SnT

Towards Automating the Design of Autonomous Robot Swarms

Dr. Grégoire Danoy

July 1st, 2025

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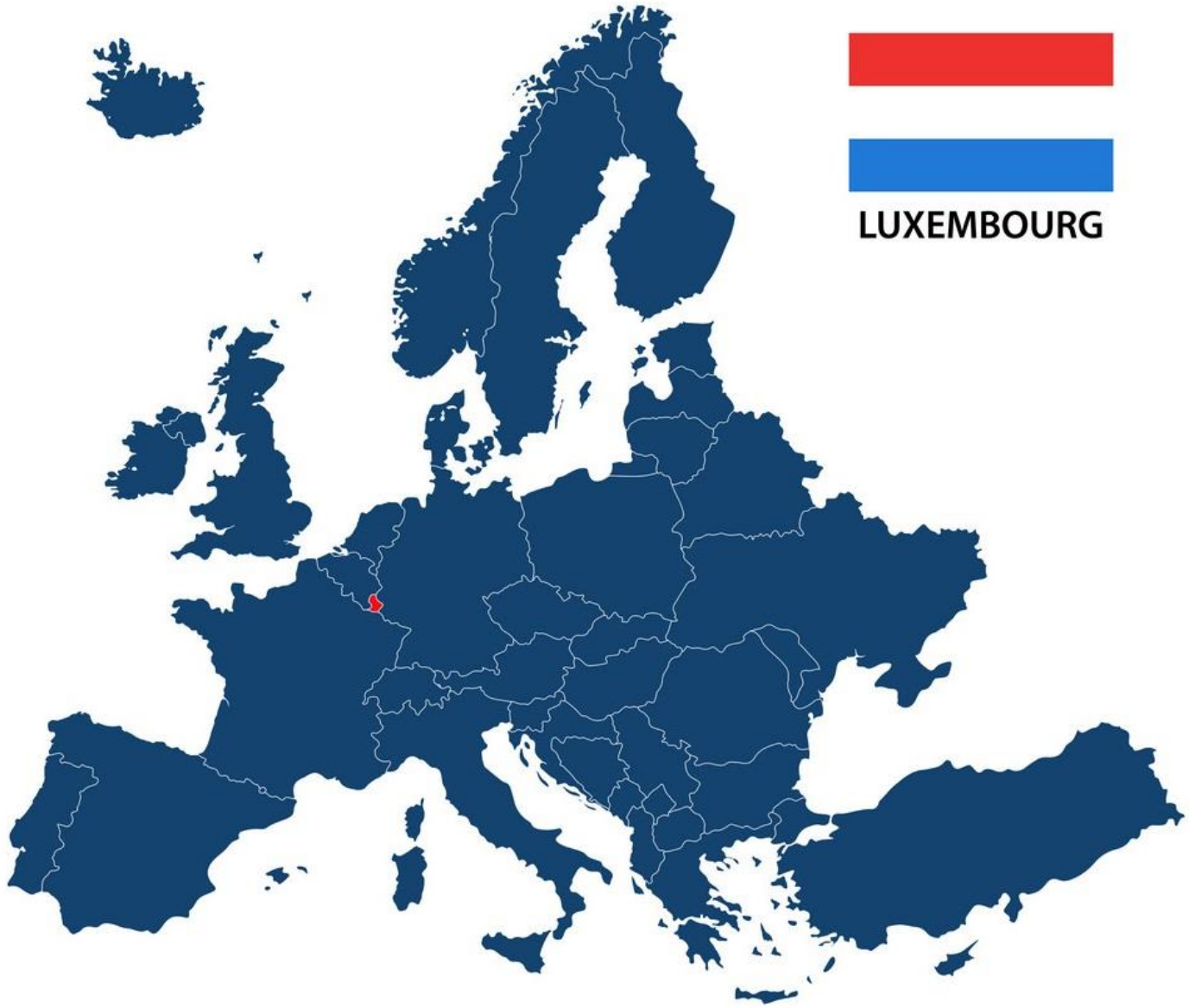

LUXEMBOURG

The University of Luxembourg

The University of Luxembourg is a research university with a distinctly **international**, **multilingual** and **interdisciplinary** character.

Ranked

25th Young University
4th International outlook
Top 125 in Computer Science

worldwide in the Times Higher Education (THE) World University Rankings 2023

UNIVERSITY OF LUXEMBOURG

20 YEARS

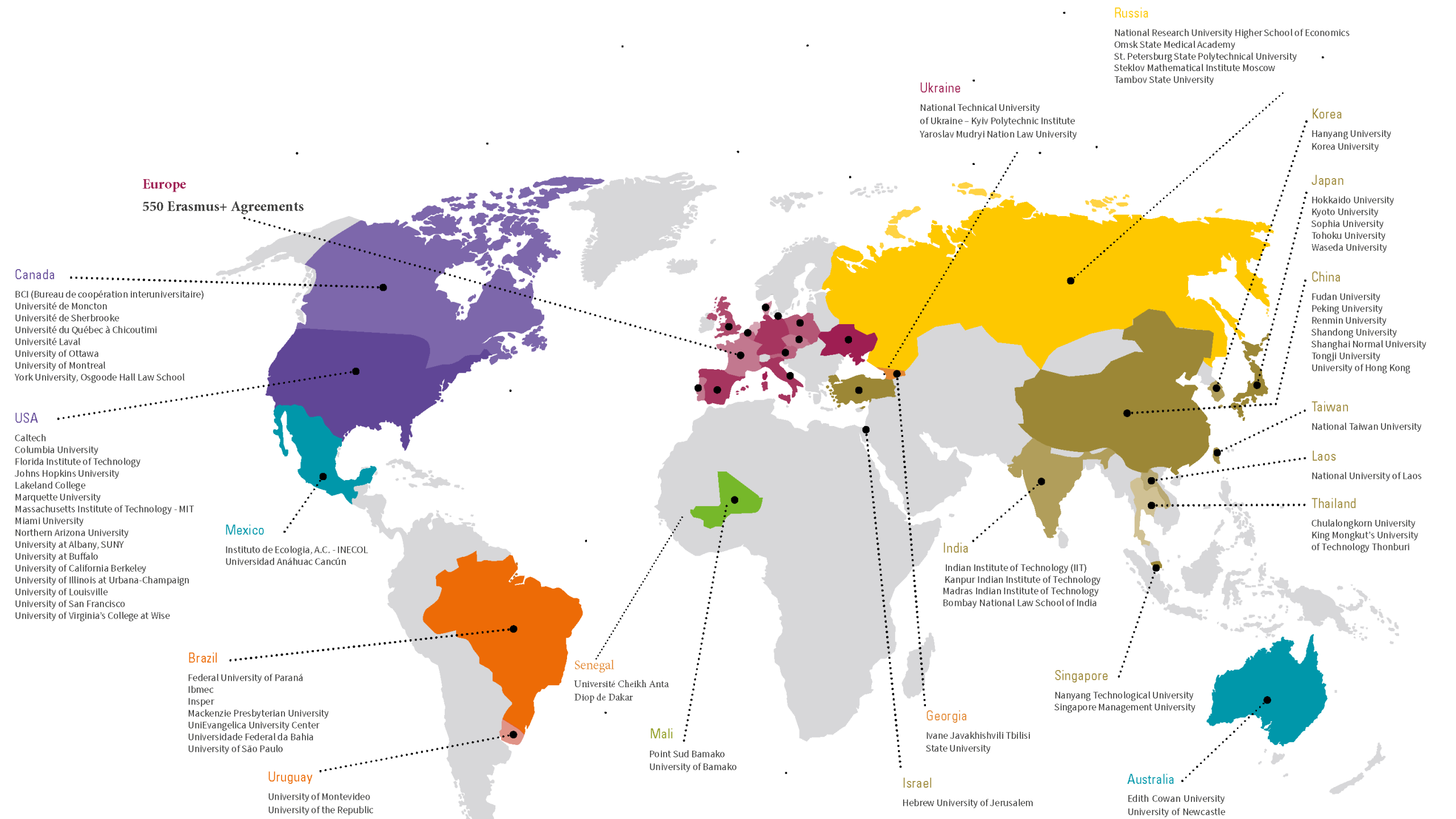
7000+ students

1000+ PhDs

300 faculty members

135 nationalities

60% international students


Europe
550 Erasmus+ Agreements
Canada
BCI (Bureau de coopération interuniversitaire)
Université de Moncton
Université de Sherbrooke
Université du Québec à Chicoutimi
Université Laval
University of Ottawa
University of Montreal
York University, Osgoode Hall Law School
USA
Caltech
Columbia University
Florida Institute of Technology
Johns Hopkins University
Lakeland College
Marquette University
Massachusetts Institute of Technology - MIT
Miami University
Northern Arizona University
University at Albany, SUNY
University at Buffalo
University of California Berkeley
University of Illinois at Urbana-Champaign
University of Louisville
University of San Francisco
University of Virginia's College at Wise
Mexico
Instituto de Ecologia, A.C. - INECOL
Universidad Anáhuac Cancún
Brazil
Federal University of Paraná
Ibmec
Insper
Mackenzie Presbyterian University
UniEvangelica University Center
Universidade Federal da Bahia
University of São Paulo
Uruguay
University of Montevideo
University of the Republic
Senegal
Université Cheikh Anta
Diop de Dakar
Mali
Point Sud Bamako
University of Bamako
Ukraine
National Technical University
of Ukraine – Kyiv Polytechnic Institute
Yaroslav Mudryi Nation Law University
Russia
National Research University Higher School of Economics
Omsk State Medical Academy
St. Petersburg State Polytechnical University
Steklov Mathematical Institute Moscow
Tambov State University
Korea
Hanyang University
Korea University
Japan
Hokkaido University
Kyoto University
Sophia University
Tohoku University
Waseda University
China
Fudan University
Peking University
Renmin University
Shandong University
Shanghai Normal University
Tongji University
University of Hong Kong
Taiwan
National Taiwan University
Laos
National University of Laos
Thailand
Chulalongkorn University
King Mongkut's University
of Technology Thonburi
India
Indian Institute of Technology (IIT)
Kanpur Indian Institute of Technology
Madras Indian Institute of Technology
Bombay National Law School of India
Singapore
Nanyang Technological University
Singapore Management University
Georgia
Ivane Javakhishvili Tbilisi
State University
Israel
Hebrew University of Jerusalem
Australia
Edith Cowan University
University of Newcastle

Parallel Computing and Optimisation Group

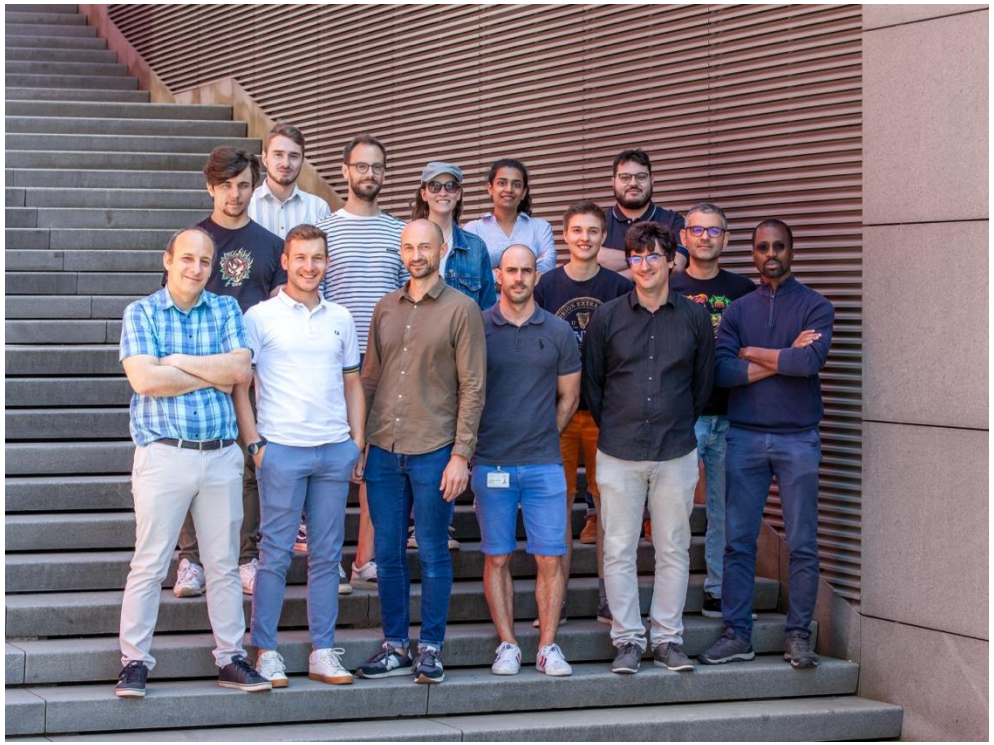
http://pcog.uni.lu

Research Topics:
- Parallel/Decentralised computing
- Optimisation/Search/Learning

Aim:
- Efficient, scalable and robust solutions to solve large-scale discrete/combinatorial problems.

Applications:
- Robust/sustainable/efficient HPC/Grid/Cloud/IoT
- Unmanned Autonomous Systems (UAS)
- Next generation networks and protocols
- Systems Bio-medicine
- Information/Document Management for Bio and Finance

Management:
- Head: Dr. Grégoire Danoy



18+ researchers
1 Professor
1 Research Scientist
8 Postdocs
9 PhD students
13 nationalities

Autonomous Robot Swarms (ARS)

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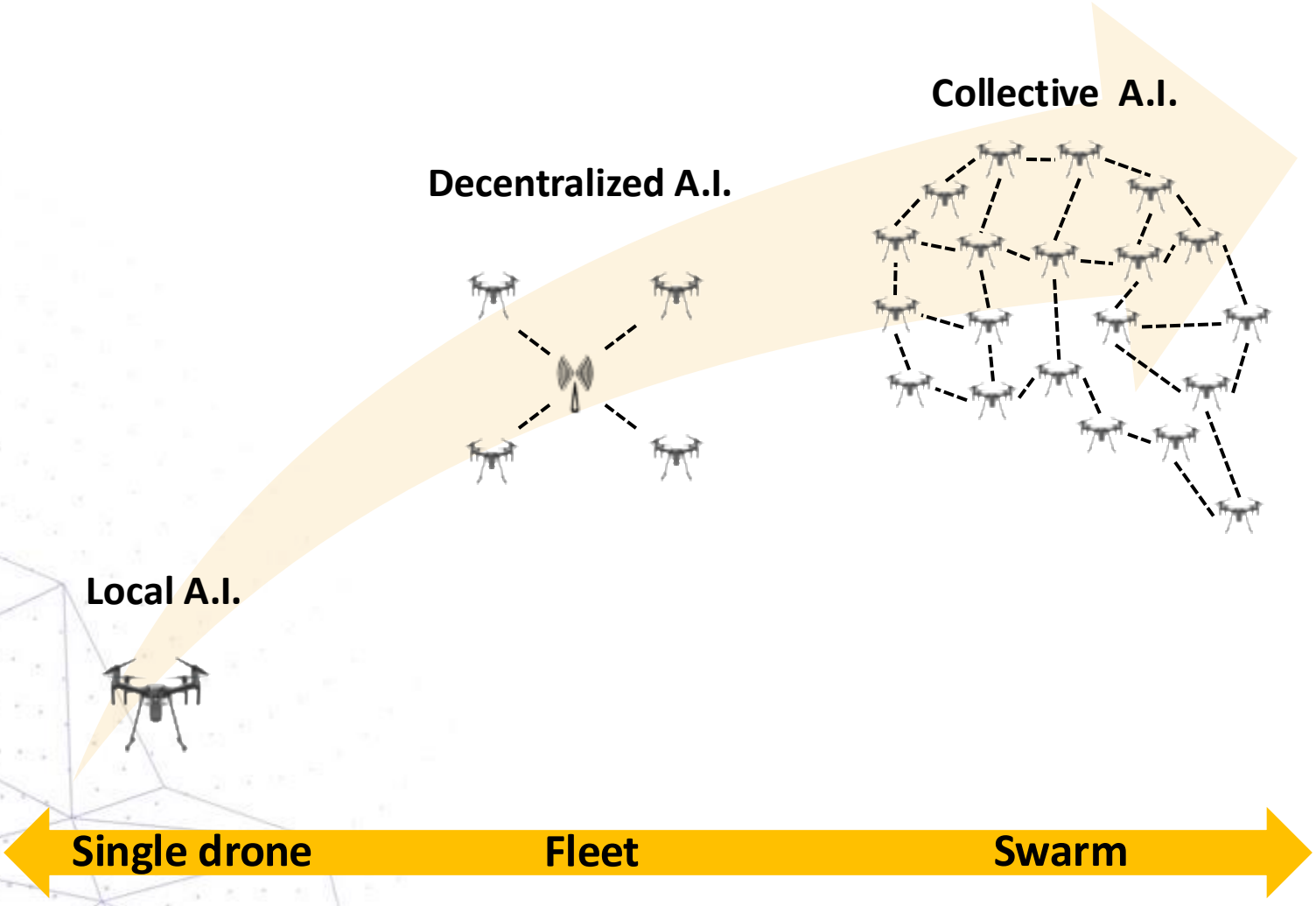
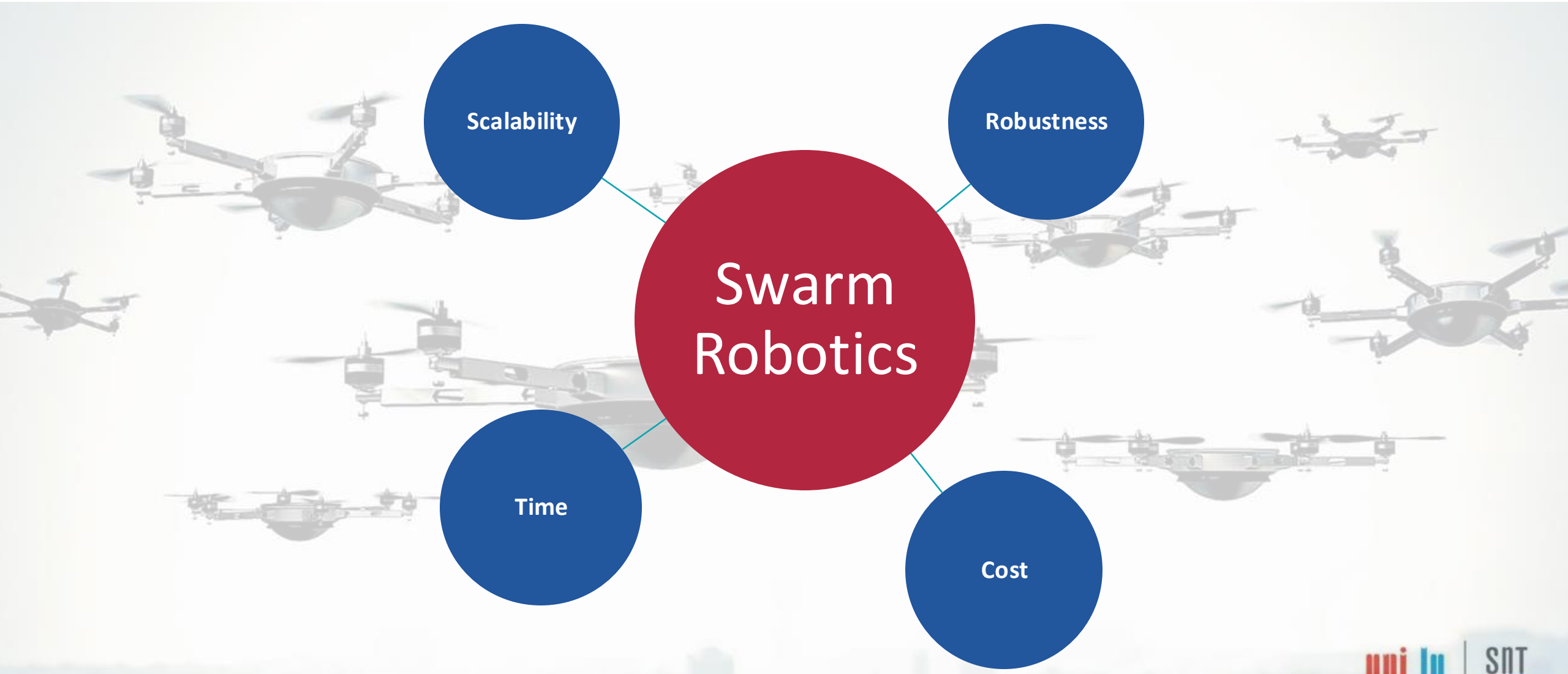
Hook

What is an autonomous robot swarm?



Why swarm robotics?



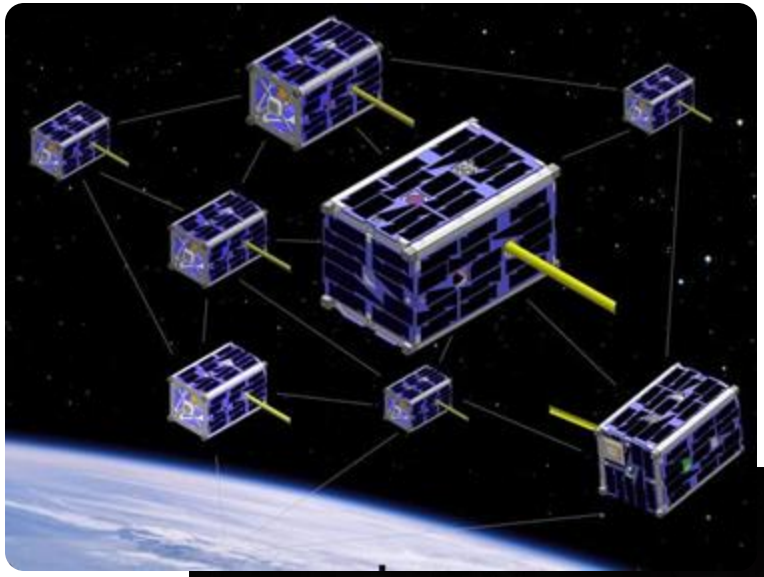
Our swarm research focus

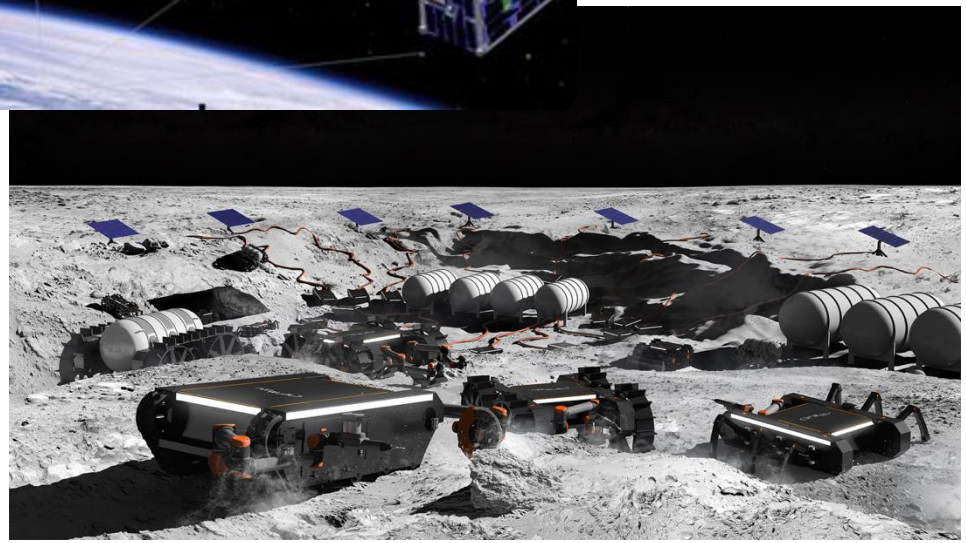
- Swarm mobility, management & optimisation
- Challenges -> Emergence
- Designing local behaviours that will lead to efficient global mission execution

What for?

Source: Hylio

Source: Korean Air

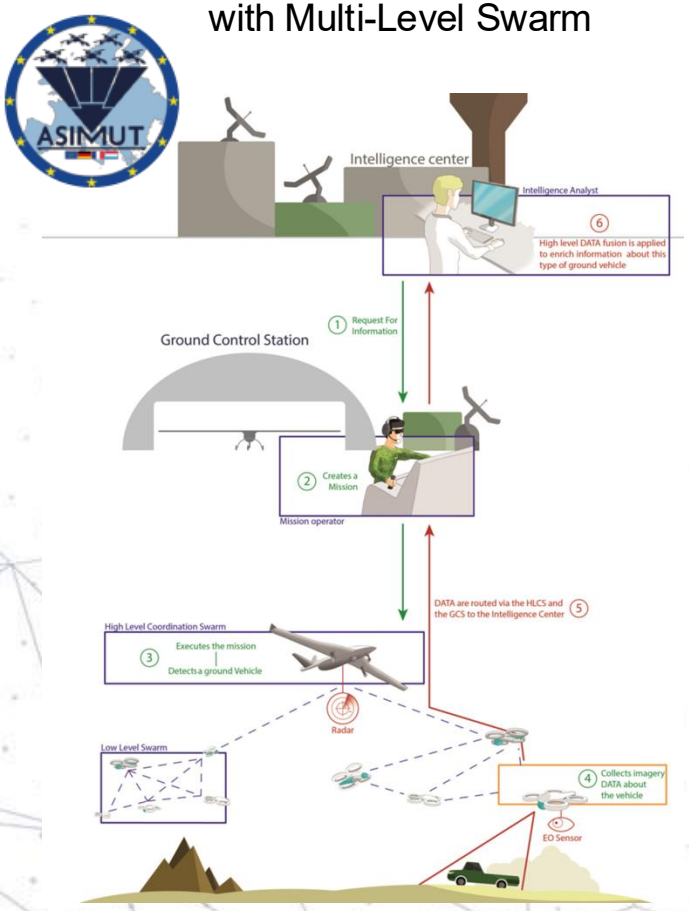




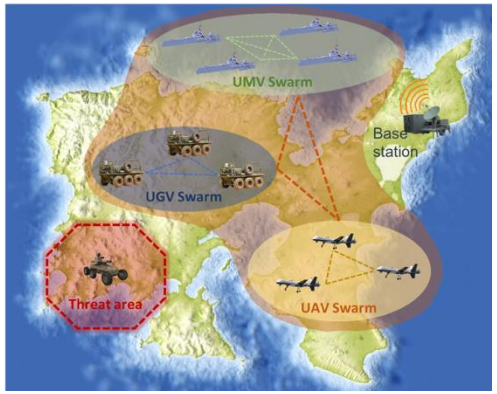
Source: OffWorld

Drone Swarms – Key Projects

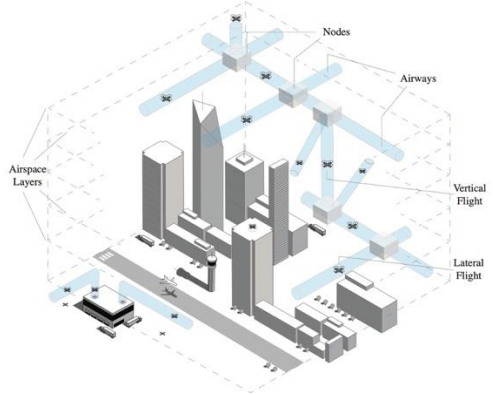
Surveillance & Tracking with Multi-Level Swarm



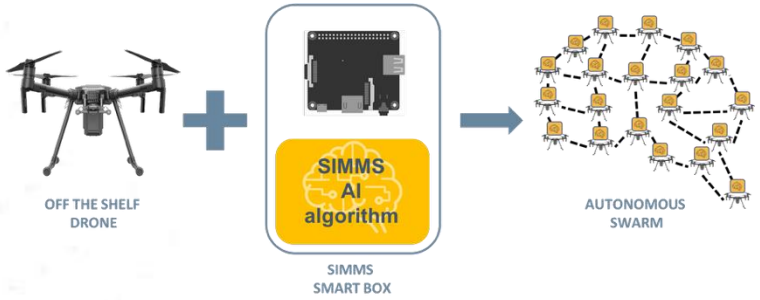
Surveillance & Tracking with Multi-Swarm Systems



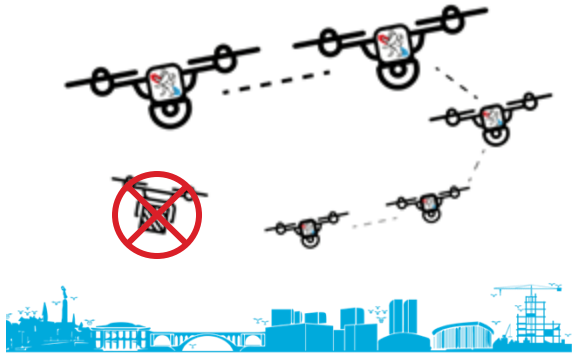
Distributed Drone Traffic Management



Technology Transfer – Swarming technology



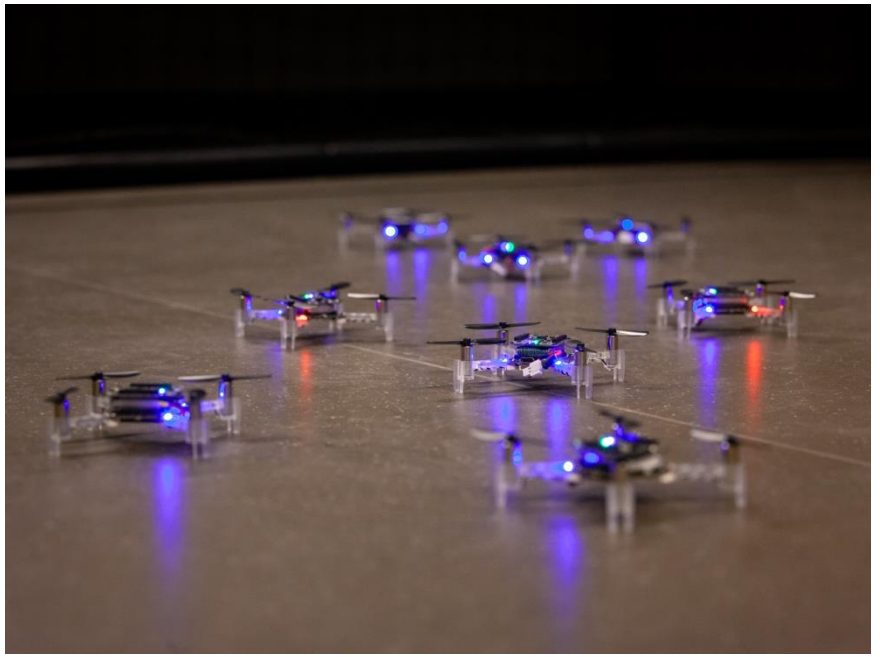
Counter Drone Systems



ILNAS · Office of Naval Research Global Science & Technology · European Defence Agency · Luxembourg National Research Fund · uni.lu | SnT

SwarmLab - The Swarm Intelligence Lab @ Uni.lu

The SwarmLab aims to develop and experiment swarm intelligence algorithms using interconnected robots that solve problems in a realistic setting.



- Ground robots: GCtronic E-Puck 2
- Nano drones: Bitcraze Crazyflie 2.1
- Indoor drone flying arena with optically-based positioning system

- Lab Manager: Dr. Grégoire Danoy

Educating Through Research Practice

Project-based learning

Master in Computer Science (MICS) – Since 2008 (with Prof. Bouvry)

🧠 Pedagogical Approach: Research-Driven, Project-Based Learning

- One-semester, 100% project-based course
- Real-world research problems proposed & supervised by researchers
- Final deliverable: research-style article + oral presentation

🎯 Learning Outcomes

- Understand and conduct computer science research
- Apply optimisation theory & software development principles
- Develop project management and collaboration skills
- Present and defend scientific solutions
- Write a research article for a conference
- Use advanced tools like the UL HPC platform

🌍 Strategic Alignment with FSTM Educational Vision

- **Interdisciplinary focus**: projects co-supervised with LCSB, RUES, INRIA (Grenoble & Nord Europe)
- **Research-enhanced learning**: real research experience; some projects led to publications
  → *Best Paper Award – IEEE CybConf 2017*

Robot Programming with the SwarmLab

Project-Based Learning with Real Robots (Since 2021)

🤖 **SwarmLab** (e-puck2 robots)
Hands-on learning: from single robot control to swarm behaviors
Enhances engagement and understanding through real-world testing
Supports both **Bachelor** and **Master** courses

🎓 **Bachelor Project**
Search algorithms (BFS, Dijkstra, LRTA*, etc.)
Comparison of real-time vs. offline methods
Python + Argos simulator → deployment on real robots

🎓 **Master Project (MICS)**
Predator-prey tournament using **evolutionary algorithms**
Swarm intelligence: predators (group) vs. prey (solo)
Simulation and real-world validation in SwarmLab

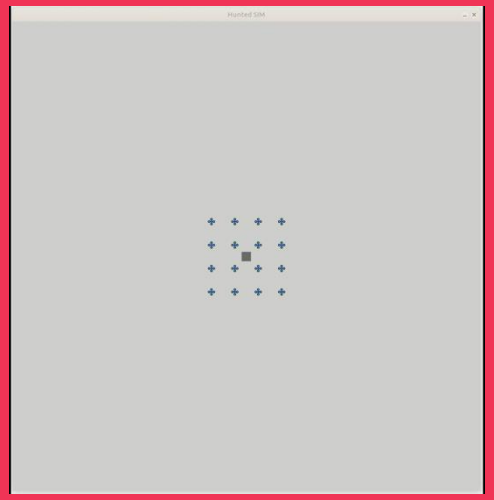
The research we have been doing: Manually Designing Robot Swarms

Bio-inspired Approaches

Manual Design of Bio-inspired Swarm Mobility

Swarming Model

High-level simulation



HPC

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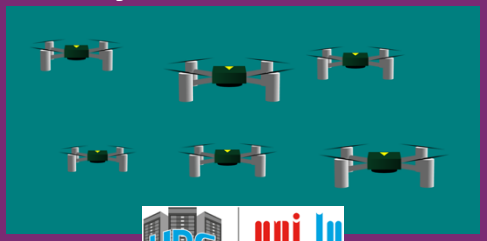
Physics simulation



HPC

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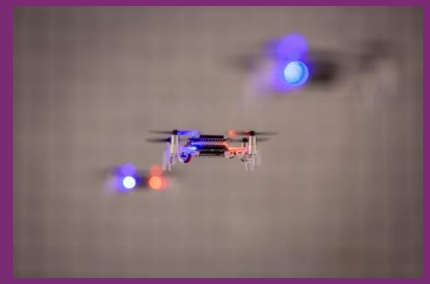
Real world tests



More than 10 years of experience in the manual design and validation of swarming models

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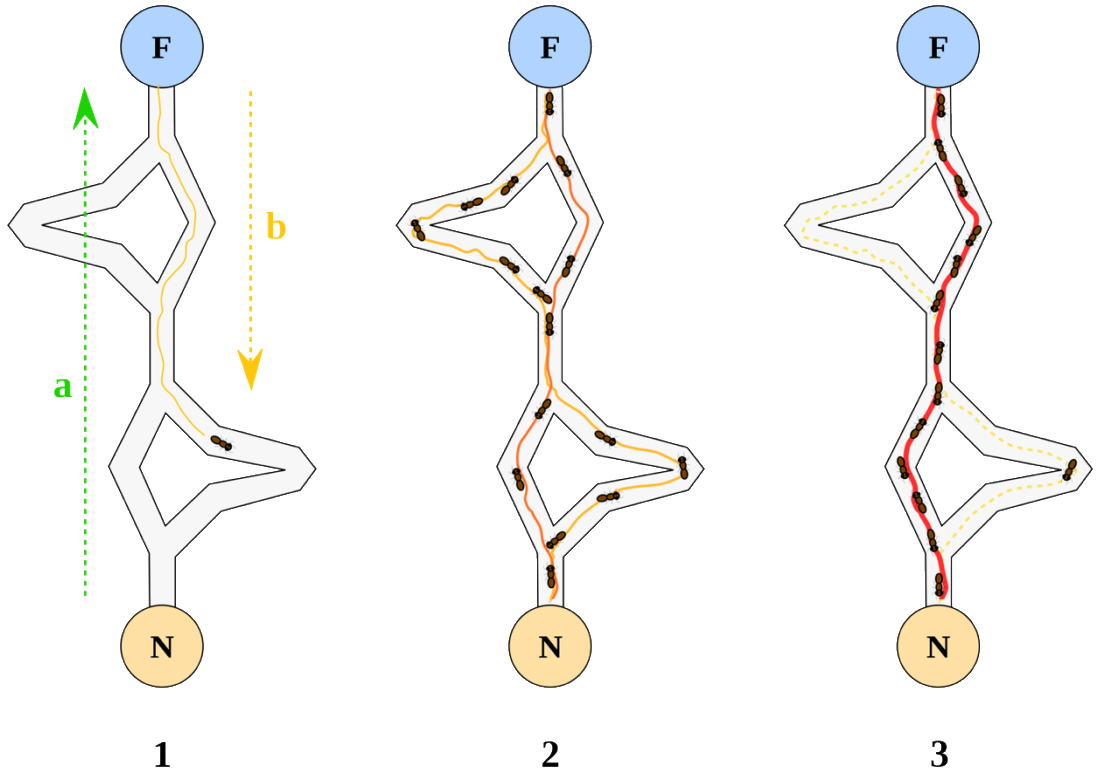
Ant Colony Optimization (ACO)

Able to find shortest route from nest to source

Stigmergy: ants are unsophisticated, but collectively they can perform complex tasks

- They communicate using pheromones



Swarms for surveillance

Objectives

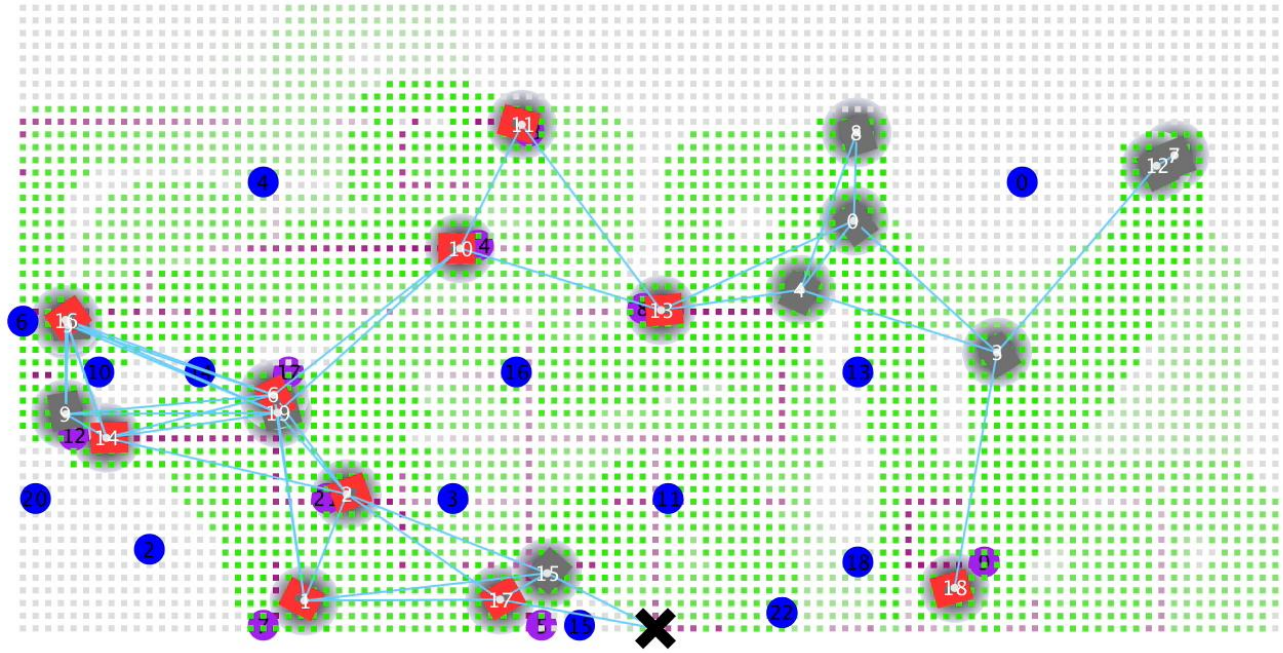
- Area coverage
- Target detection

Dual pheromone approach

- Repulsive: Area coverage
- Attractive: Target tracking

Allows to track moving ground targets

- With additional improvement on the area coverage



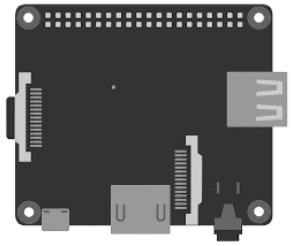
M. R. Brust, M. Zurad, L. Hentges, L. Gomes, G. Danoy, and P. Bouvry. Target tracking optimization of UAV swarms based on dual-pheromone clustering. In CYBCONF, pages 1–8. IEEE, 2017, Best Paper Award.

Manual design of robot swarms – real-world tests

Bring swarm intelligence to off the shelf drones

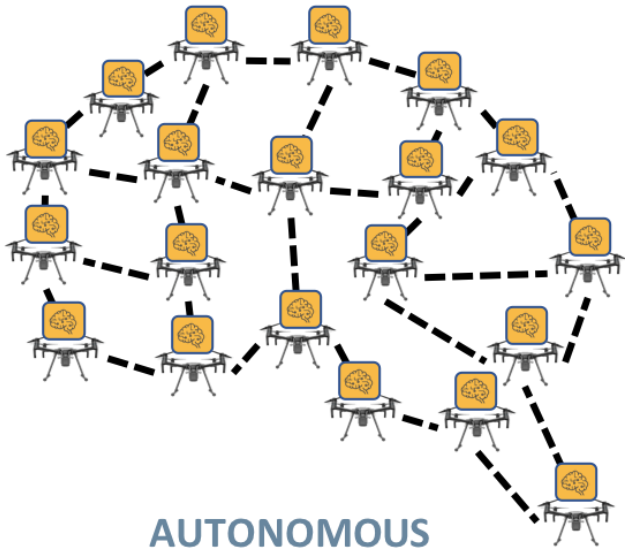
SIMMS
Swarm Intelligent Mission systeMS

OFF THE SHELF DRONE



SIMMS AI algorithm

SIMMS SMART BOX



AUTONOMOUS SWARM

Manual Design of ARS - Summary

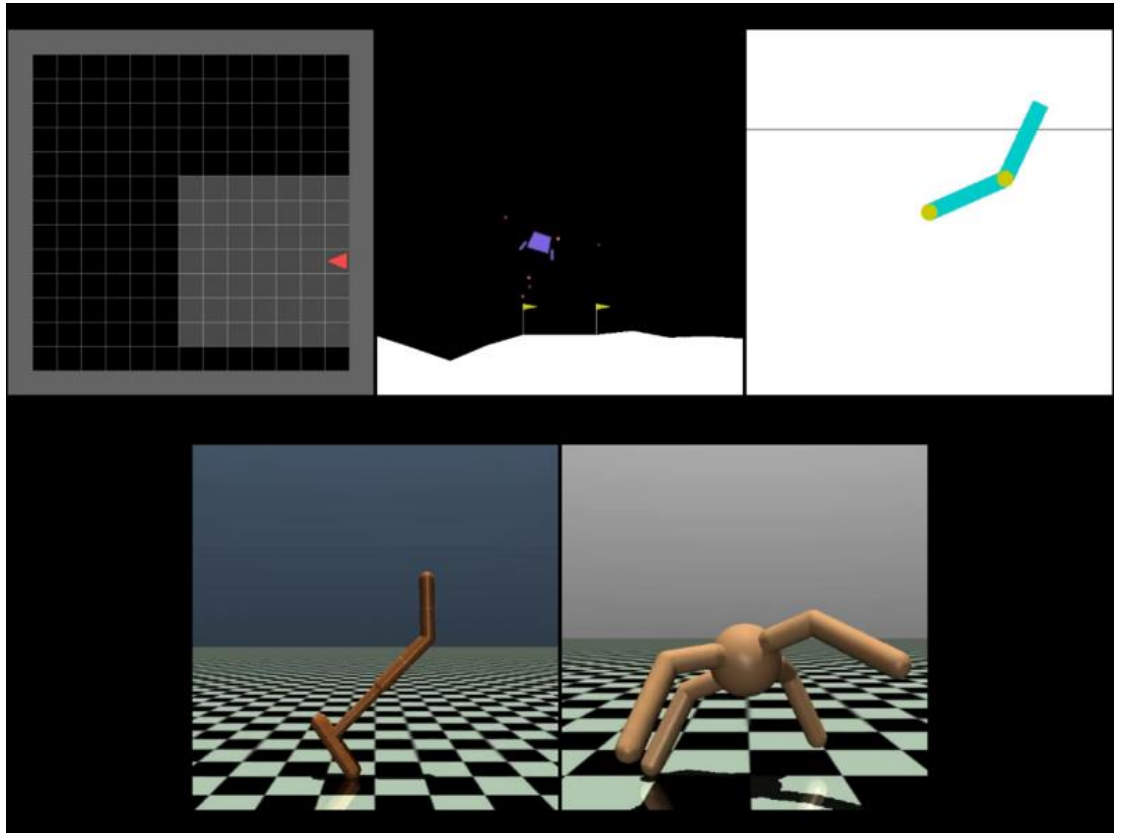
- Requires deep domain knowledge + trial-and-error
- Poor generalization to new tasks or environments
- Not feasible for complex, multi-agent, dynamic systems

Automating the design of robot swarms

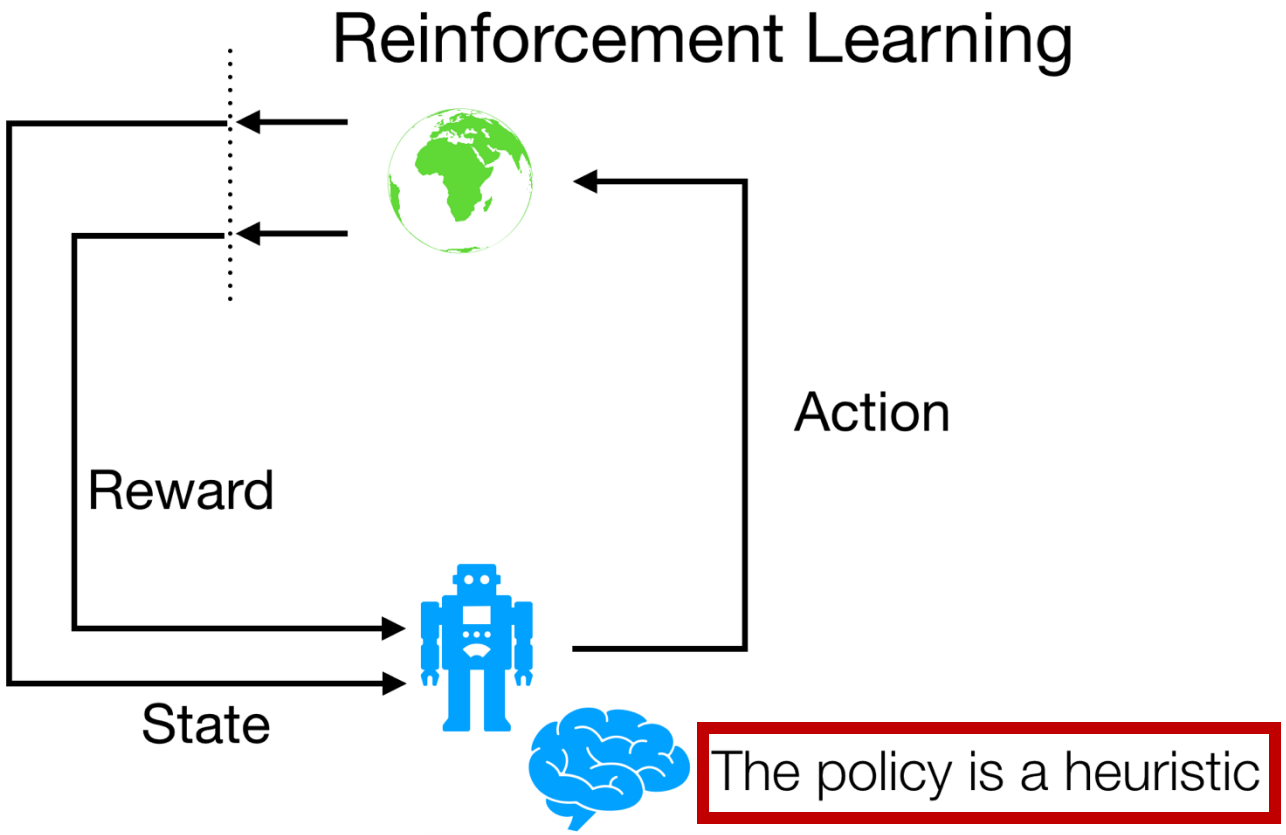
MIT News
ON CAMPUS AND AROUND THE WORLD

Automating the search for entirely new “curiosity” algorithms

Researchers show that computers can “write” algorithms that adapt to radically different environments better than algorithms designed by humans.



How to generate swarming behaviours?



Luxembourg National Research Fund

Automatic generation of swarming behaviours

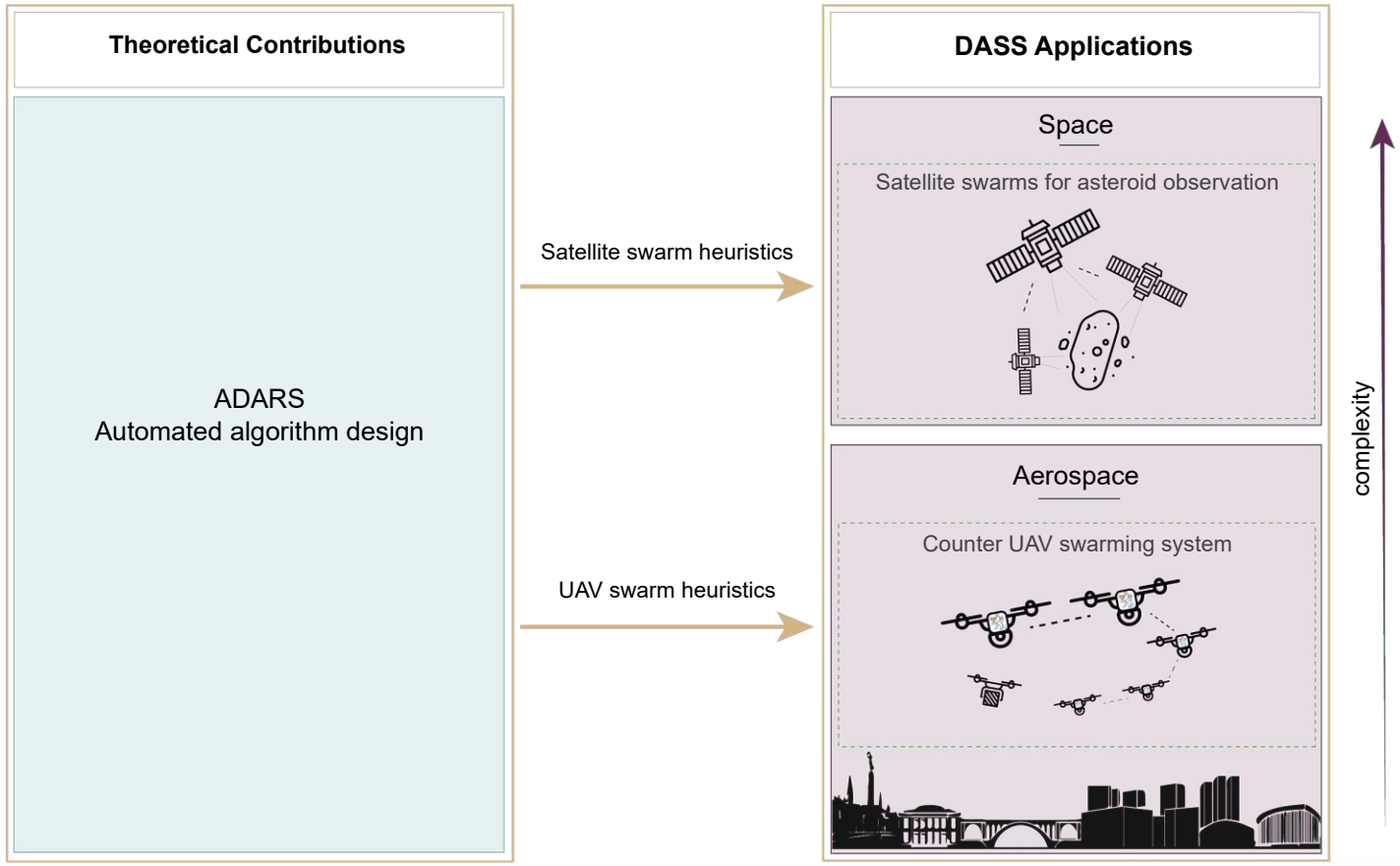
http://adars.uni.lu

Automating the Design of Autonomous Robots Swarms

Objective: Obtain efficient, scalable and reusable heuristics

Application domain: Distributed Aerospace and Space Systems

ADARS
A project at uni.lu



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Reinforcement Learning Environment

States

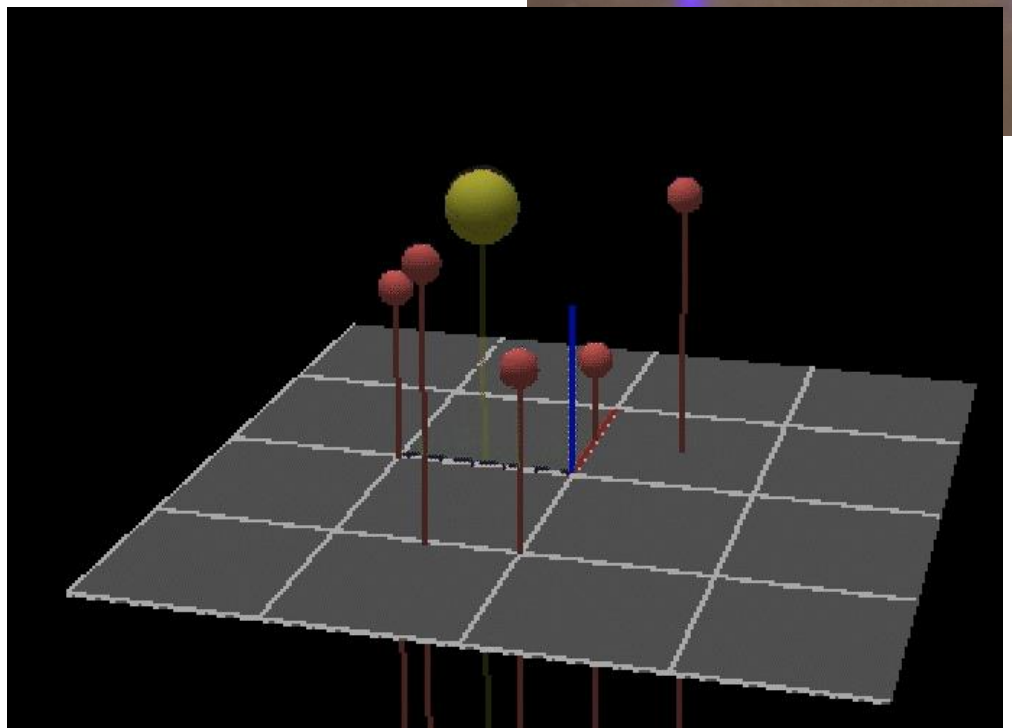
- Each drone perceives x, y, z coordinates of everyone

Actions:

- 3D speed vector

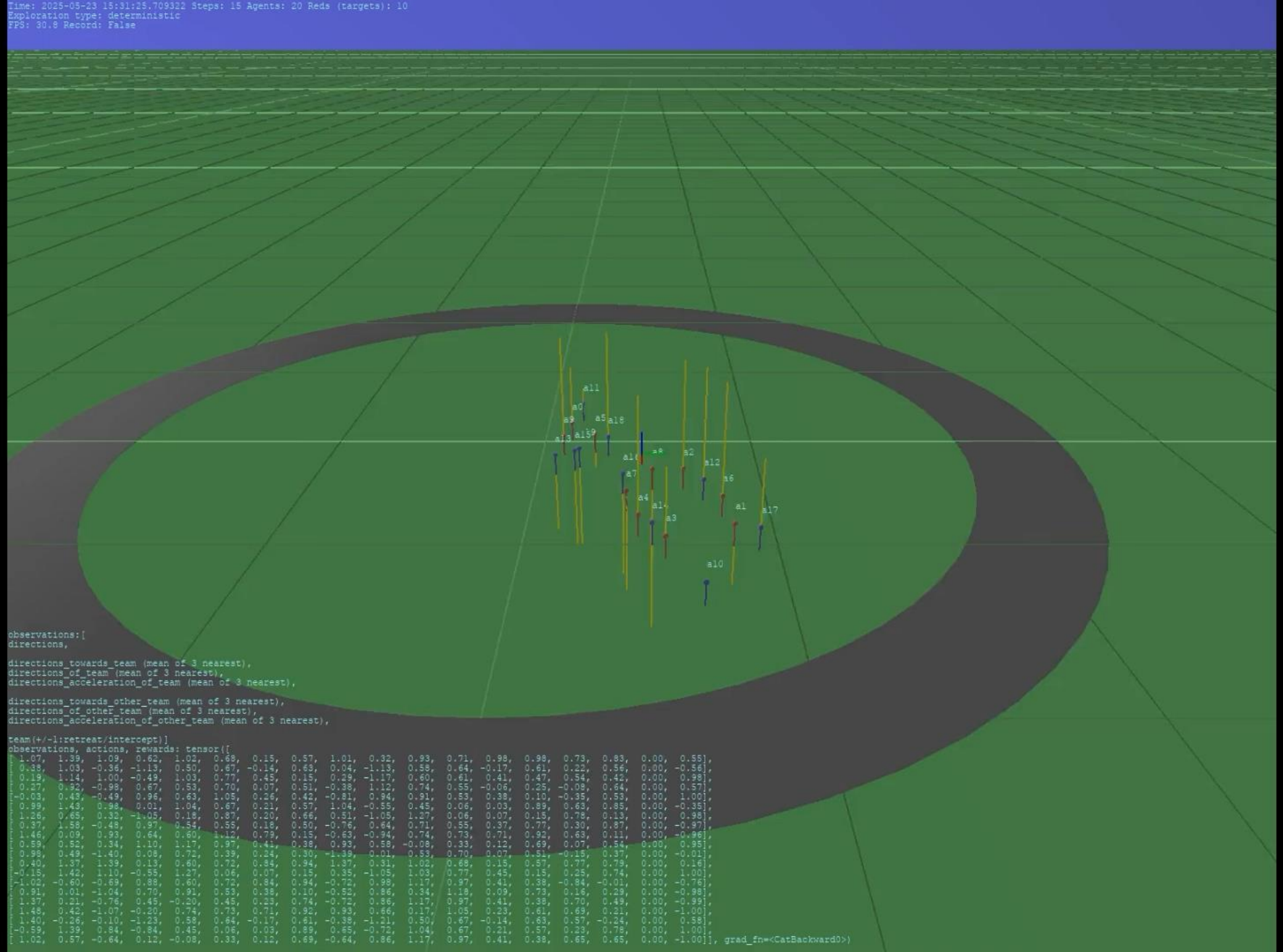
Objectives:

- Close to target
- Far from other agents (avoid collisions & spread)



Surround

Agents learn to make a formation around the yellow one.


Time: 2025-05-23 15:31:25.709322 Steps: 15 Agents: 20 Reds (targets): 10
Exploration type: deterministic
FPS: 30.8 Record: False
a11
a0
a9
a5
a18
a13
a15
a19
a14
a8
a2
a12
a7
a6
a4
a1
a17
a3
a10
observations:[
directions,
directions_towards_team (mean of 3 nearest),
directions_of_team (mean of 3 nearest),
directions_acceleration_of_team (mean of 3 nearest),
directions_towards_other_team (mean of 3 nearest),
directions_of_otheF_team (mean of 3 nearest),
directions_acceleration_of_other_team (mean of 3 nearest),
team(+/-1:retreat/intercept)]
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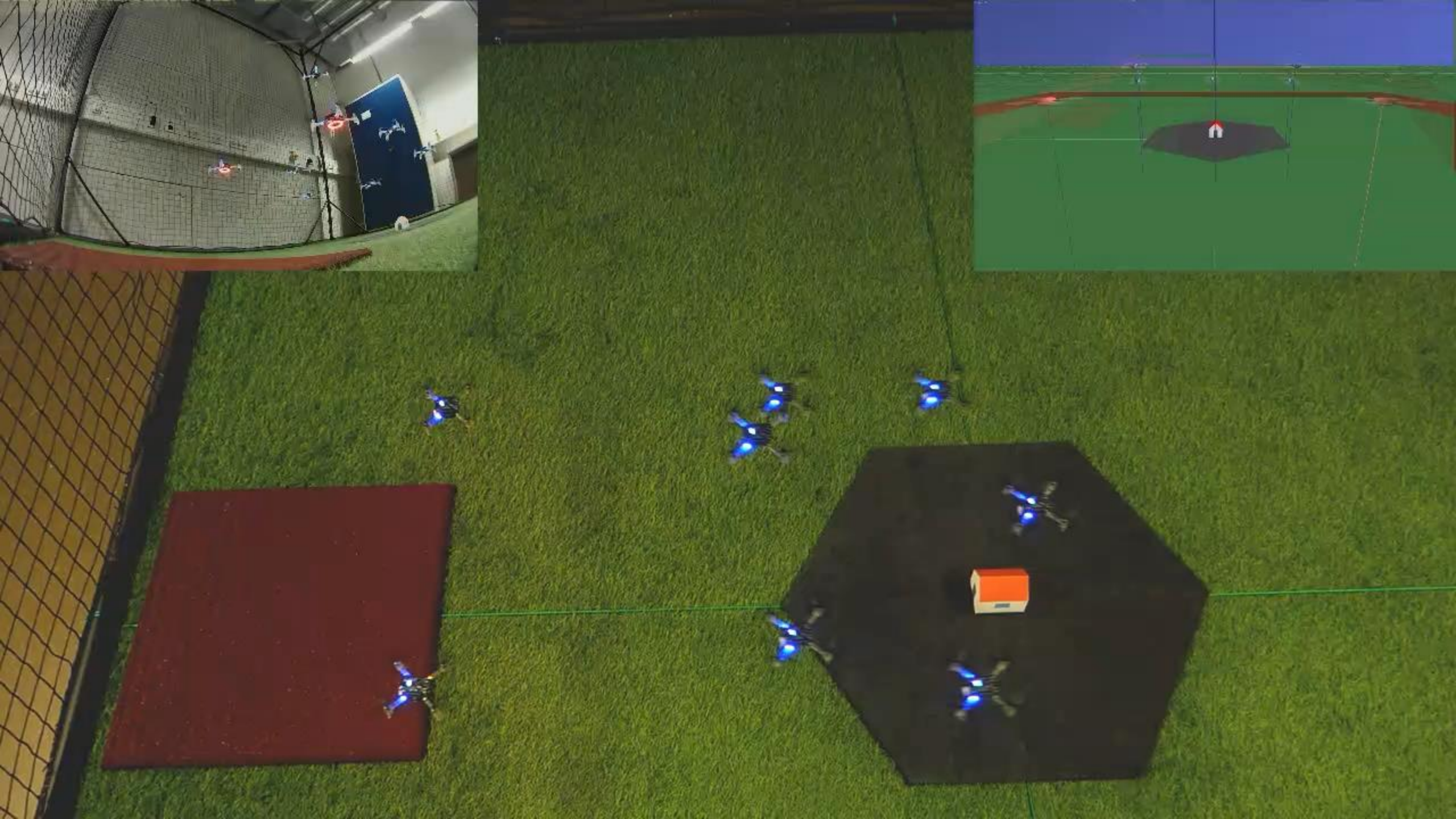

Summary

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Summary

Overview of 10+ years of research contributions in swarming algorithm design

Towards automated algorithm design

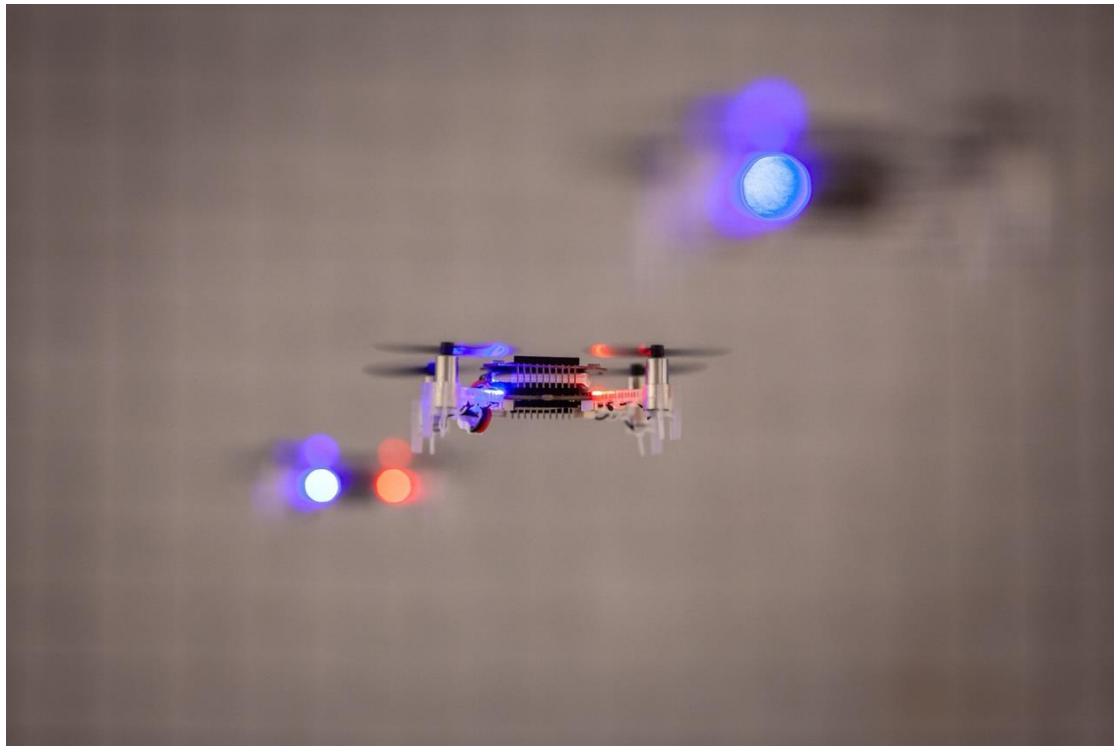
- From manually designed and optimised nature-inspired mobility models
- To automated algorithm design via reinforcement learning

Bridging the reality gap

- From high-level simulations
- To real-world validations using indoor/outdoor drones

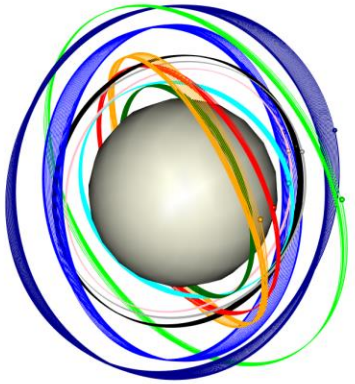
Integrating research into teaching

- Hands-on, project-based learning with real robots and HPC platforms



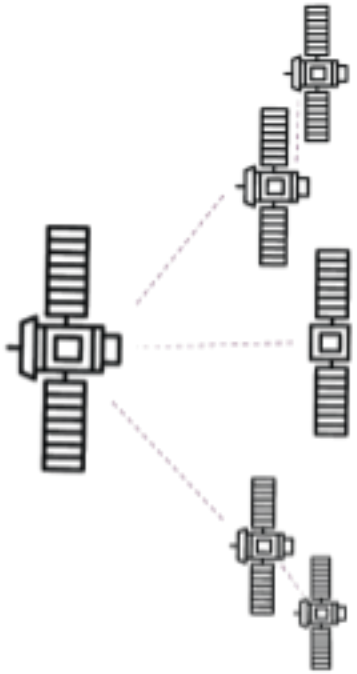
What’s next?

Swarms also have applications in space!

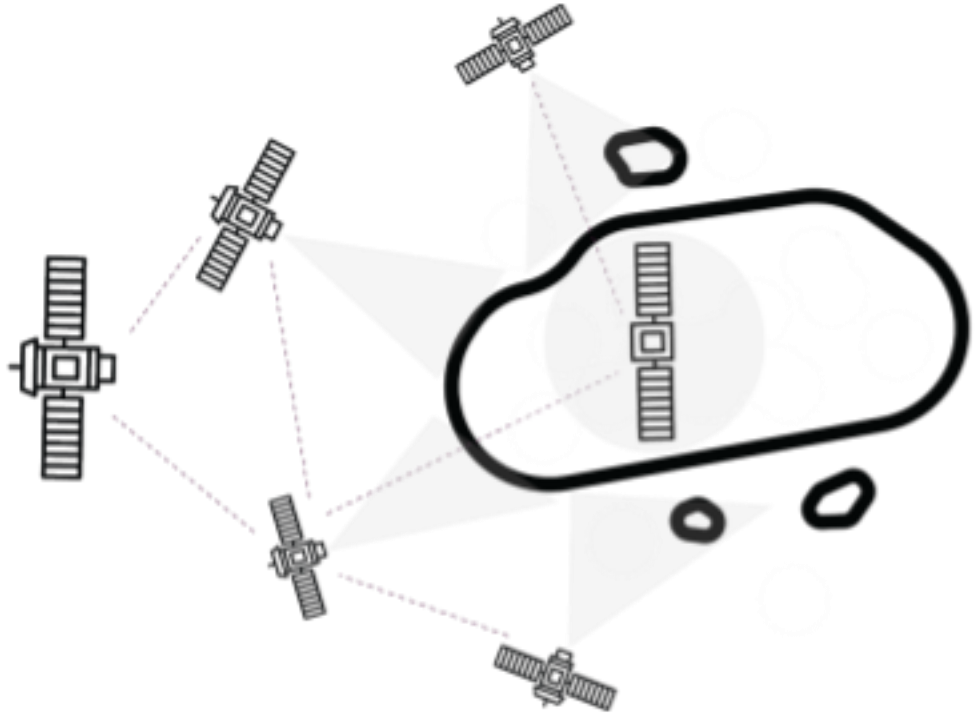


Satellite swarms for asteroid observation

Earth departure



Satellite deployment



Satellite swarm formation/optimisation for asteroid observation

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