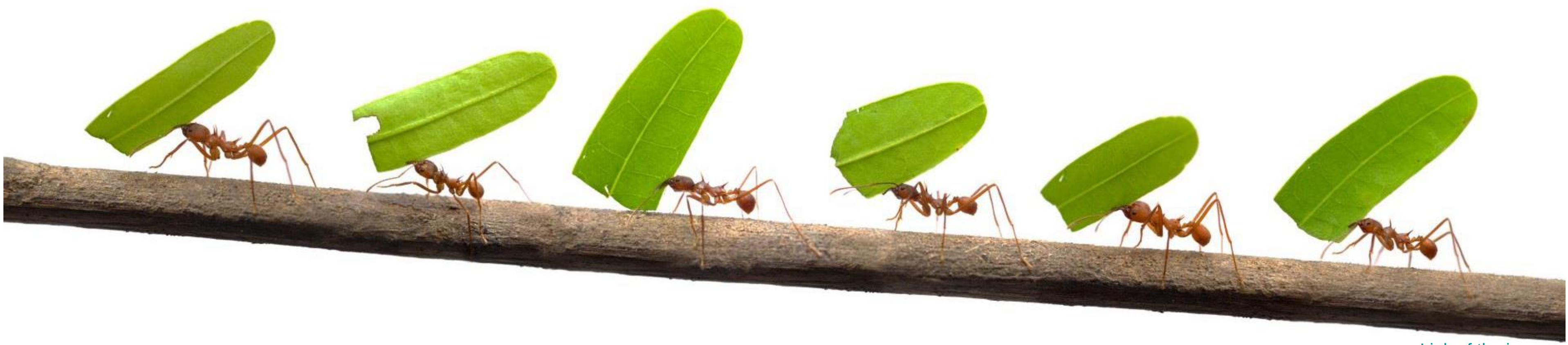
Institute of computer science

GEORG-AUGUST-UNIVERSITÄT
GÖTTINGEN

Swarm – Sensor Lab

Winter Semester 2024/25



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Supervisor:
Dr. Parisa Memarmoshrefi

Implemented Modules

- Implements Modules:
  - Master (6 ECTS-Credits):
    - M.Inf.1820 Practical Course on Wireless Sensor Networks
  - Bachelor (6 ECTS-Credits):
    - B.Inf.1803 Fachpraktikum I
    - B.Inf.1804 Fachpraktikum II
    - B.Inf.1805 Fachpraktikum III

- Language of the course is English
- As for other courses, you need to register at FlexNow! (TBA)
- Contact persons:
  - Supervisor: Parisa Memarmoshrefi (memarmoshrefi@informatik.uni-goettingen.de)
  - Tutor: Sanchit Khurana (sanchit.khurana01@stud.uni-goettingen.de)

Outline

- What is Swarm Intelligence (SI)
- Biological systems
- Swarm Intelligence Organizing Principles
- An Example of SI: Ant Colony Optimization (ACO)
- Course organization
  - Corse objectives and requirements
  - Some proposed topics
  - Course plan

Swarm Intelligence (SI)

- A field of artificial intelligence (AI) focused on collective behavior in decentralized system
- Emergent of collective intelligence of groups of simple individuals
- Inspired by nature (like ant colonies or bird flocks)
- It enables simple agents to work together to solve complex problems:
  - Each individual uses only local information about the presence of other individuals and of the environment
  - There is no predefined group leader

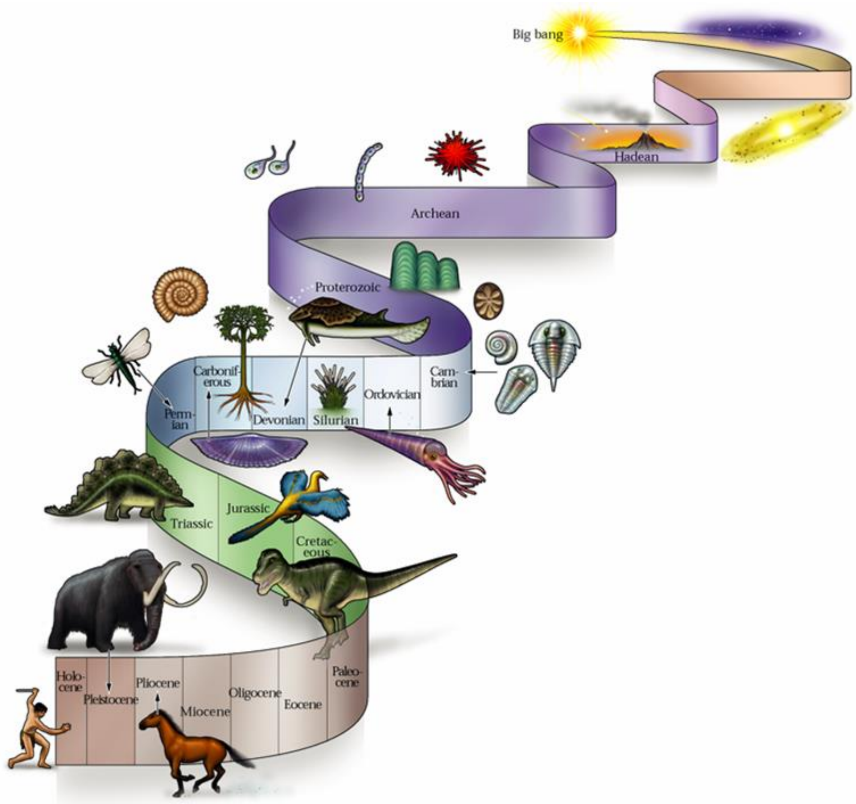
Flock of flying birds

Biological systems

Biological systems result from an evolutionary process

Biological systems are
- robust
- complex
- adaptive

Equilibrium is an important concept in nature



Self-organization

- Self-organization is a process in which pattern at the global level of a system emerges solely from numerous interactions among the lower level components of the system.

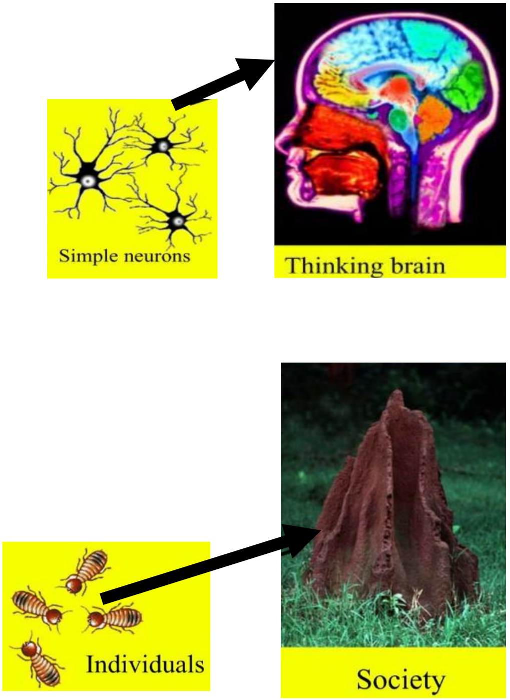


Image from the companion slides for the book Bio-Inspired Artificial Intelligence: Theories, Methods, and Technologies by Dario Floreano and Claudio Mattiussi, MIT Press

Top-down vs. bottom-up approaches

- Top-down approaches
  - Get the broad view of the system and then looks into the details
  - Start from a high level specification
  - Derive the policy rules from high-level representation

- Bottom-up approaches
  - Simplest life forms possess a comprehensive level of robustness and adaption
  - Look at how high-level functionalities would emerge from the interaction of lower level units.

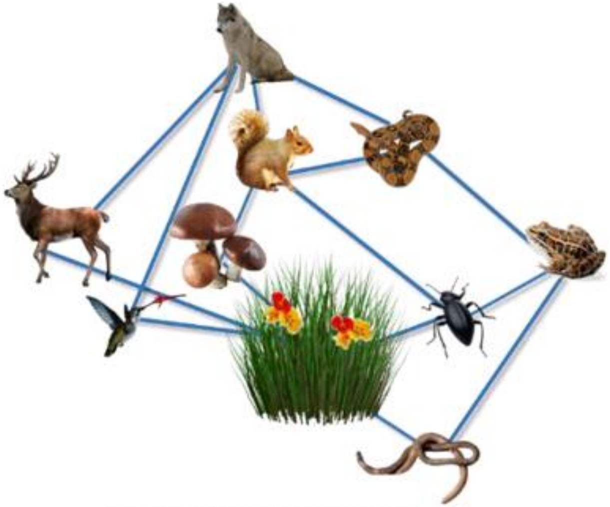
➢ In general nature has a rather more bottom-up approach

Homeostasis

In general stability is a desired characteristic for both biological and synthetic systems.

Homeostasis (similar + stable)

The property of a system to self-regulate and remain in a relatively stable conditions



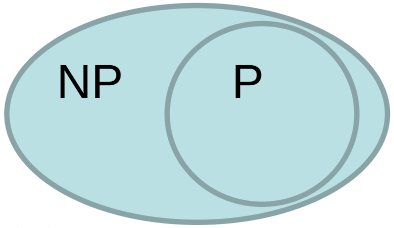
Food web representation

Image from the book: Bio-inspired networking

Nature, Heuristics, Metaheuristics

- Metaheuristics
  - adapting a general concept from one domain and apply that concept to solve problems in another domain.
- Heuristics (to find or to discover)
  - exploit problem-dependent information to find a solution to specific problem
  - a solution based on the experience that a given procedure reaches a *good enough* result
  - most cases, even if possibly not reaching the optimal solution.
  - used when optimal solutions are too costly, or impossible, to reach with the available time and/or computational resources.
- Examples
  - jumping heads on in a dark water river!
  - find a perfect gift for Mother’s Day in two days!

Complexity



P problems (Polynomial time)

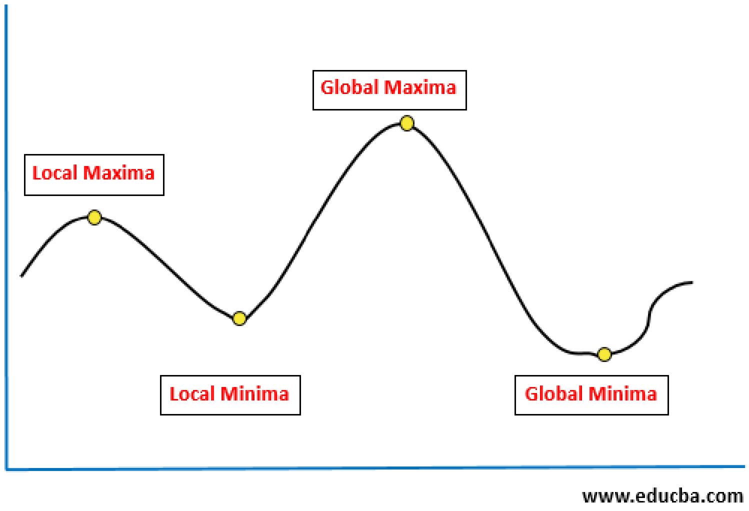
- easy to solved and easy to check
- questions can be answered in polynomial time
- example: multiply, greatest common divisor (GCD)

NP problems (Nondeterministic Polynomial time)

- hard to solved but easy to check if it is correct
- questions can not be answered quickly, but an answer can be *verified* in polynomial time.
- example: Sudoku, puzzle, traveling salesman

Global and local optimum in heuristics solution

- when using a heuristic, we are trying to find the optimal solution (maximum or the minimum possible values)
- using a heuristic, we are trying to find the maximum or the minimum possible values
- Local minimum/maximum is a value that is smaller/higher than its neighbors, but not necessarily the global one
- objective of the heuristic is to be as close as possible to a global minimum/maximum, avoiding getting stuck into a local one



Heuristic and nature

Structural view

- Communication is an intrinsic part of an organization of biological system
  - ants used pheromones to communicate
  - Brain neurons exchange electrical signals
  - Communication in human societies

- Individual organization
  - Animals and insects (ant/bee colony)
  - Brain (organization of neurons)
  - Human society

Swarm Intelligence (SI)

- Computational techniques for solving distributed problems inspired from biological examples provided by
  - social insects such as ants, termites, bees,
  - flock of bird
  - fish shoals (school of fish)

- Approaches to controlling and optimizing distributed systems

- Decentralized, self-organized techniques

SI Organizing Principles

- Emergence:
  - The intelligence exhibited is not present in the individuals, but rather emerges somehow out of the entire swarm..
- Robustness:
  - No central coordination takes place, which means that there is no single point of failure
  - It can recover form unexpected disruptions
- Massively parallel:
  - Tasks can be performed by individuals within the group same time.

SI Organizing Principles

- Autonomy:
  - The system does not require outside management or maintenance. Individuals are autonomous, controlling their own behavior in a self-organized way
- Adaptability:
  - Based on local interaction, the system is able to adapt itself to changes
- Scalability:
  - SI abilities can be performed using groups consisting of a few, up to thousands of individuals with the same control architecture.
- Flexibility:
  - Any individual can be dynamically added, removed, or replaced.

Stigmergy

- Stigmergy: stigma (sign, mark) + ergon (work)
- Characteristics of stigmergy
  - Indirect agent interaction modification of the environment
  - The information is local: it can only be accessed by individuals (insects) that visit the locus in which it was released
  - Work can be continued by any individual

SI Communication Forms

- Indirect communication
  - Known as Stigmergy communication.
  - Implicit communication that takes place between individuals via the surrounding environment.
  - Example Ants leave a chemical substance (pheromone)

- Direct Communication
  - Explicit communication that can also take place between individuals.
  - Example: trophallaxis (food or liquid exchange, e.g. mouth-to-mouth food exchange)

https://www.alexanderwild.com

Road map for design of bio-inspired solutions

- First step

search in the natural world for systems that present the desired behavior understanding the natural system and its components.

- Second step

create a realistic, or as realist as possible, computational model of the biological system.

- Third step is

process of simplifying the model to capture its essence, fine-tuning the various parameters to improve the performance of the model in order to perform the desired tasks

Application domain

Bio-inspired strategies have been applied to a large range of problems, but normally these problems present some of these characteristics:

- the absence of a complete and standard mathematical model
- large number of interdependent variables
- nonlinear systems
- combinatorial or extremely large solution space

Tasks that SI can be Applied

AI Ethics

- Ethical decisions making
- Collective wisdom
- Ethical opinion formation
- Fair recourse distribution

Optimization

- Route planning
- Scheduling
- Resource allocation

Search and Rescue

- Coordinated searches in disaster zones
- Swarm drones or robots locate survivors

Swarm Intelligence capabilities

Traffic Management

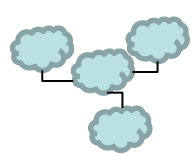
- Optimizing traffic flow
- Control vehicle movement

Exploration and Mapping

- Deep see, caves, outer space

Environmental Monitoring

- Collecting data for climate search and air pollution



Distributed Computing and Network Management

- Distribute of task, manage network traffic
- Load balancing, data routing

Swarm Intelligent Models

- Ant Colony Optimization (ACO)
  - Inspired form social insect colonies such as ant colonies.

Link of the image

- Particle Swarm Optimization (PSO)
  - Inspired from flocking birds or schooling fish

- Artificial Bee Colony (ABC)
  - Inspired from bee colony

Link of the Image

Image of PSO from the companion slides for the book Bio-Inspired Artificial Intelligence: Theories, Methods, and Technologies by Dario Floreano and Claudio Mattiussi, MIT Press

Some Proposed Real-world Application

Following application can be considered but not limited to:

- **Dynamic Task Allocation**: In this application a swarm of agents needs to allocate tasks dynamically based on changing conditions. This could be inspired by scenarios like disaster response. Or resource allocation, or workflow optimization in cloud services

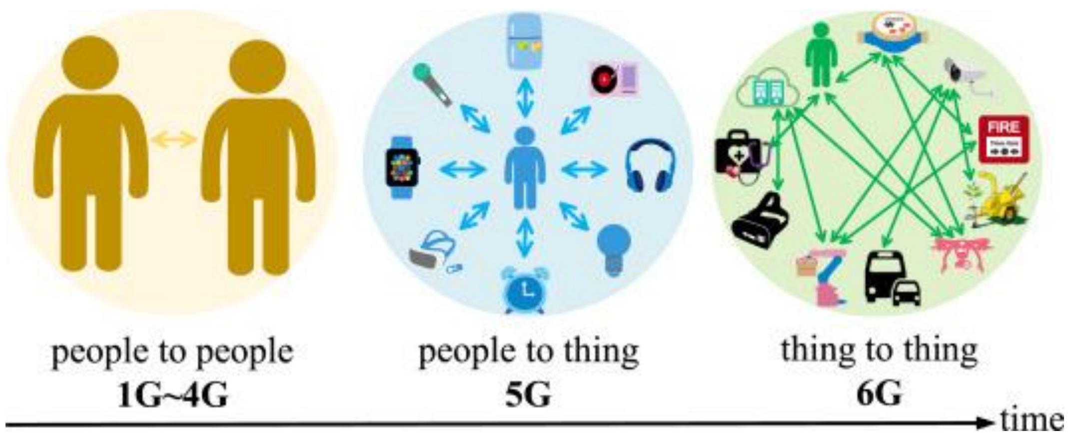
- **Social Behavior Simulation**: Social behaviors using swarm intelligence, can be simulated such as modeling the collective AI ethics decision making, spread of information, opinion dynamics.

- **Swarm-Based Clustering**: swarm-based clustering algorithm to group data points based on similarity. Experiment can be done with different swarm behaviors to achieve effective clustering

Application example
Wireless Communication Challenges

Nature of mobile communications changes over time:

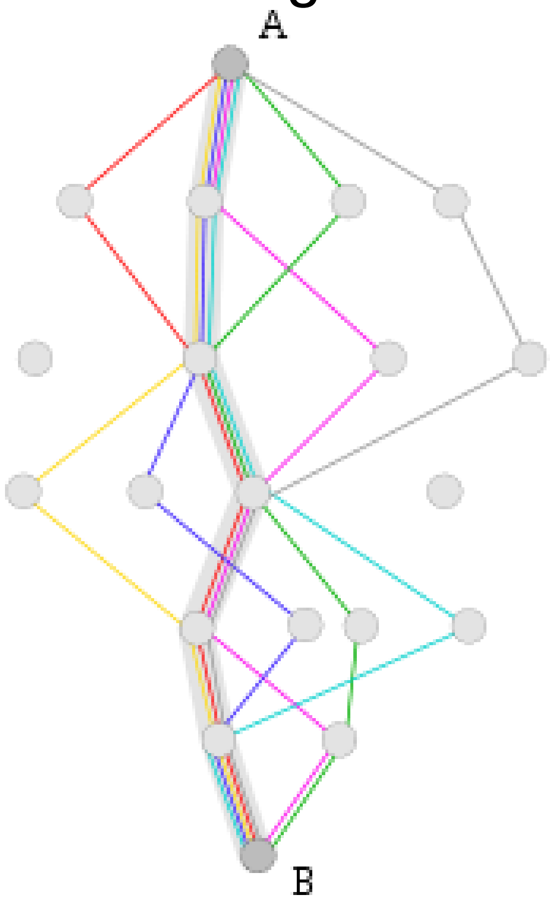
- Dynamic nature of wireless networks
- Growing the number of nodes
- Demand for infrastructure-less and autonomous operations



Yiqing Zhou, Ling Liu, Lu Wang, Ning Hui, Xinyu Cui, Jie Wu, Yan Peng, Yanli Qi, Chengwen Xing, Service-aware 6G: An intelligent and open network based on the convergence of communication, computing and caching, Digital Communications and Networks, Volume 6, Issue 3, 2020.

Application example

- Data routing

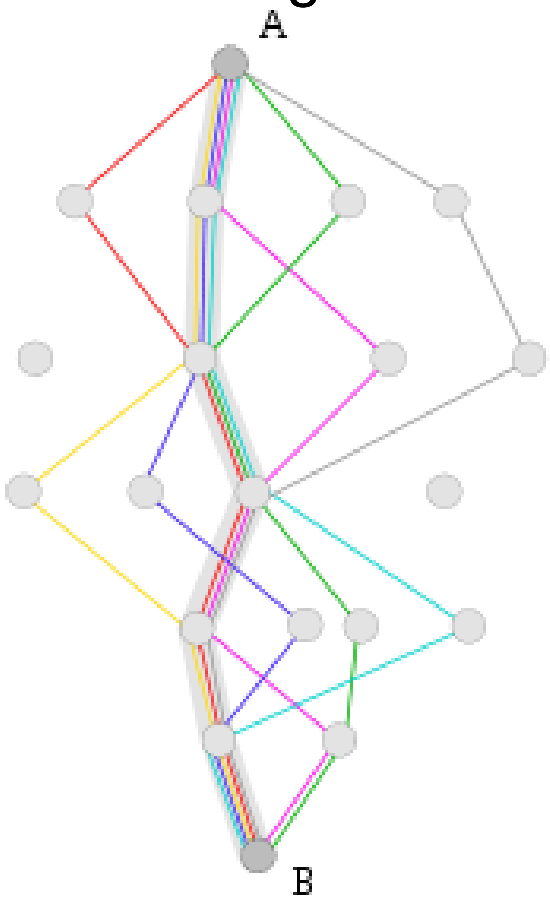


Swarm-Based Network Optimization

- Swarm intelligence techniques to optimize network data routing
- use Ant Colony Optimization (ACO) algorithm to solve a routing problem, such as finding the shortest path in a graph

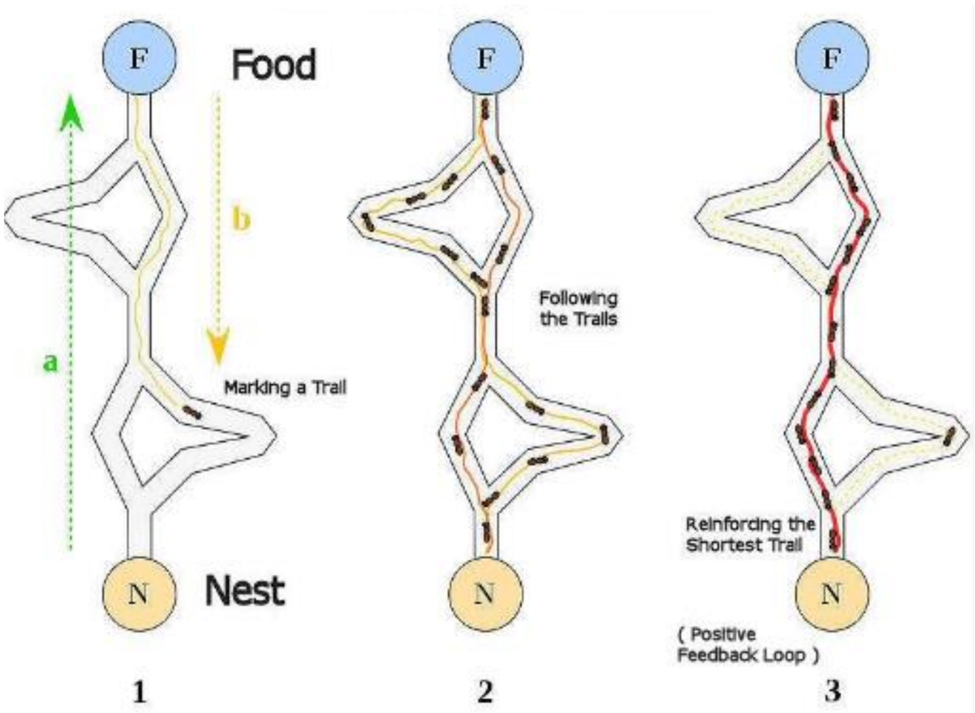
Application example

- Data routing



(1)

- Ant colony optimization



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Course Organization

Seminar: Bio-inspired Networking

Objective of this practical course is:

- To search and learn Swarm Intelligence solutions
- Model the solutions on the target domain
  - Theoretical
  - Practical
- Applying these solutions to the real world problems

➢ Seminar welcomes inter- discipliner topics, including Biology, Sociology, etc.

Expected Outcome

You are expected to:

1. Solve a real world problem with SI
2. Compare different SI algorithms on an given target application

Demonstration of the results

1. Using a multi-agent simulation environment like NetLogo, you can simulate the behavior of agents and to investigate it

2. Using your chosen programing language and show your results (e.g. comparative results) – some tools like Jupyter Notebook. Etc. can be used.

Course Requirements

- Scientific presentation
- Scientific report
  - IEEE format
- Compliance with set deadlines
- Participating in other students’ presentation with active discussion

Evaluation and Grading

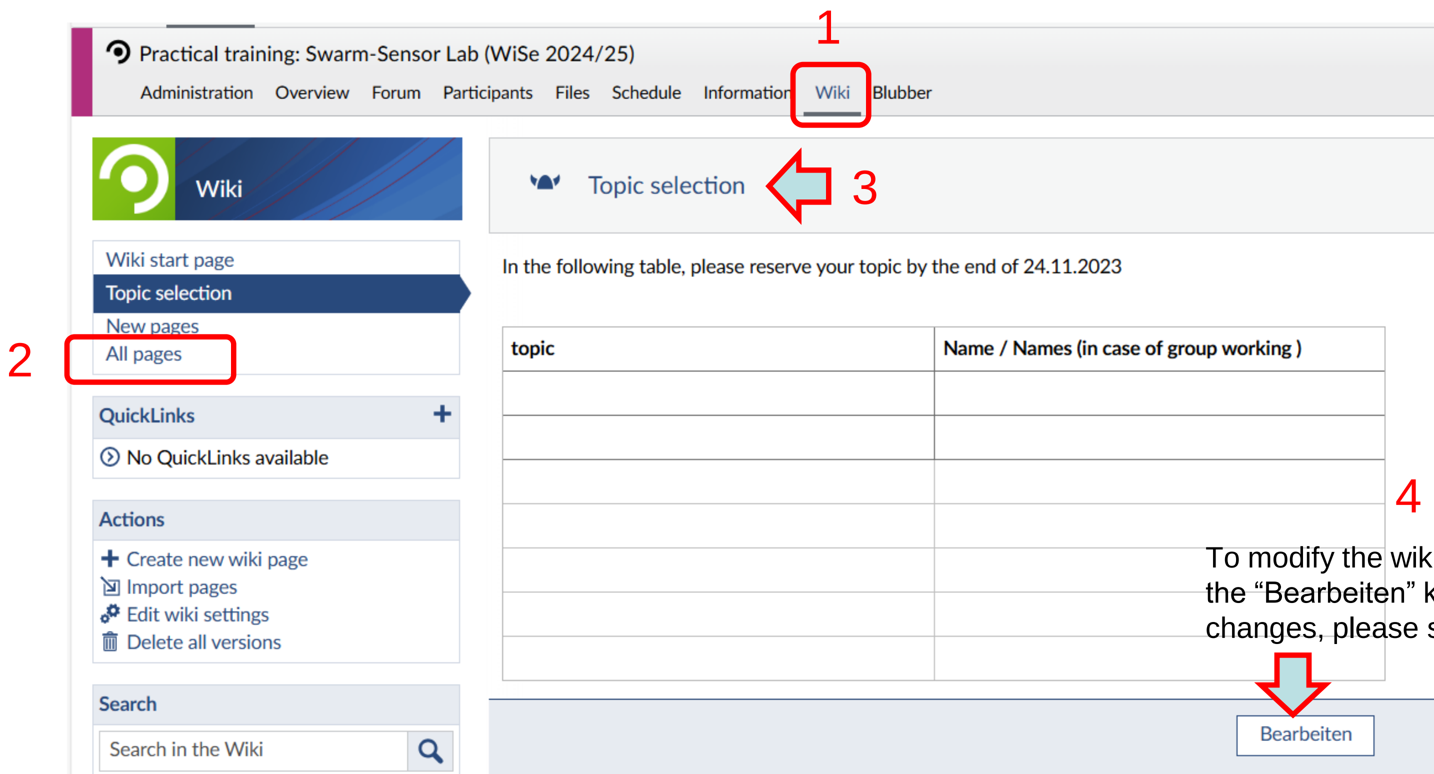
- Presentation (30 min + 15 for Q&A): 60%
  - Presenting of your research and result
  - Make a poser from your work
- Report: 40%
- Participating 80% of the seminar sessions
- Avoiding plagiarism
- Keep the deadlines

Course Plan

1	Introduction	08.11.2024
2	An overview to some SI algorithm	22.11.2024
3	Choose your topic – by adding to wiki page	25.11.2024
4	Prepare your outlines and a time slot for your presentation – by adding to wiki page	30.11.2024
4	Registration to FlexNow!	TBA
6	Date of presentations (version 1)	TBA
7	Some on-demand sessions	...
8	Submission of your slides (last version) + Poster	One week before your presentation
9	Final presentations	Fr. 31.01.2025 & 07.02.2025 TBA - See the Wiki
10	Submission of the final report	15.03.2025

StudIP – Wiki page

- Please reserve your topic by the end of 24.11.2024, adding in the wiki page: "StudIP -> Seminar: Self-organized networks -> Wiki -> All pages -> Topic selection"



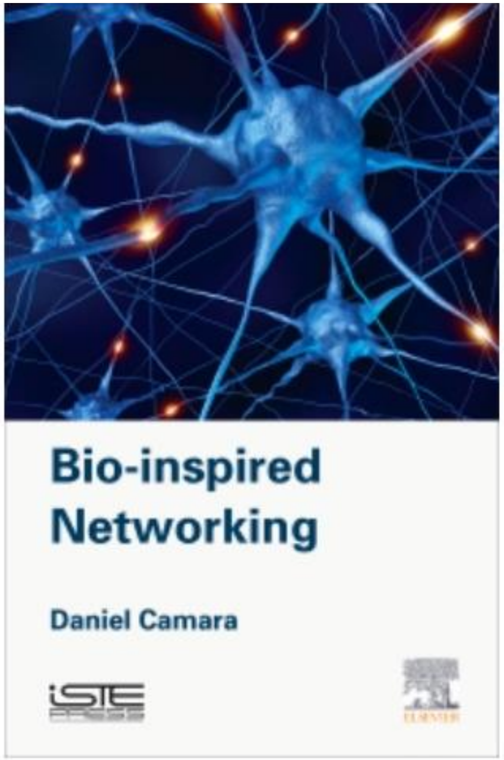
To modify the wiki page, please press the "Bearbeiten" key, and after your changes, please save the page.

Topics and references

- Your proposed topic is also very welcome!
- Group working in possible.

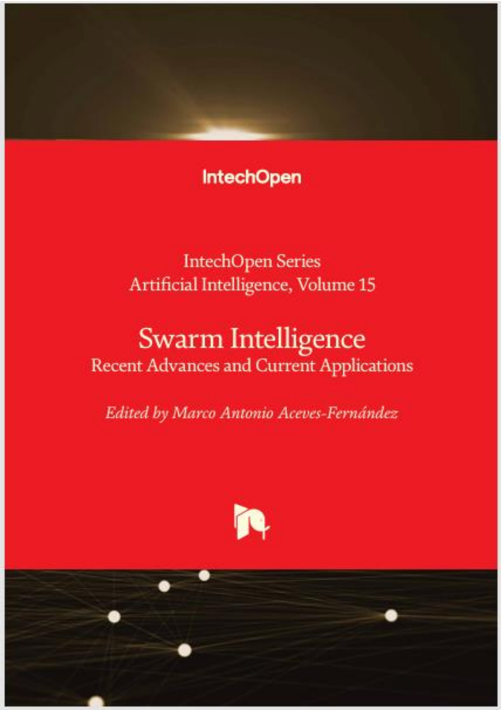
Topics and references

[Bio-inspired Networking,
Chapter 4:
Swarm Intelligence (SI)]



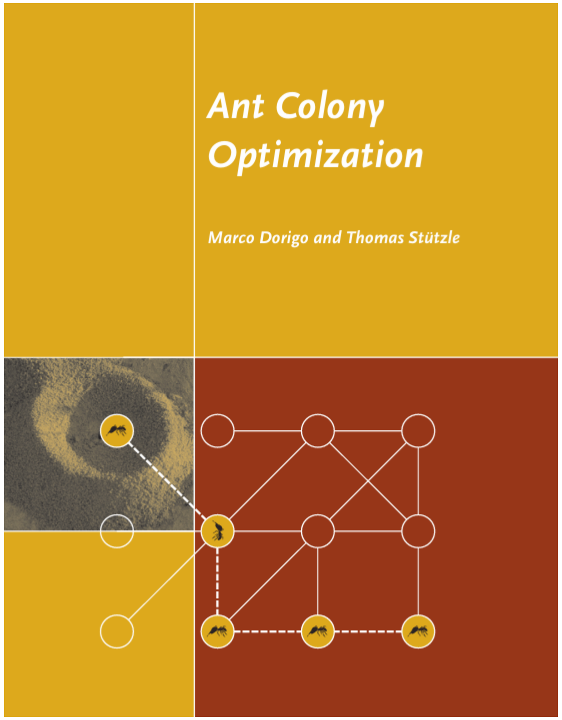
Topics and references

Swarm Intelligence Recent Advances and Current Applications



Topics and references

"Ant Colony Optimization" by Marco Dorigo and Thomas Stützle (Comprehensive insights into ACO).



Topics and references

NetLogo Models of Swarm

- NetLogo agent based simulation environment comes with a large library of sample models NetLogo

Some proposed topics

Swarm intelligence and human behavior

- Analysis of Human Behaviors in Real-Time Swarms, Link
- Swarm intelligence in humans: diversity can trump ability, Link
- Swarm intelligence in animals and humans, Link
- HuGoS: a virtual environment for studying collective human behavior from a swarm intelligence perspective, Link

Some proposed topics

Swarm intelligence for task scheduling

- Exploring swarm intelligence optimization techniques for task scheduling in cloud computing: algorithms,

  Prity, F.S., Uddin, K.M.A. & Nath, N.

  Performance analysis, and future prospects. *Iran J Comput Sci* **7**, 337–358 (2024)

  Link

Some proposed topics

Swarm intelligence for clustering

- Ant-based and swarm-based clustering, Link
- Research on particle swarm optimization based clustering: A systematic review of literature and techniques, Link
- Cluster images with AntClust: a clustering algorithm based on the chemical recognition system of ants

  Winfried Gero Oed, et. al., 2023, Link
- Directed Bee Colony Optimization Algorithm, Link

Some proposed topics

Parameter setting for swarm intelligence

- A survey of dynamic parameter setting methods for nature-inspired swarm intelligence algorithms. Phan, H.D., Ellis, K., Barca, J.C. *et al. Neural Comput & Applic* **32**, 567–588 (2020)

  Link