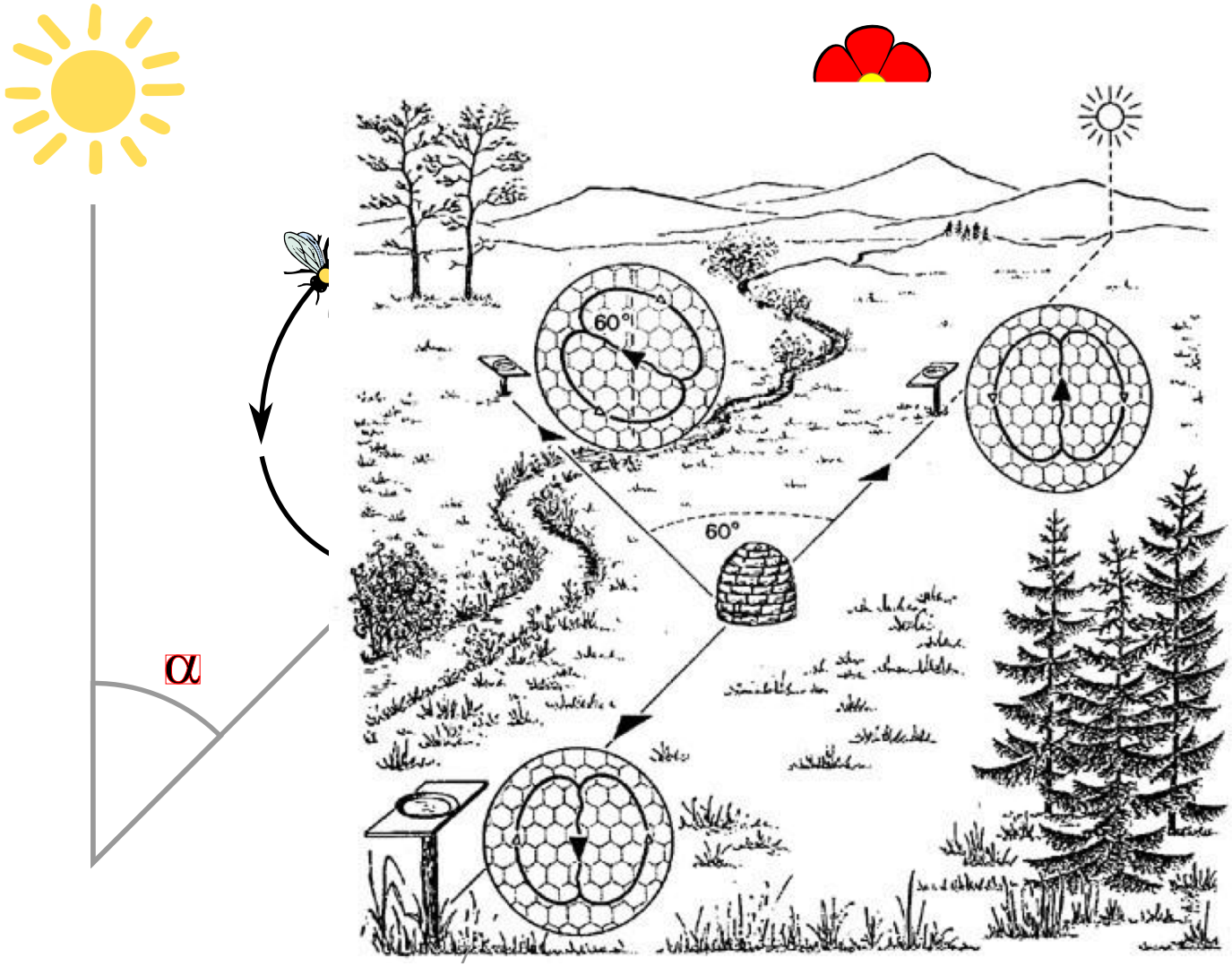
- **Recruitment**: directly in nest (dancing)
  - sharing PI vector
  - length of dance indicates quality of food source
  - autocatalytic

Bee Swarming





Recruitment Dance



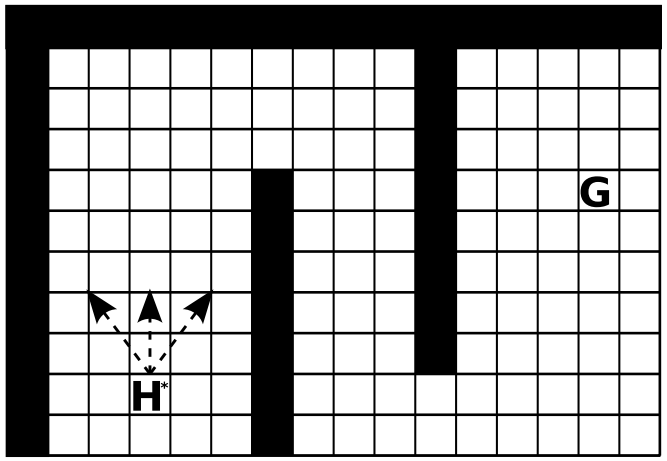
Stigmergic Landmark Foraging

- Path integration assumes unobstructed flight
  - Not directly applicable to ground-based robots!

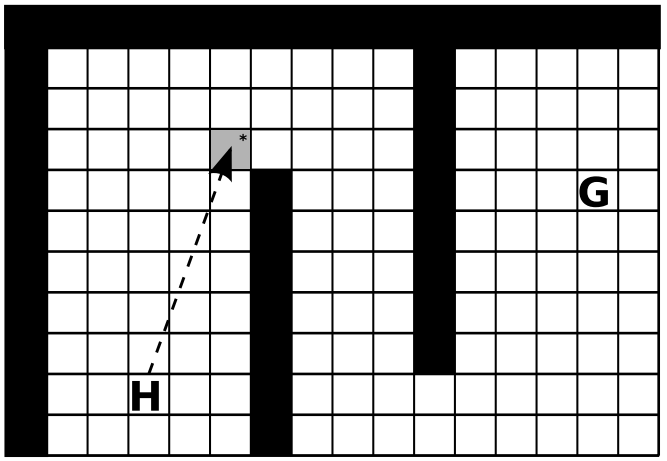
- **Idea**: combine stigmergy and direct communication

- **Stigmergic Landmark Foraging**:
  - "Bees" create landmarks along their path
  - Landmarks contain PI vector information
    - towards goal (or next landmark)
    - towards nest (or next landmark)

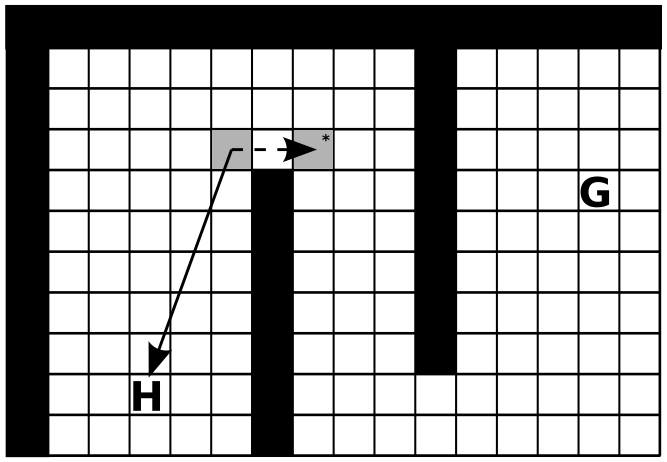
Stigmergic Landmark Foraging



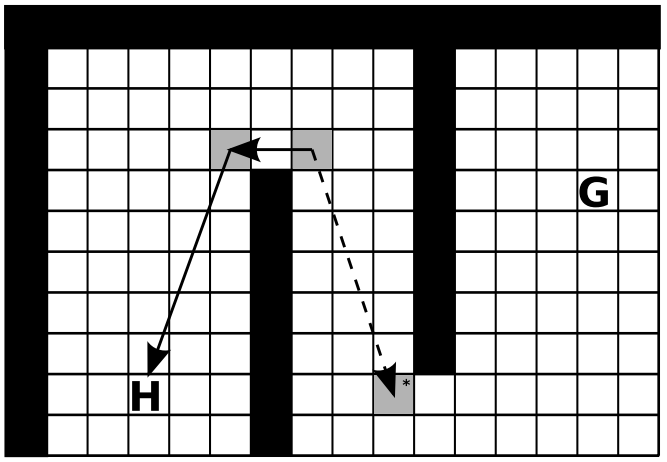
(a) Exploring



(b) Landmark Found

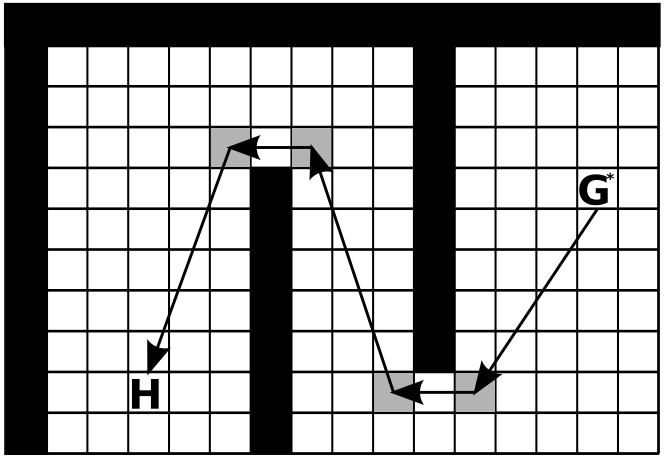


(c) LHV created + Landmark found

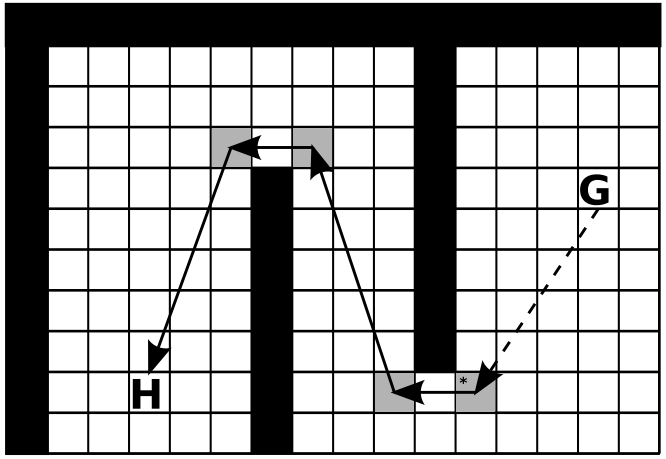


(d) LHV created + Landmark found

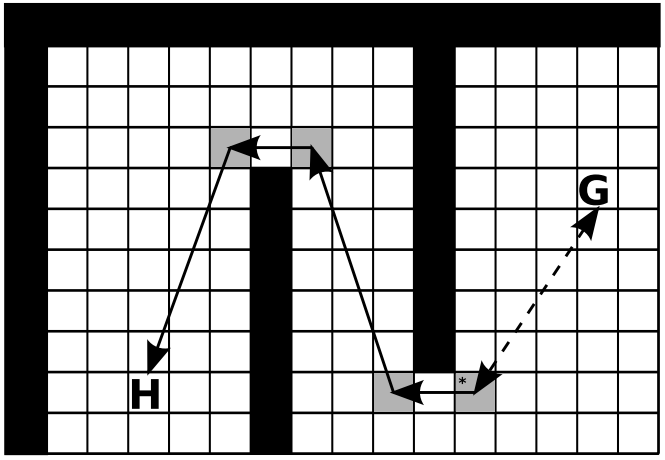
Stigmergic Landmark Foraging



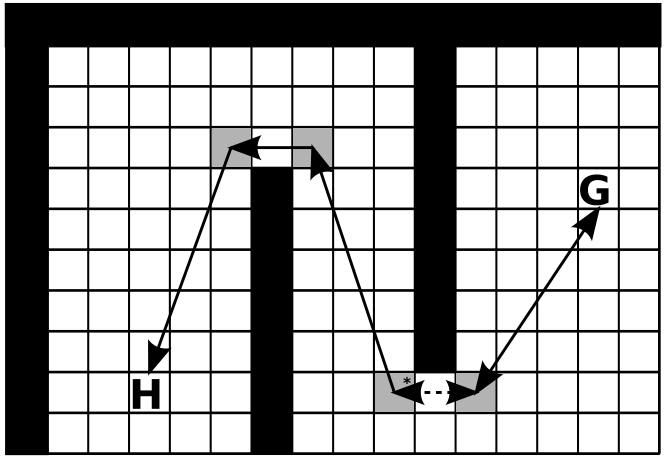
(a) Agent at goal



(b) Return over LHV



(c) Landmark found + LGV created



(d) Landmark found + LGV created

Stigmergic Landmark Foraging

- Landmarks can be:
  - Radio-frequency identification (RFID) tags
  - Individual robots

- Landmarks provide a possible way to **implement a pheromone-based mechanism** in the real world

- Standard Bee System forages **more efficiently** than Ant System in **open environments**

- Adding landmarks helps **navigating around obstacles**

Swarm Intelligence

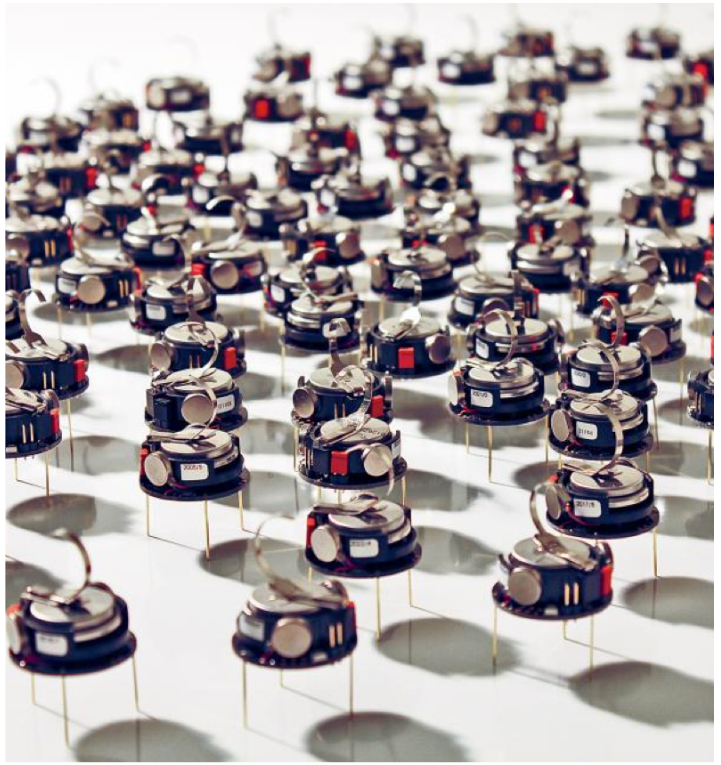
- We have seen three swarm based approaches:
  - Particle Swarm Optimisation
  - Ant Colony Optimisation
  - Bee-inspired foraging

- **What do these have in common?**
  - **Decentralised**, no central control
  - Parallel search: efficient, **scalable**
  - **Adaptive**, flexible
  - And, especially in swarm robotics: **robust**!

Swarm Robotics

- Many swarm principles have been successfully applied to robotics

- Three examples:
  - **Synchronization**
    based on fireflies
  - **Coverage**
    based on pheromones
  - **Foraging**
    based on bees



Firefly Synchronization

Fireflies are able to synchronize their flashing by minimizing the lag between them and their neighbours

=> local interaction!

Alexandre Campo
Université Libre de Bruxelles

StiCo: Stigmergic Coverage

- **Task**: cover an unknown environment
  - all robots start in one location
  - robots have limited sensing range
  - they need to disperse

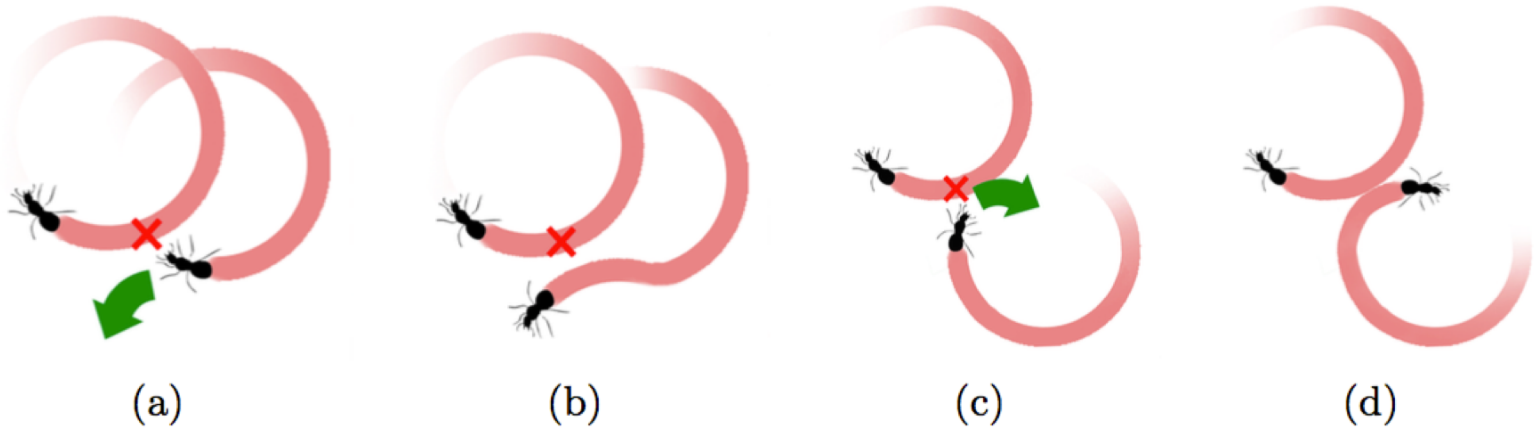
- **Stigmergy**: only indirect communication
  - pheromones are chemical or electrical markers
  - on real robots: simulated by light / fluorescence

Bijan Ranjbar-Sahraei, Karl Tuyls
Maastricht University, UoL

StiCo: Motion Policy

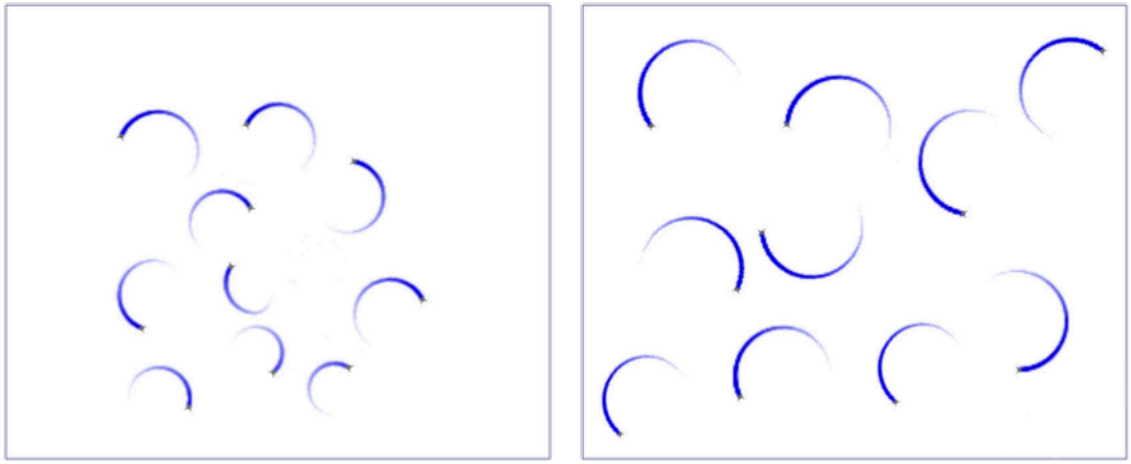
Very simple behaviour:

DO
Circle around
IF pheromone is detected
Change circling direction
END IF



StiCo: Territory Size

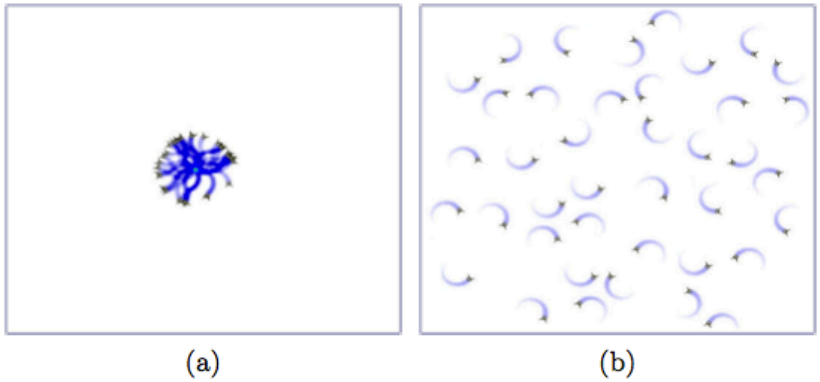
- Adaptive territory size:
  - Robots **increase** their circling radius when they don't sense any pheromone for a while
  - Robots **decrease** their territory size when they sense too much pheromone for a while

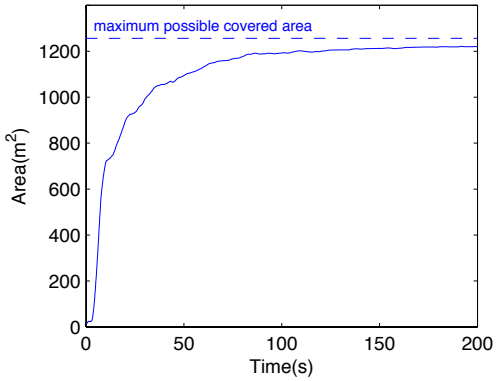


StiCo: Results (I)

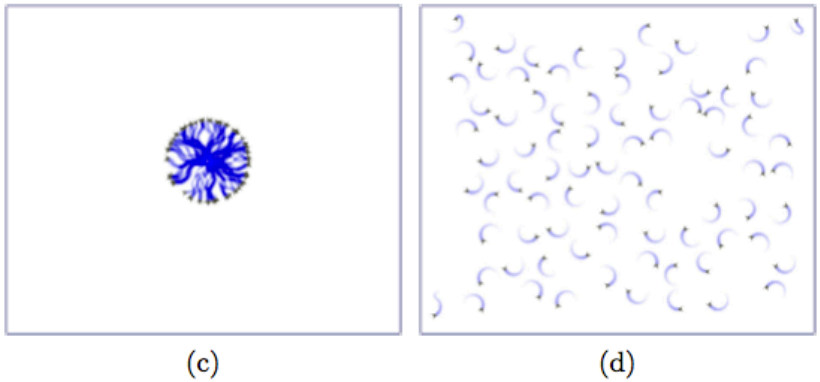
Efficient coverage in simple environment:

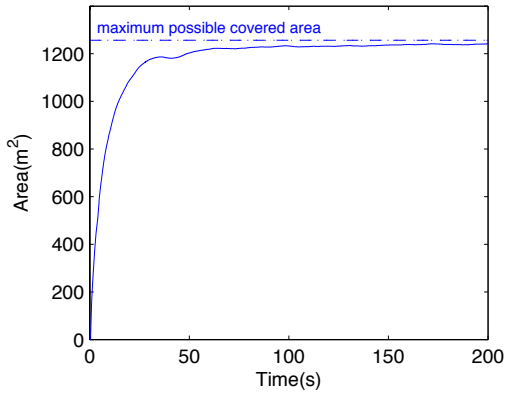
40 Robots →





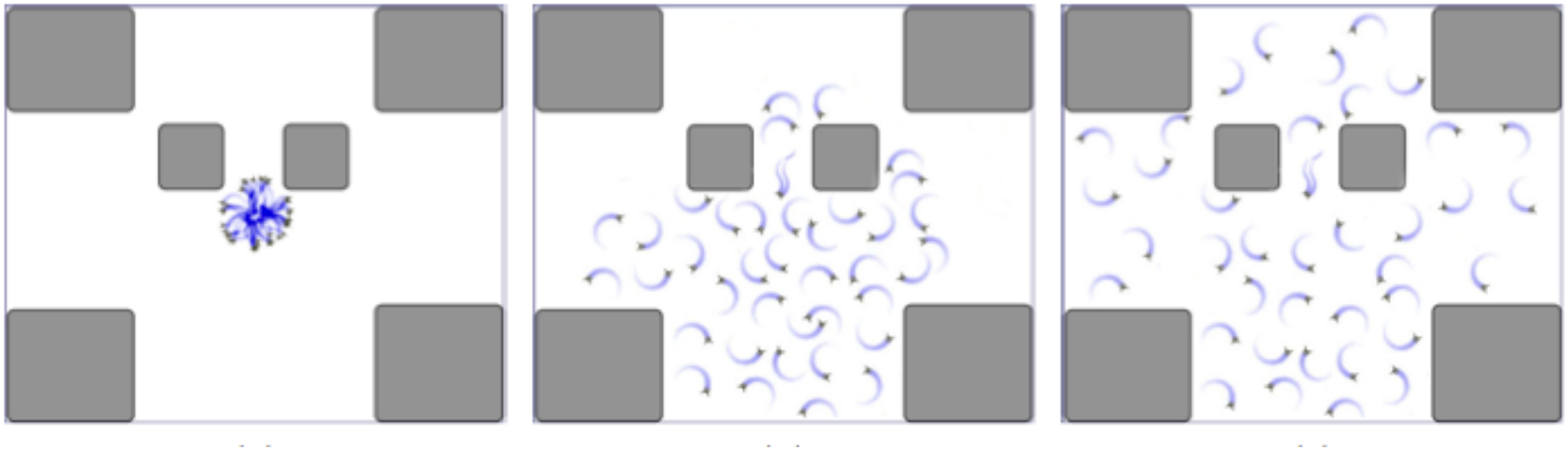
80 Robots →



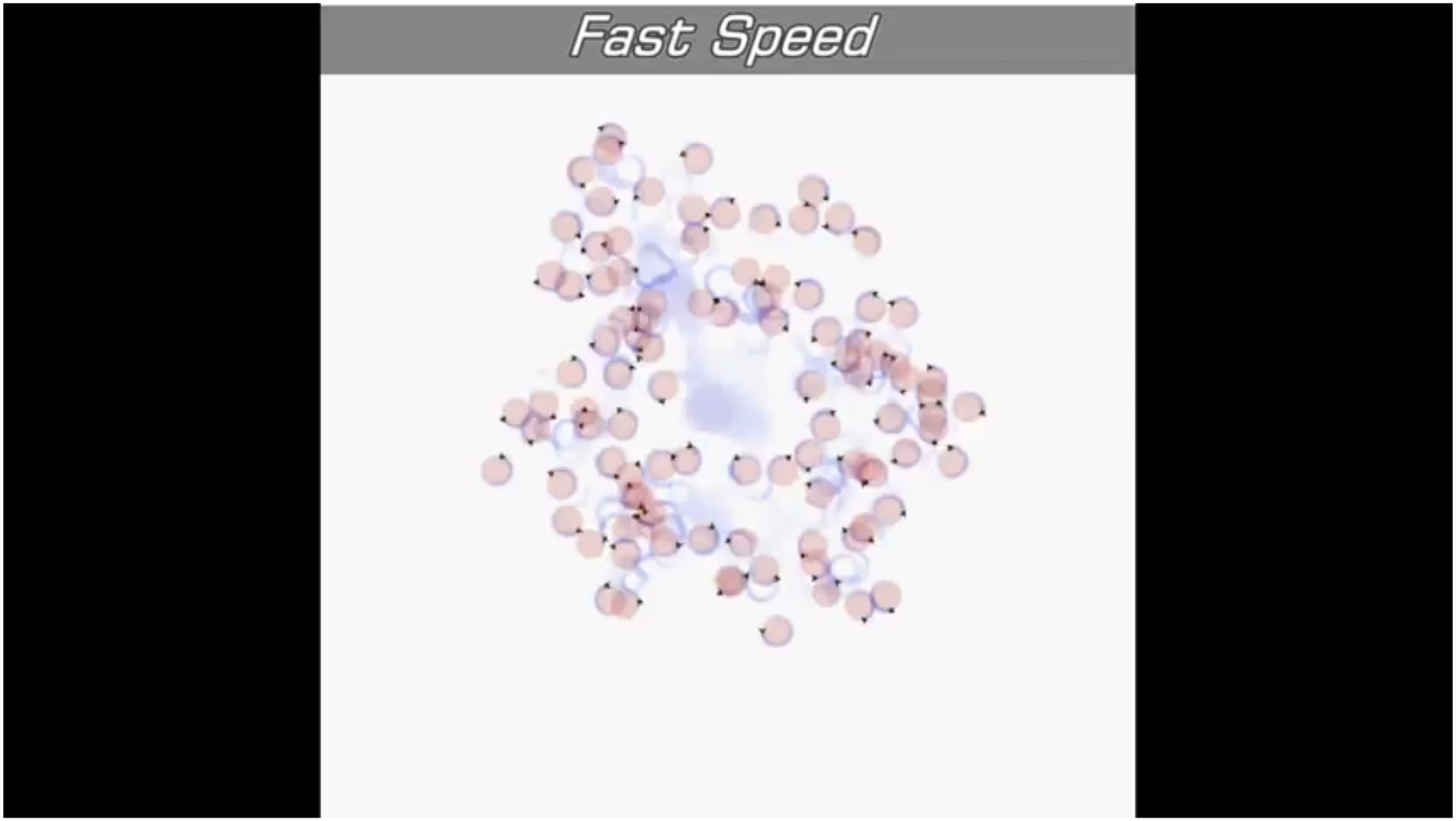


StiCo: Results (II)

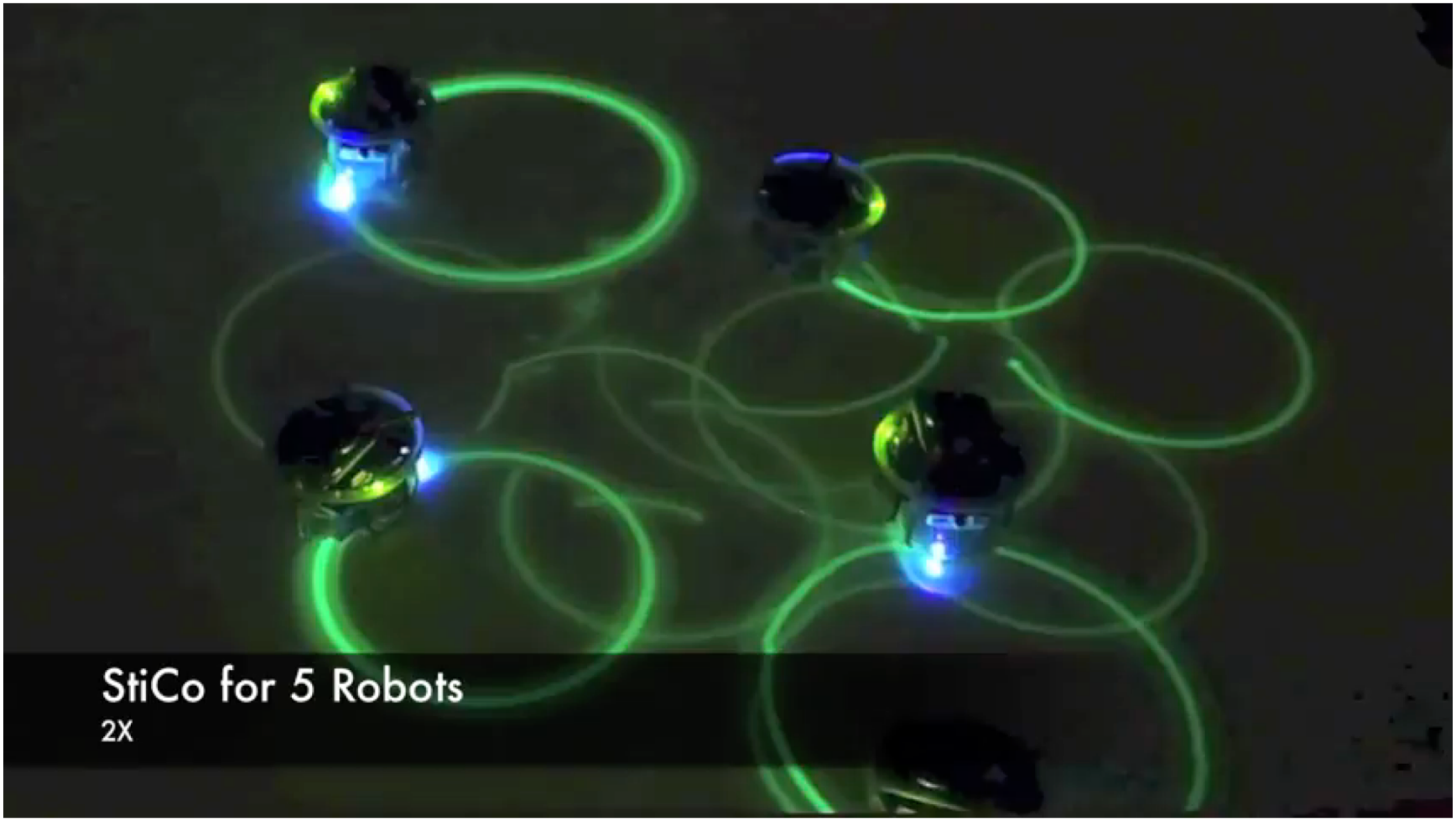
Efficient coverage in non-convex environments:



StiCo: Simulation Demo



StiCo: E-puck Robot Demo



Bee-Inspired Foraging

- Multi-robot foraging
  - Using TurtleBots
  - Limited visibility
- Implementation:
  - Lévy flight + path integration
  - Robots cummunicate PI vectors when they see each other
  - Nest and food identified using visual markers

Sjriek Alers, Daniel Claes, Karl Tuyls
Maastricht University / UoL

Bee-Inspired Foraging

Swarm Robotics

- Many more applications exist
  - Flying robot swarms
  - Mobile wireless sensor networks
  - Morphogenesis
  - …
- Most deal with exploration / coverage / anomaly detection / patrolling / ...
- The swarm paradigm provides great benefits
  - Limited and/or local communication
  - Scalability
  - Robustness
  - Adaptivity

Wrap up

- Bee Colonies and Swarm Robotics
  - Bee-inspired algorithms
  - Swarm Robotics
    - Fireflies (synchronization)
    - StiCo (coverage)
    - Bee-Inspired Foraging